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Fossil fuel consumption, economic growth and CO_2 emissions. Causality evinced from the BRICS world

Rochna ARORA
Guru Nanak Dev University, India
Rochna.arora17@gmail.com
Dr. Baljit KAUR
Guru Nanak Dev University, India
baljit17_kaur@yahoo.co.in

Abstract. *The present study looks at the long term relationship among fossil fuel consumption, economic growth and CO_2 emissions in the BRICS economy. The data runs from the period 1990-2014. The unit root tests prove that the data contain unit root following which Pedroni's and Kao's cointegration test is applied. The results of cointegration prove that there is a long term relationship that exists. The long run estimates from DOLS and FMOLS show that increase in fossil fuel consumption will increase growth but at the same time with more carbon emissions the level of growth will decrease. Additionally increase in economic growth will reduce the amount of CO_2 emissions thus favouring Kuznets inverted U hypothesis. Finally causality results are arrived at by using Dumitrescu-Hurlin panel causality technique. The results from causality tests show that unidirectional causality from energy to GDP; bidirectional relationship between emissions and GDP and unidirectional causality from fuel consumption to environmental degradation. The causality directions serve important policy implications for the government of the emerging economies to focus more on non-conventional sources of energy so as to keep the environment in the best of its health and at the same time make growth sustainable in the long run.*

Keywords: energy consumption, economic growth, emissions, causality, BRICS.

JEL Classification: C23, O44, O57.

1. Introduction

The concept of sustainable development was first discussed in the Brundtland Report (1972). The growth thereafter was always questioned whether it is sustainable or not. Numerous regulations and summits found place in the economic domain addressing the issue of environmental cost of growth and development. Though there does exist a negative relation between energy consumption and CO_2 emissions for almost all the economies of the world but at the same time energy consumption in all its forms supports economic growth. Energy is regarded as a precondition for economic growth. The U.S. Energy Information Administration (EIA, 2013) conjectured the momentous role played by energy in the process of economic growth. It stated: A country's economy and its energy use, particularly electricity use, are linked. Short-term changes in electricity use are often positively correlated with changes in economic output (measured by gross domestic product (GDP). However, the underlying long-term trends in the two indicators may differ. All else equal, a growing economy leads to greater energy and electricity use. The literature world across has corroborated these results for mixed set of economies (Apergis and Payne, 2010; Campo and Sarmiento, 2013; Pradhan, 2010; Omri, 2013; Mohanty, 2015 and many others).

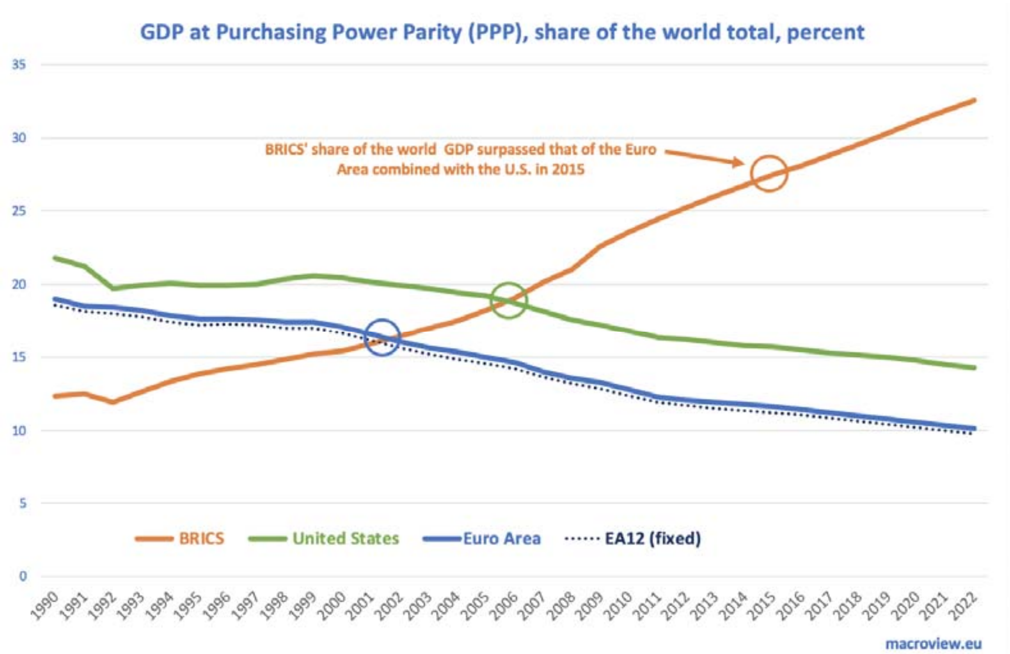
The effect of energy consumption on economic growth can be regarded as a positive externality but another dimension to this is the existence of even stronger but negative externality in the form of environmental degradation. CO_2 emissions from the consum-ption of energy have taken a serious toll on the performance of economic growth of many economies particularly the developing ones. For instance China has surpassed the state of USA when it comes to the emissions of the most important greenhouse gas i.e. CO_2. India is also the third largest emitter of CO_2 in the world lying below China and USA.

Interestingly China is touted as the world's fastest growing economy too. It's very evident from this postulate that china's growth is detrimental to the environment. Having said that, one cannot imagine an economy's existence without growth. But growth of such nature would actually be illusionary. The Chinese economy attempted to estimate its green GDP back in 2000's but the exercise was abandoned because it abridged the value of its GDP. Even then the role of green economy is stressed upon. Green Economy is defined by United Nations Environment Program (UNEP) as way of operation of an economy which ameliorates human's well-being together with trimming down the inequality and environmental risks so as to facilitate sustainable development. In Green Economy, the main concern in not only on economic growth but it requires investing in those projects which are more environment-friendly. The advancing and emerging economies are not only seeing an increase in their economic growth but are also experiencing environmental problems of increased pollution and global warming. Though the contribution of developing countries in GHG emissions is lower than that of developed countries yet it won't be wrong to expect adoption of environmental friendly modes of working from them.

The developing economies have always exhorted the effort to go for cleaner technologies but at the same time there is a general consensus among all that cleaner technologies are dearer and a misfit for them. It needs to be the responsibility of the developed world to come forward in leading the world for clean technology. If the choice has to be made between growth and environment, the developing countries will surely go for growth instead of pursuing environmental friendly policies which will be jolting their growth values. There clearly exists a trade-off between growth and environment conscious policies. To achieve one, the other has to be sacrificed.

BRICS brings together five major emerging economies, comprising 43% of the world population, having 30% of the world GDP and 17% share in the world trade. In 2019, BRICS combined GDP will surpass (using PPP-adjusted GDP) that of G7 economies, and in 2020, based on IMF forecasts, it will exceed the combined share of the world GDP for the US + EU27 economies (see figure below). With the projections of BRICS economy surpassing the other well grown economies in the near future, the economic activity will definitely see a rampant change. Together with growth increases, the region has also recorded increase in the CO_2 emissions. The BRICS share of carbon dioxide emissions from fossil fuel combustion in the global total increased from 27 per cent in 1990 to 42 per cent in 2018 (BP, 2019a).

For comparison, over the same period, the share of G7 countries (Canada, France, Germany, Italy, Japan, the United States and the United Kingdom) in global carbon dioxide emissions from fossil fuel combustion shrank from 42 per cent to 25 per cent. The existing reserve of fossil fuels in these economies makes sense as to why there is immense dependence on these fuels for meeting the energy needs for their operation. The BRICS region comprises of 32.3% of the proved fossil fuel reserves with individual countries holding Brazil (16.9), China (378.8), India (265.7), Russia (427.7) and South Africa (26.1).



The present study can be differentiated from the existing literature in three respects.

1. Most of the studies delving into the energy-income relationship take up per capita consumption of electricity as a variable representing energy statistics while the present study will take up fossil fuel energy consumption as a representative variable.
2. The study differs from the existing literature by taking up the set of most important emerging economies namely BRICS which display a potential to influence the World economics. Thirdly, the study adopts modern panel econometric techniques in the form of panel stationarity, panel cointegration techniques along with Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) techniques.
3. Apart from these, what differentiates the present paper from the already existing ones is the application of an alternative to Granger causality test which has been the base of almost all the causality studies conducted among various set of variables. Instead of Granger causality tests, the study applies Dumitrescu-Hurlin panel causality technique which is regarded as an alternative to Granger causality tests.

The present research paper is carried out to achieve the following mentioned objectives

1. To see if there exists any long term relationship among the three variables of fossil fuel energy consumption, economic growth and CO_2 emissions for the BRICS economy.
2. To estimate the long run elasticity coefficients of each variable with respect to other.
3. To find out the direction of short term causality between all the variables, taking 2 variables each time.

The present analysis is divided into 5 sections including the present one. The second section elaborates the existing literature talking about the relationship among the three variables of concern. Section 3 describes the variables that form part of the study and also details the methodology adopted for carrying out the research. Results are provided in section 4. Conclusions and relevant policy implications are laid out in the last section i.e. section 5.

2. Review of literature

The studies pertaining to the selected variables were initially bivariate in form with major focus on energy-growth relationship. On the basis of the relationship, Ozturk (2010), Squalli (2007) and Magazzino (2011) provide four hypotheses about the direction of causality between energy consumption and GDP.

The first is the hypothesis of neutrality, which holds that there is no causality (in either direction) between these two variables.

The second is the energy conservation hypothesis, which holds that there is evidence of unidirectional causality from GDP growth to energy consumption.

Under the third hypothesis, which is known as the growth hypothesis, energy consumption drives GDP growth.

The fourth hypothesis is the feedback hypothesis, which suggests a bidirectional causal relationship between energy consumption and GDP growth. Numerous studies have been conducted for various economies of the world each supporting one of the four hypotheses. The list of studies that conform to the different hypotheses have been presented in the following table.

Table 1. *Studies on energy-income relationship*

Growth Hypothesis	Squalli (2007), OPEC countries Apergis and Payne (2009, 2010), American economies. Lean and Smyth (2010), ASEAN Mohanty and Chaturvedi (2015)
Conservation hypothesis	Cheng (1999), India Ghosh (2002, 2009), India Pradhan (2010), India Odhiambo (2016) South Africa
Feedback hypothesis	Belke (2011), OECD countries Zhang and Xu (2012), Chinese economy Omri (2013) MENA countries Lao and Zheng (2014) SSA countries Campo and Sarmiento (2013), Latin American countries Osman (2016) GCC countries Ahmad et al. (2016), India Kirrikaleli (2018) 35 OECD countries

Source: Authors' compilation.

The above mentioned studies talk about the bivariate relationship between the variables of energy consumption and economic growth. The studies that explicitly took CO_2 emissions as an additional variable in the model are presented here under.

Farhani and Rejeb (2012) examined the direction of causality among energy consumption, Gross Domestic Product and CO_2 emissions for set of 15 MENA countries covering the period 1973-2008 by applying panel unit root tests, panel cointegration models and panel causality tests. The findings of the study point to no causality between GDP and electricity consumption and between CO_2 emissions and energy consumption in the short run. However a unidirectional causality is found in the long run from GDP to CO_2 emissions and energy consumption. Thus serving an important policy perspective that MENA countries can go in for conservation policies without impeding the growth of the economy. Another study for MENA countries was undertaken by Omri (2013) for the period 1990-2011.

Using simultaneous equations model the causality worked out was bidirectional and thus in favour of feedback hypothesis for energy and growth and energy and CO_2 emissions as well. Lao and Zheng (2014) explored the causal relationship among electricity consumption, economic growth and carbon-di-oxide emissions for a group of 14 Sub-Sahara Africa (SSA) countries from 1980-2009 using a panel cointegration and panel Vector Error Correction modelling methods. The findings demonstrate that in the long run electricity consumption has a statistically significant positive impact on CO_2 emissions thus validating the existence of U-shaped Environment Kuznets Curve (EKC).

The panel causality tests indicate that there is short-run unidirectional causality from economic growth to CO_2 emissions and electricity consumption. In the long run the causality becomes bidirectional running between electricity consumption to growth;

electricity consumption and CO_2 emissions and economic growth to CO_2 emissions. Thus it implies that electricity consumption would promise growth together with environmental degradation. For the environment protection suitable policies need to be initiated without retarding the growth of the economy.

3. Database and methodology

A dataset on the 5 BRICS countries, namely Brazil, Russia, India, China and South Africa is used to study the linkage among the three variables of fossil fuel consumption, CO_2 emissions and economic growth. Annual data for 1990-2014 is extracted from the dataset on the World Bank website. Table 1 clearly highlights the variable given by their abbreviations EC denotes the fossil fuel energy consumption (% to the total), CO_2 and EG indicate the amount of emissions (kg per 2011 GDP) and the GDP constant at 2011 U.S. dollars respectively. These variables which form a part of the study are expressed in their natural logarithmic forms.

Table 2. *List of variables*

Variables	Representation
CO_2 emissions (kg per 2011 PPP $ of GDP)	CO
Fossil fuel energy consumption (% of total)	EC
GDP per capita, PPP (constant 2011 international $)	EG

To study the long term relationship and the causality pattern among the stated variables certain technical pre requisites are required to be met starting with the stationarity properties of the selected variables. If the variables are non-stationary at level then first differenced variables are used for the empirical assessment. Most of the variables normally become stationary at first level. If the variables fail to establish stationary at first difference, second difference will be computed. The level at which variables become stationary is important because that marks the order of integration of the study. After establishing the non stationarity of the variables at level and stationarity properties at first difference (unit root stationary), the cointegration properties of the model will be tested.

The existence or non-existence of cointegration is of high importance because that will drive the future course of modelling for meeting the research objectives. If the variables are cointegrated, meaning that they share a long run relationship, their relationship will be quantified.

Lastly causality tests will be carried out to clearly mark off the direction of relationship that exists between the two variables at a time. The stationarity tests available in the literature are Levin, Lin, and Chu (2002), Breitung and Candelon (2005), Im, Pesaran, and Shin (2003), Maddala and Wu (1999), and Choi (2001) unit root tests. The stationarity tests can be conducted under three models: intercept, trend and intercept and none of the two. The present analysis is based on intercept and trend model. There exists a starking difference between these multiple panel unit root tests. The tests of Im, Pesaran, and Shin (IPS), Augmented Dickey and Fuller-Fisher (adf-Fisher) and Phillips and Perron-Fisher (PP-Fisher) (Im et al., 2003, Maddala and Wu, 1999, and Choi, 2001) consider single unit root along with different autocorrelation coefficients for different cross sections but Levin-Lin-Chu (LLC) and Breitung unit root tests (Levin et al., 2002, and Breitung and Candelon, 2005) allow common unit root along cross sections. For the same order of integration I (1) variables cointegration linkage is investigated using Pedroni (1991) test. But this test can only be applied if the order of integration of all the selected variables is same. Pedroni (1999) defines seven statistics divided into 2 groups: within dimension and between dimension. The former includes 4 test statistics which are Panel v-Statistic, Panel rho-Statistic, Panel PP-Statistic and Panel ADF-Statistic while the latter category includes Group rho-Statistic, Group PP-Statistic and Group ADF-Statistic. Pedroni (1999) also states that out of these seven statistics the two most important ones are Panel ADF-Statistic and Group ADF-Statistic. The null hypothesis in these tests states no cointegration which needs to be rejected. The rejection of Null hypothesis will be true if four statistics out of seven reject the null hypothesis. But in case of conflicting results the final conclusion for rejection of null hypothesis will be dictated by Panel ADF-Statistic and Group ADF-Statistic. If these two reject the null hypothesis that would ensure the existence of long run relationship among the variables in consideration. The cointegrating equations will be run by considering all variables in turn dependent variable. With three variables under study there will be three cointegrating equations. The equation specification is given under:

$$lnEG_{it} = \alpha_i + \delta_{it} + \beta_{1i}\ ln\ EC_{it} + \gamma_{it}\ lnCO + \varepsilon it \quad [1]$$

$$lnEC_{it} = \alpha_i + \delta_{it} + \beta_{1i}\ ln\ EG_{it} + \gamma_{it}\ lnCO + \varepsilon_{it} \quad [2]$$

$$lnCO_{it} = \alpha i + \delta_{it} + \beta_{1i}\ ln\ EG_{it} + \gamma_{it}\ lnEC + \varepsilon_{it} \quad [3]$$

In these equations, α_i represents the country specific impacts, δ_i is representative of the time trends in the analysis and lastly ε_{it} is the residual term. The two subscripts also have a significant meaning wherein i = 1, 2,…, N represent panel members and t = 1, 2,…, T represent time periods.

The first equation studies the long run impact of energy consumption and CO_2 emissions on economic growth; the second equation looks into the impact of economic growth and CO_2 emissions on energy consumption and the last equation with CO_2 emissions as the dependent variable works out the long run impact of energy consumption and economic growth on the dependent variable. Apart from Pedroni's cointegration test, Kao's residual cointegration test is employed as a robustness check for cointegration in the analysis. Once the cointegration tests verify the presence of long run relationship in all the three models, the quantification of the results will be carried out using Pedroni's Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) tests. These tests will help us in arriving the elasticity estimates of the variables. After this Dumitrescu-Hurlin panel causality technique has been applied to discover causality properties between energy consumption, economic growth and CO_2 emissions in the panel format. There is a specific reason involved in applying this particular causality test rather than the conventional Granger Causality test. The reason behind the application of Dumitrescu-Hurlin panel causality technique is that it makes no assumption about homogeneity among the cross sections involved in the analysis while the infamous Granger causality test is based on homogeneous cross sectional units.

4. Results

We first check the stationarity properties of the variables by employing the tests mentioned in the previous section. The results of the stationarity tests are presented in the adjoining table. We find out that all the variables of economic growth, fossil fuel consumption and carbon-di-oxide emissions fail to reject null hypothesis of no unit root. As a result when we find out the first difference of the variables and check for the stationarity of the variables we see that variables become stationary. This means that all the variables contain unit root and thereby deduce the order of integration to be 1 i.e. I (1).

Table 3. *Unit root results*

Variables		LLC	Breitung	IPS	ADF-Fisher	PP-Fisher
At level	EG	-0.586	2.932	1.076	11.648	11.591
	EC	0.233	0.694	0.018	9.956	5.780
	CO	2.119	2.190	1.677	15.884	8.740
At first difference	EG	-4.076*	-2.291**	-3.186*	28.316*	49.506*
	EC	-4.419*	-1.297***	-6.438*	52.594*	299.394*
	CO	-2.005**	-2.436*	-2.468*	22.881**	65.983*

* significant at 1%, ** significant at 5%, ***significant at 10%. Also the model is run using intercept and deterministic trend.

Hereafter, since the variables contain unit root, we proceed with Pedroni' long run cointegration test by taking each variable as a dependent variable in turn. The results of cointegration tests of both Pedroni as well as Kao have been reproduced in the ensuing table.

Table 4. *Panel cointegration results*

Pedroni Residual cointegration test				Kao residual cointegration test
Within dimension	Statistic	Between-dimension	Statistic	t-statistic (ADF)
Model 1: EG-EC-CO				
Panel v - statistic	0.0124	Group rho-statistic	-0.627	
Panel rho-statistic	-1.946**	Group PP-statistic		-1.779**
Panel PP-statistic	-3.959*	Group ADF-statistic	-3.820*	
Panel ADF-statistic	-3.931*		-3.867*	
Model 2: EC-EG-CO				
Panel v - statistic	0.481	Group rho-statistic	-3.609*	
Panel rho-statistic	-3.944*	Group PP-statistic		-2.167**
Panel PP-statistic	-8.553*	Group ADF-statistic	-10.928*	
Panel ADF-statistic	-5.052*		-5.036*	
Model 3: CO-EG-EC				
Panel v - statistic	-1.873	Group rho-statistic	-1.908**	
Panel rho-statistic	-2.346*	Group PP-statistic		-0.485
Panel PP-statistic	-7.944*	Group ADF-statistic	-10.172*	
Panel ADF-statistic	-7.211*		-7.677*	

* represent 1% level of significance, ** represent 5% level of significance.

In all the models the null hypothesis of no cointegration is rejected after drawing ample evidence against it from Pedroni's as well as Kao's test. Though in the third model Kao's test fails to reject no cointegration hypothesis, yet we find six out seven statistics of Pedroni claiming the same thing.

Table 5. *FMOLS and DOLS results*

Dependent variable		Independent Variables	
Model 1: EG-EC-CO		EC	CO
EG	FMOLS	3.44* (8.15)	-1.36* (-10.23)
	DOLS	2.66* (5.83)	-1.15* (-8.15)
Model 2: EC-EG-CO		EG	CO
EC	FMOLS	0.17* (8.39)	0.19* (4.28)
	DOLS	0.16* (7.45)	0.18* (3.31)
Model 3: CO-EG-EC		EG	EC
CO	FMOLS	-0.50* (-9.92)	1.43* (4.09)
	DOLS	-0.50* (-10.14)	1.63* (4.34)

*, **, *** signify 1%, 5%, 10% level of significance. The values in parenthesis denote t-statistic.

The outcome of the FMOLS and DOLS for all the three models is presented in the above table. The results of both cointegration estimates are highly synchronised without any discrepancy between FMOLS and DOLS coefficients. The signs and the level of significance is same under both the criterion. The FMOLS estimates for energy consumption is positive and significant for economic growth. This coefficient value ranges from 3.44 (in FMOLS) to 2.66 (in DOLS). This means that a percent increase in fossil fuel consumption will lead to increase in the level of economic growth to the tune of 2.66-3.44. But on the other hand, increase in CO_2 emissions will pull down the economic growth value. This is evident from the negative coefficient of CO in the first model. It shows that a percent increase in emissions of CO_2 will hurt economic growth to the level of 1.15-1.36. This symbolises a commensurate increase and decrease in economic growth accompanied with the usage of fossil fuels which will cause the emissions to grow. The net change in economic growth will be positive or negative depending on the magnitude of both its determinants.

The conclusions from model 3 are even more insightful. This is because increase in economic growth is causing the level of emissions to go down. This means that a percent increase in economic growth will cause the emission level to decrease by 0.50 units. The most plausible reason behind this can be switch to non-conventional sources of energy. The renewable sources of energy in the form of wind, solar, tidal, hydro, geothermal require a lump-sum investment which the economies can't afford at an early stage. But with more economic growth marking the scenes in the developing world could certainly provide them with money for undertaking research in that direction. This research will smoothen out the transition from conventional to non-conventional sources of energy for meeting the energy needs of the country. Thus the research validates the working of Kuznets inverted U hypothesis. Alongside this, a simplistic reasoning holds true that more fossil fuel consumption will eventually lead to more emissions in the economy. In the present case, a percent increase in energy consumption will cause the emission levels to rise up to the tune of 1.43-1.63 units. This is why the increased usage of fossil fuels is criticised. The findings of all the three models are in line with the existing literature.

Apart from estimating the long run coefficients using FMOLS and DOLS, we have applied Dumitrescu-Hurlin panel causality test to find if there is any causality between economic growth, energy consumption, and CO_2 emissions in the short-run. The results of causality are produced in following table.

Table 6. *Causality results of Dumitrescu-Hurlin*

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
LOG_ENERGY does not homogeneously cause LOG_GDP	6.45047	3.68153	0.0002*
LOG_GDP does not homogeneously cause LOG_ENERGY	1.93158	-0.27908	0.7802
LOG_CO does not homogeneously cause LOG_GDP	6.05207	3.33234	0.0009*
LOG_GDP does not homogeneously cause LOG_CO	5.60938	2.94435	0.0032*
LOG_CO does not homogeneously cause LOG_ENERGY	2.91527	0.58308	0.5598
LOG_ENERGY does not homogeneously cause LOG_CO	4.78403	2.22096	0.0264**

* represent 1% level of significance, ** represent 5% level of significance.

The results of causality help us to reject the hypothesis claiming that there is no causality from energy consumption to GDP. Thus there exists unidirectional causality from fuel consumption to economic growth without any reverse effect for the BRICS countries. This implies that fuel consumption will significantly contribute to improvement in the growth levels of the selected countries. There exists bidirectional causality between emissions and GDP levels. These results are significant at 1 percent level. Similar were the findings from FMOLS and DOLS estimates. But additional those estimates provided us with the sign of relationship between the variables which is not discussed at all by the causality tests. Lastly there exists unidirectional causality between fuel consumption and emissions level of CO_2.

5. Conclusions and policy implications

The present study ventured into studying the nature of relationship and the direction of causality between these variables. For this the data was culled from World Development indicators for the BRICS nation spanning 1990-2014. While most of the studies talk about bivariate relationship between electricity consumption and economic growth, some have extended it to a tri-variate analysis involving CO_2 emissions also into the model. As per the existing knowledge the study on this aspect has been untouched for the BRICS nations which represent the set of most important economies of the world. Thus the present study fills in this gap in the literature. Using advanced econometric techniques the results produced in the paper are highly important.

From strategic point of view, the results highlight a dire need to substitute conventional sources of energy with non-conventional ones in order the save the environment from being degraded to another level. Unless and until we do not surrender the use of fossil fuels we won’t be able to correct the environmental issue that the world economies are confronted with. But at the same time if an economy seeks to growth it will have to use fossil fuels to generate electricity which is the backbone of any growing economy. But an economy needs to be considerate enough to realise the importance of generating electricity from sources other than fossil fuels once the ball of economic sets rolling. What is expected from a growing economy is an understanding and readiness on its part to accept the notion of developing the environmental friendly methods of generating electricity.

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