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RESEARCH ARTICLE

Residential energy environmental Kuznets curve in emerging economies: the role of economic growth, renewable energy consumption, and financial development

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Abstract

The aim of the present paper is to determine residential energy environmental Kuznets curve (EKC) in Next-11 and BRICS countries with the specific consideration on the role of economic growth, renewable energy consumption, and financial development from an era of 1990–2015. In order to determine the cross-section independence and to control the heterogeneity between cross-sections in the paper, we have applied unique and advanced techniques of econometrics panel data. Moreover, the following tests have been applied which are the CIPS unit root test, co-integration test, fully modified ordinary least square (FMOLS), and heterogeneous panel causality technique. The outcomes revealed that in the long run, all the variables are co-integrated. Moreover, there is a significant and positive influence of residential energy consumption, economic growth, and financial development on environmental degradation. However, in the reduction of carbon dioxide (CO_2) emissions, essential role is performed by renewable energy. On the other hand, findings show great support for the residential energy EKC hypothesis in emerging countries.

Keywords Residential energy environmental Kuznets curve · Renewable energy consumption · Financial development · Panel co-integration tests · Causality test

Introduction

The environmental Kuznets curve represents the relationship between income per capita and other different indicators of environmental degradation. It reveals that as income increases or countries proceed towards development at the same time pollution and degradation increases too but after maturity, it decreases. Therefore, it has an inverted u-shaped curve (Zaman et al. 2016; Raza et al. 2017). The existing study analyzes residential energy consumption and CO_2 emissions relationship in emerging economies. Residential energy is an energy which is consumed by the people of the state on a daily basis. It has been observed that the rate of usage of residential energy is increasing day by day. Hence, the discharge of CO_2 is also increasing. Many countries to some extent have achieved lower industry energy consumption as they have adopted the strategy of off-shoring their energy-intensive industries in other countries that have low standards of the environment. Unfortunately, it is not the solution as it is not possible to offshore residential energy and this is the main reason of global warming across the world. As the income of an individual increases, the consumption of energy also increases and it results in CO_2 emissions. Therefore, emissions depend on the consumption of residential energy. CO_2 emissions are rapidly deteriorating the ecosystem. This is the key source of vast change in the weather.

The relationship between residential energy and CO_2 emissions is a direct relationship because as one variable increases, i.e., residential energy, the other also increases (CO_2 emissions). Moreover, as the average person's standard of living, income, and usage of home appliances, and transportation increases, it will likely increase the figure of national

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residential energy consumption (Baek & Gweisah, 2013) because in the early 1990s and 2000s, the rates of the residential division were approximately 10 to 35% (European Environment Agency 2015). Therefore, recently, great attention has been engaged in the residential sector's part in generating greenhouse gases (GHG). The excessive CO_2 emissions in the environment are the cause of global warming in root the present era Ang (2009). Due to excessive use of residential energy, CO_2 discharges rapidly and the climate has been changing that results in cyclones, extreme heat waves, floods, the rise in sea levels, and drought. The sustainable economic progress is slow down by the degradation of the environment in short as well as in the long run (Panayotou, 1993). Moreover, along with the economy, the people's living standard and quality of life are also negatively affected, whereas the energy consumption of the world is 80% dependent on different fossil fuels such as coal, oil, and natural gas (Lau et al. 2014). Furthermore, they all have boosted up the greenhouse gas (GHG) emissions concentration of the atmosphere and this results in ozone layer exhaustion, global warming, and climate change with critical impacts on international and regional levels of the economy and on overall society.

Nejat et al. (2015a, b) conducted research on the top 10 CO_2 emitting countries in order to provide an overall review globally of the following dimensions: firstly about energy consumption, secondly CO_2 emissions, and lastly the residential sector policies. In this paper, researchers mentioned certain principle details for the energy consumption growth; it is related to both, for the whole world and specifically for mentioned ten countries which are China, the USA, Russia, Japan, Germany, the UK, South Korea, Canada, India, and Iran. First of all, the main reason is population growth. Everyone knows that the rate of population has been increasing rapidly, so it is obvious that the usage of energy is also getting increased. Moreover, the requirements are also increasing with the increase in population. Secondly, urbanization is the other main cause of energy consumption. Many nations are moving towards industrialization, so the usage rate is also increasing. Another reason mentioned in that study is an immense increase in the possessions of personal appliances because of which residential consumption ratio has increased. Moreover, due to strict policy in the UK, Russia, Japan, and Germany, consumption has decreased successfully. In addition, this paper also possesses many other points related to CO_2 emissions. The main and important point the researcher revealed that throughout the period of the last two spans at an annual rate of 2%, the global CO_2 emissions have increased gradually from the residential sector.

Coal is replaced by other fuels that are less polluting such as natural gas; this practice has been done in most of the developed countries. Moreover, in the previous 20 years, a dramatic increase in the emissions of CO_2 is observed in three developing countries that belong to the ten leading emitters which are China, Iran, and India 25%, 245%, and 84% respectively (Narayan & Narayan, 2010). On the other hand, some countries such as Germany, South Korea, Russia, and the UK have set and follow certain principles in order to reduce GHG emissions. It includes strict policies, functioning building energy codes, natural gas and electricity are highly used, the penetration of modern and efficient technologies, huge investment in renewable energy, and high standards of the environment. Therefore, it results in the greatest reduction in GHG by Germany, South Korea, the UK, Russia, and Canada, i.e., − 30%, − 18%, − 16%, − 14%, and − 4% respectively.

Though in the USA and Japan emissions steadily rose during the same phase, the hopes are high for the greenhouse gas (GHG) emissions reduction from residential buildings in the future because of their serious new policies and latest struggles. Moreover, as per the present study, if current trends continue then by the end of current period, second and third largest emitters of CO_2 would be India and Iran. In this era, all countries are focused on its growth; therefore, they all are working day and night to be at the top in all aspects. Many countries have developed and ruling the world while on the other hand, some are working on it and they are considered as the next 11 countries (N-11) and countries of BRICS. In the present study, these countries are being selected for the research as between developed and developing countries, there is an increase in the level of competition with the advancement in globalization among the world's economies. Therefore, in order to compete and to be a strong developed country, all developing countries are struggling. They are slowly and gradually moving towards industrialization and urbanization. So it would be the need of this time to analyze how much these countries are contributing to it.

The reason for choosing BRICS countries (Brazil, India, China, Russia, and South Africa) are these countries have a total GDP of 37.5 trillion dollars which is more than 30% of global GDP and 42% of the world population live in these countries (Central Intelligence Agency, 2017). According to Pao and Tsai (2010), it is expected that by the year 2050, the GDP of these countries will be more than G7 countries. Furthermore, these countries consume 36.9% of primary energy sources consumption (Rodionova et al. 2018). According to the international agency Global Energy and CO_2 Status Report (2018), China, the USA, and India together account for nearly 70% of the energy demand. In fact, these countries are among those nations which are a larger contributor to CO_2 emissions. China is now one of the largest CO_2 emitter countries followed by the USA, EU-28, India, Russia, India, Russia, Indonesia, Brazil, Japan, Canada, and Mexico (Energy, 2018). However, these countries are also working heavily in the development of renewable energy (Rodionova et al. 2018).

The reason for choosing N-11 countries (South Korea, Mexico, Bangladesh, Egypt, Indonesia, Iran, Nigeria, Pakistan, the Philippines, Turkey, and Vietnam) are they are identified as the world largest economies by Sachs (2015) who was an investment banker and Jim O'Neill, an economist in the twenty-first century. Sachs (2015) further stated that these countries will share two-thirds size of the G7 economies by the year 2050. These countries comprised 7% of the world economy, consume 9% of the total world energy, and contribute 30% share in CO_2 emissions. As BRICS and N-11 countries are working extensively to promote economic growth, it is immensely important to understand the contribution of economic growth, residential energy consumption, renewable energy consumption, and financial development in reducing CO_2 emissions.

In the past studies, the association between financial development, economic growth, renewable energy, and CO_2 emissions is widely discussed; however, the role of residential energy is discussed limitedly. The importance of residential energy consumption has grasped the attention of the researchers. The role of residential energy consumption has been explored in the context of economic growth (Pablo-Romero et al. 2019) and CO_2 emissions (Pablo-Romero and Sánchez-Braza 2017; Fremstad et al. 2018; Mohan 2018; Gioda 2019). Some studies explored the association between CO_2 emissions with other macro-economic variables such as financial development (Lu 2018; Khan et al. 2018; Destek and Sarkodie 2019), renewable energy (Pata 2018; Rasoulinezhad and Saboori 2018; Raza and Shah 2018; Zafar et al. 2019), and economic growth (Dogan and Seker 2016; Bekhet and Othman 2018). However, no study to the best of our knowledge has been done which takes all the variables together.

Majority of the studies in the context of residential energy consumption and CO_2 emissions has been done in the top 10 emitting countries (Nejat et al. 2015a, b): China (Bai et al. 2019), Brazil (Gioda 2019) in low and lower middle income (LLMI), upper middle income (UMI), and high income (HI) countries (Narayan and Doytch 2017). However, no study has been conducted in BRICS and N-11 countries.

This study contributes to the literature in a number of ways: (i) this is the first study that has taken all the variables together, i.e., residential energy consumption, renewable energy consumption, financial development, economic growth, and CO_2 emissions in the context of N-11 countries and BRICS study; (ii) no study to the best of our knowledge is conducted that has examined this association in the context of N-11 and BRICS countries individually or combined; (iii) most of the studies previously ignore the issue of cross-sectional dependence and heterogeneity and used simple econometric technique. This study overcomes these issues by using a heterogeneous panel technique. The cross-sectional dependence between variables is analyzed by using the Pesaran (2004) cross-sectional dependence. The long run association between the variables is analyzed by using the Pedroni (1999) and Westerlund (2007) technique. The long run association between the variables is analyzed by using fully modified ordinary least squares (FMOLS) technique and the causal relationship between the variables is analyzed by using the heterogeneous panel test (Dumitrescu and Hurlin 2012).

Methodology

Data and model

This study determines the association between renewable energy, residential energy, and CO_2 emissions in N-11 and BRICS economies, and the list of the countries is displayed in Table 1. The sample size includes data from 1990 to 2015 that is 26 years and on the basis of availability of data, the sample period is selected.

The impact of financial development and the economic growth on environmental degradation are also analyzed because many past studies identified them as the significant factors which cause CO_2 emissions (Kais and Sami 2016; Ozturk and Acaravci 2013). From the indicators of the World Bank, the data is extracted for all the factors that are managed by the World Bank. In Table 2, the information regarding variables is presented. It can be seen that different units have been used for the measurement of all variables just to prevent normality issues. As per the recommendations of Sharif and Raza (2016), Bhattacharya et al. (2016), and Alam et al. (2017) before the application of statistic tool, it is of great importance to normalize the data into an even measurement. Hence, by following the preferred approach in the current study, a natural log growth form has been used; by transforming the data also through elasticity, the coefficients in the model can be described.

The impact of renewable energy, residential energy, financial development, and economic growth on CO_2 emissions is examined through the model that is stated below:

$$COE_{i,t} = \alpha_{i,t} + \beta_1 GDP_{i,t} + \beta_2 FID_{i,t} + \beta_3 REN_{i,t} + \beta_4 RNE_{i,t} + \varepsilon_{i,t}$$

The mentioned model represents the following terms. Firstly, t is basically denoting the number of observations over time and i represents the number of countries. COE is the

Table 1 List of countries

BRICS	N-11 countries	
Brazil	Bangladesh	Pakistan
Russia	Egypt	Philippines
India	Indonesia	Turkey
China	Iran	South Korea
South Africa	Mexico	Vietnam
	Nigeria	

Source: authors' estimation

Table 2 Variable definitions

Variable	Full form	Definitions
GDP	Gross domestic product	It refers to the quantitative change or expansion in a country's economy. In other words, it is the general rise in the living standard of residents of a country.
RNE	Residential energy consumption as per capita	It is the amount of energy used in a house for household work. The amount of energy used per household varies widely depending on the standard of living of the country, the climate, and the age and type of residence.
REN	Renewable energy consumption as kg of oil equivalent per capita	Renewable energy is derived from natural processes that are replenished constantly.
FID	Financial development as a proxy of domestic credit to the private sector of GDP	Financial development is part of the private sector development strategy to stimulate economic growth.
COE	Carbon emissions as metric tons per capita	It is the release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time.

Source: authors' construction

carbon dioxide emissions, *GDP* is the gross domestic product, *FID* is the financial development, *REN* is the residential energy consumption, *RNE* is the renewable energy, and the error term is denoted by ε. We also study the existence for Kuznets hypotheses between economic growth and CO_2 emissions and to judge this, we, later on, add the variable GDP^2 in the above model.

Empirical techniques

The different panel techniques have been applied in order to analyze the relationship between residential energy consumption, renewable energy, financial development, economic growth, and CO_2 emissions.

Unit root test

An initial phase is to analyze the stationary properties of the variables by using the unit root test. But before applying any test, firstly, the cross-sectional dependence is applied as it supports us to recognize the most suitable unit root test and there are chances of biased results if the existence is ignored (Pesaran 2004), and as per the research of Alam and Paramati (2016) and Paramati et al. (2016), first-generation unit root test would be invalid. Moreover, Cerrato et al. (2011) mentioned that there are multiple reasons behind the occurrence of cross-sectional dependence such as common shocks or model specification. In order to check the cross-sectional dependence, the test given by Pesaran (2004) is applied in the present study regardless of the several tests that are available for determining the cross-sectional dependence. For this test, the null hypothesis is developed as there is no cross-sectional dependency between the series. Moving further, the second-generation unit root test that is provided by Pesaran (2007) CIPS is applied after determining the cross-sectional dependence existence in the study. CIPS gives the more robust result as it implements under the notion of cross-dependence and heterogeneity in the series.

Co-integration test

In the prior section, the stationary properties of the variables are analyzed. Now in this, we determine the co-integration in the long run. It means the purpose is to check that whether in the long run, the variable is co-integrated or not by means of both first-generation co-integration and second-generation co-integration tests. In the first and second generation, Pedroni (1999) and bootstrapping co-integration test are applied respectively. Westerlund (2007) developed the bootstrapping co-integration test. Moreover, in earlier studies, the Kao, Pedroni, and Johansen co-integration techniques were used frequently but in panel data, the power to examine the co-integration relationship among variables is affected as they depend on the postulation of the cross-section dependence. Due to this weakness, over the first generation, the second-generation test, i.e., the bootstrapping co-integration test, is preferred as in finding the co-integration link between the variables, it considers the problem of cross-section dependence and heterogeneity.

By using two different tests, firstly group mean test and secondly panel test, the hypothesis of second-order co-integration is assessed. The four test statistics was developed by Westerlund (2007) on the basis of the model of error correction and bootstrapping procedure. These four test statistics are Ga, Gt, Pa, and Pt also all of them are distributed normally. By using the standard error parameters of the Error Correction model the Gt, Pt is calculated in the standard way. On the other hand, Newey and West (1994) gave standard errors and on the basis of those Ga and Pa are calculated that adjusted from autocorrelations and heteroskedasticity. Furthermore, the absence of co-integration is evaluated by this test by examining either error correction is present for the entire group or in individual panel members as well. The long run dimensions are calculated on the basis of co-integration presence. Also, to run this test, all the variables are supposed to be stationary at first difference $I(1)$; therefore, we also used the $I(1)$.

Long run estimation

By using the fully modified ordinary least square (FMOLS) technique, the long run association between renewable energy, residential energy, financial development, economic growth, and CO_2 emissions is studied. Initially, Phillips and Hansen (1990) introduced the mentioned technique after that Pedroni (2001) further modified it. In the present study, we have selected this technique as it gives accurate results and the problems regarding endogeneity and autocorrelation are accounted for by the technique. Furthermore, by using this technique, we analyzed both linear and quadratic association between the variables in N-11 and BRICS countries.

Panel causality test

The causal association between the variables is examined by using the heterogeneous panel causality test given by Dumitrescu and Hurlin (2012). As this test permits the coefficients to be different through the cross-sections, also for the analysis, the first difference variables are used because variables are required to be stationary for running the test.

Descriptive statistics

The descriptive indicators associated with the N-11 and BRICS countries are shown in Table 3. In N-11, the renewable energy consumption represents the maximum significance of 688.867% and the lowest value of 8.190% with a mean value of 215.567% and standard deviation of 185.166% of total final energy consumption. The financial development displays the maximum and minimum value of 114.724% and 8.710% through a mean and standard deviation of 31.596% and 19.585% of GDP. The CO_2 emissions represent the highest number of 8.454 and the lowest number of 0.147 with a mean and standard deviation of 2.047 and 2.014 metric tons per capita respectively. The economic growth has the highest value of 9510 US dollars and the lowest value of 400 US dollars with a mean and standard deviation of 2815 US dollars and 2553 US dollars respectively. The residential energy consumption has the maximum value of 0.911 and a minimum value of 0.012 with a mean and standard deviation of 0.258 and 0.208 per capita.

In BRICS countries, renewable energy consumption shows the highest value of 652.304 and the minimum value of 142.737 with a mean value of 334.466 and standard deviation of 143.201 of total renewable energy consumption as kg of oil equivalent per capita. The financial development shows the highest and lowest value of 160.125% and 8.334% with a mean and standard deviation of 71.451% and 44.655% of GDP. The CO_2 emissions have the highest value of 13.980 and the lowest value of 0.711 with a mean and standard deviation of 5.423 and 4.172 metric tons per capita respectively. The economic growth has the highest value of 11,797 US dollars and the lowest value of 536 US dollars with a mean and standard deviation of 5693 US dollars and 3599 US dollars respectively. The residential energy consumption has the maximum value of 1.027 and a minimum value of 0.018 with a mean and standard deviation of 0.476 and 0.314 per capita.

Table 3 Descriptive statistics of the variables

	RNE	FID	COE	GDP	REN
N-11					
Mean	215.567	31.596	2.047	2815.111	0.258
Median	196.366	25.456	1.267	1866.007	0.211
Maximum	688.867	114.724	8.454	9510.596	0.911
Minimum	8.19	8.71	0.147	400.259	0.012
Std. dev.	185.166	19.585	2.014	2553.826	0.208
Observations	205	205	205	205	205
BRICS					
Mean	334.466	71.451	5.423	5693.011	0.476
Median	284.047	53.549	2.832	6107.568	0.47
Maximum	652.304	160.125	13.98	11,797.45	1.027
Minimum	142.737	8.334	0.711	536.432	0.018
Std. dev.	143.201	44.655	4.172	3599.168	0.314
Observations	130	130	130	130	130

RNE is the renewable energy consumption, FID is the financial development, COE is the carbon emissions, GDP is the economic growth, and REN is the residential energy consumption

Results

Unit root test

Firstly, in the present paper by employing the test of Pesaran (2004), that is CD test, we check whether the variable series have cross-sectional dependence or not. Table 3 represents the results and it reveals that in the data, cross-sectional dependence do exist as the null hypothesis is rejected. Therefore, Pesaran (2007) CIPS unit root test is applied. Moreover, in the presence of cross-dependence and heterogeneity, more accurate results are given by CIPS unit root test and that is the reason behind preferring it over the first-generation test. It includes Levin, Lin, and the Chu, Im, Pesaran, and Shin, Augmented Dickey-Fuller. Table 4 demonstrates the results and as per the table, all the variables at the level are non-stationary but become stationary at the first difference I (I).

Co-integration test

By using Pedroni (1999) co-integration test, the long run relationship between the variables is examined after the unit root

Table 4 Results of cross-sectional dependence and CIPS unit root test

Variable	CD test	*p* value	CIPS test	
			Level	1st difference
N-11				
COE	21.261	0.0000	− 1.258	− 3.856***
GDP	25.324	0.0000	− 1.685	− 3.527***
FID	19.792	0.0049	− 2.005	− 3.551***
REN	20.390	0.0000	− 0.986	− 4.280***
RNE	19.625	0.0000	− 2.127	− 3.325***
BRICS				
COE	8.092	0.0000	− 2.107	− 3.227***
GDP	14.393	0.0000	− 0.478	− 4.249***
FID	6.239	0.0049	− 1.241	− 3.146***
REN	10.251	0.0000	− 1.356	− 3.558***
RNE	3.274	0.0011	− 1.701	− 3.829***

***, **, * indicate statistical significance at 1%, 5%, and 10%. Source: authors' estimation

test. Table 5 represents the results and it reveals that in all six frameworks, the test measurements of ADF and PP are dependent on within the dimension, and group-based method statistics exhibit the refusal of the null hypothesis of no co-integration in the support of alternate and it declares that variables are co-integrated in N-11 and BRICS countries and thus display a valid long run relationship.

Table 5 Results of Pedroni (Engle-Granger based) panel co-integration

Estimates	Stats.	Prob.
N-11		
Panel v-statistic	− 0.134	0.553
Panel rho-statistic	− 0.046	0.482
Panel PP statistic	− 3.566	0.000
Panel ADF statistic	− 4.397	0.000
Alternative hypothesis: individual AR coefficient		
Group rho-statistic	0.728	0.767
Group PP statistic	− 4.641	0.000
Group ADF statistic	− 4.626	0.000
BRICS		
Panel v-statistic	0.801	0.212
Panel rho-statistic	− 0.641	0.261
Panel PP statistic	− 4.990	0.000
Panel ADF statistic	− 4.836	0.000
Alternative hypothesis: individual AR coefficient		
Group rho-statistic	0.706	0.760
Group PP statistic	− 2.205	0.014
Group ADF statistic	− 2.835	0.002

The null hypothesis of Pedroni's (1999) panel co-integration procedure is no co-integration. Source: authors' estimation

By using the bootstrap panel co-integration, we also analyzed the co-integration between the variables and in Table 6, the results are displayed. With and within dimension, both outcomes are reported and show that alternative hypothesis is accepted; thus, null hypothesis is rejected. The conclusion is to draw that in the long run, all the variables are co-integrated. The result is robust and accurate as this technique for the period of estimation handles the issues of cross-section dependence and heterogeneity.

Thus, from the test of Pedroni, combined conclusion can be derived as it shows that within the dataset, the cross-sectional dependence is present and it is the reason behind the invalidating of results. Therefore, the more accurate and reliable test is of Westerlund (2007) and works as the major co-integration results for this examination.

Long run estimation

The association between renewable energy, residential energy, financial development, economic growth, and CO_2 emissions is analyzed by using the FMOLS technique. The results are reported in Table 7 and show that in the case of N-11 countries, GDP, FID, and REN are positively significant with the CO_2 emissions, while the RNE has the significant negative relationship with the CO_2 emissions. This implies that a 1% increase in GDP, FID, and REN rises the CO_2 emissions by 0.920%, 0.162%, and 0.027 respectively; however, a 1% increase in RNE decreases the CO_2 emissions by 0.053%.

As seen in Table 7, the BRICS countries' results are slightly different from the N-11 countries. The two variables GDP and REN show the same positive association with the CO_2 emissions, whereas FID and RNE show the significant negative relationship with the CO_2 emissions. This implies that a 1% rise in GDP and REN raises the CO_2 emissions by 0.544%

Table 6 Results of Westerlund (2007) bootstrap panel co-integration

Statistic	Value	*Z* value	*p* value
N-11			
Gt	− 3.257	− 4.530	0.000
Ga	− 3.221	− 2.908	0.002
Pt	− 9.257	− 3.889	0.000
Pa	− 7.057	− 1.854	0.032
BRICS			
Gt	− 9.528	− 5.225	0.000
Ga	− 2.559	− 4.998	0.000
Pt	− 7.249	− 3.985	0.000
Pa	− 2.557	− 1.642	0.050

The null hypothesis of Pedroni's (1999) panel co-integration procedure is no co-integration. Using the bootstrap approach of Westerlund (2007) to account for cross-sectional dependence, the number of replications is 400. Source: authors' estimation

Table 7 Results of linear long run analysis through FMOLS

Variable	N-11			BRICS		
	Coeff.	t-stats.	Prob.	Coeff.	t-stats.	Prob.
GDP	0.920	18.929	0.000	0.544	4.897	0.000
FID	0.162	6.108	0.000	− 0.190	− 4.723	0.000
REN	0.027	2.691	0.008	0.290	3.361	0.001
RNE	− 0.053	− 2.623	0.010	− 0.458	− 3.306	0.001

indicate statistical significance at 1%, 5%, and 10%. Source: authors' estimation

and 0.290%, respectively; however, a 1% increase in FID and RNE decreases the CO_2 emissions by 0.190% and 0.458%.

Thus, both the countries show the same result except for the variable FID, which shows the positive effect on CO_2 emissions in the case of N-11 countries and negative effect in the case of BRICS countries.

In Table 8, the results of quadratic FMOLS are stated. The result is consistent with the linear FMOLS model, significance and coefficient size are similar however, and to some extent, it contrasts in terms of their magnitude. We run the quadratic form FMOLS, to explore the existence of the EKC hypothesis between the GDP and CO_2 emissions in the N-11 and BRICS countries. In the model, there is an addition of the new variable that is the square root of economic growth (GDP^2) just for the aim of analysis. On the new variable, the quadratic long run estimation has been applied. In addition, the existence for a u-shaped relationship that is EKC hypothesis is confirmed as the coefficient of economic growth (GDP) and the (GDP^2) depict positive and negative values respectively. The studies which supported the stated result are Managi (2006), Nasir and Rehman (2011), and Kais and Sami (2016).

Thus, findings suggest that when the economic growth is at initial states, the CO_2 emissions increase but as the countries achieve the sustainable level of economic development and become stable, the CO_2 emissions start to decline. This is because in the early period of growth, the economies consume both natural resources and polluted energy resources but when the economies reach a certain threshold point, a further improvement in growth initiates a reduction in emissions gradually. As stated by Sarkodie and Strezov (2019) as the income level of the economy increases, the environmental awareness also increases, thus, that drive the populace to demand clean environment, resulting in the environmental law and regulations enforcement which in turn reduces the CO_2 emissions.

Table 8 Results of quadratic long run analysis through FMOLS

Variable	N-11			BRICS		
	Coeff.	t-stats.	Prob.	Coeff.	t-stats.	Prob.
GDP	2.348	7.113	0.000	1.217	2.460	0.015
GDP^2	− 0.223	− 4.327	0.000	− 0.231	− 3.648	0.000
FID	0.134	6.574	0.000	− 0.167	− 4.106	0.000
REN	0.026	3.424	0.001	0.514	4.887	0.000
RNE	− 0.013	− 2.211	0.028	− 0.683	− 4.525	0.000

indicate statistical significance at 1%, 5%, and 10%. Source: authors' estimation

The positive association between residential energy consumption and CO_2 emissions is in line with the study of Pablo-Romero and Sánchez-Braza (2017). This implies that the more the residential energy increases in the region, the more will be the CO_2 emissions. The residential energy acts as a prime contributor to CO_2 emissions because residential buildings use the highest amount of electricity. Furthermore, the usage of electronic appliances in these buildings, i.e., refrigerators, generators, and heaters, causes carbon emissions. Moreover, the constant usage of products that contain GHG and the way the waste is handled all emit carbon emissions in the region. The construction of buildings involves the process of land deforestation which also increases the CO_2 emissions.

The negative relationship between renewable energy consumption and CO_2 emissions is consistent with the work of Dogan and Seker (2016), Zoundi (2017), and Raza and Shah (2018). This implies that the more the economics opt for renewable energy consumption the less will be the CO_2 emissions. This might be because of the circumstance that the renewable energy sources produce no or less air pollution and are considered eco-friendly. Moreover, they act as the driving force which minimizes the greenhouse gas emissions. Furthermore, these countries also start investing in renewable energy sources to ensure a clean and safe environment.

The positive association between financial development and CO_2 emissions is found in N-11 and is supported by the studies of Jobert et al. (2010) and Saidi and Hammami (2015). The result implies that a rise in financial development boosts the CO_2 emissions in the state. This is due to the fact that financial development promotes investment and the easy access to loans encourages the users to purchase electronic appliances, refrigerators, or to use these financing to buy a car or other big-ticket durable items which increase the energy consumption and ultimately result in more CO_2 emissions. Furthermore, the developed countries with stringent environmental policies and regulations when entering the developing countries with lex environment policies transfer their dirty technologies, hence adding to their pollution stock which leads to more CO_2 emissions (Sarkodie and Strezov 2019).

The negative relationship between the financial development and CO_2 emissions is found in BRICS countries which are consistent with the studies of Shahbaz et al. (2013), Jalil and Feridun (2011) and Tamazian et al. (2009). This implies that an increase in financial development decreases the CO_2 emissions in the region. The reason behind this is if the issued loans are utilized for the environment-friendly ventures, it will help in reducing the CO_2 emissions in the region.

Heterogeneous panel causality test

The causal relationship between the variables is examined by the heterogeneous panel causality test and Table 9 contains the outcome. Moreover, results reveal that the unidirectional causal relationship is found between the GDP and CO_2 emissions in both N-11 and BRICS countries. The outcome implies that GDP leads the CO_2 emissions in the economies; however, CO_2 emissions do not cause GDP. The two directional causal relationship is found between the residential energy and CO_2 emissions, renewable energy consumption, and CO_2 emissions in both the N-11 and BRICS countries which imply that residential energy and renewable energy consumption cause the CO_2 emissions and vice versa. The financial development and CO_2 emissions have a unidirectional causal relationship in the case of N-11 countries whereas the bidirectional causal association is found in BRICS countries.

Conclusion and policy implications

The economic degradation is one of the prime issues and all the countries around the globe are committed to reducing the CO_2 emissions by the year 2030, and under the United Nations Framework Convention on Climate Change (UNFCC), they have summited their emissions reduction goals. Despite these efforts, the CO_2 emissions are increasing and will reach to 43.2 billion metric tons by the year 2040 International Energy Outlook (2016). The prime reason behind these carbon emissions is because of the energy consumption, and controlling of residential energy consumption globally is the more effective strategy than the other sectors because it is difficult to displace offshore. Therefore, it is quite interesting to study the role of residential energy consumption and CO_2 emissions nexus.

The purpose of this study is to analyze the relationship between residential energy consumption, renewable energy consumption, and CO_2 emissions in the N-11 and BRICS countries by using the data 1990–2015. The techniques applied to the dataset include stationary analysis, FMOLS, co-integration, and causality tests. The results reveal that in long run, all the variables are co-integrated. The FMOLS displays that GDP, residential energy consumption has a significant positive association with the emissions, whereas renewable energy consumption has a significant negative association in both N-11 and BRICS countries. However, financial development shows a positive association with emissions in N-11 countries and a negative association in BRICS countries. The causality test shows that unidirectional causality exists between the GDP and CO_2 emissions and bidirectional causality exists between the residential energy and CO_2 emissions, renewable energy consumption and CO2 emissions in both the N-11 and BRICS countries. Moreover, unidirectional causality is found between financial development and CO_2 emissions in the case of N-11 countries whereas the bidirectional causal association is found in BRICS countries. Furthermore, the EKC hypothesis between GDP and CO_2 emissions is also tested and found its existence in both countries.

From the above result, it is observed that the residential energy is among one of the significant contributors in the CO_2 emissions and highlights the importance to draft those strategies which minimize its usage. The government should encourage the residential users to purchase efficient equipment and appliances and should provide loans or subsidies to those users who have a low-income level because it acts as the main constraint and affects the purchase of efficient appliances. The developed residential buildings should be upgraded and the governments should ensure that the new buildings should use more energy efficient materials. In the N-11 countries, the low-income level is one of the causes which hinders the process of the adoption of the energy efficient appliances, so the government should also take measures to promote economic growth because it will improve the income level in the region.

The conventional energy policies should be replaced by the solar panel policies and the economical solar panel should be launched in the market. The products like solar heaters and solar geyser should be initiated in the market because they will

Table 9 Results of heterogeneous panel causality test

Null hypothesis	Stats.	Prob.
N-11		
GDP does not homogenously cause COE	2.024	0.043
COE does not homogenously cause GDP	1.518	0.129
FID does not homogenously cause COE	2.959	0.003
COE does not homogenously cause FID	0.761	0.447
REN does not homogenously cause COE	2.158	0.031
COE does not homogenously cause REN	3.931	0.000
RNE does not homogenously cause COE	4.536	0.000
COE does not homogenously cause RNE	3.917	0.000
BRICS		
GDP does not homogenously cause COE	19.613	0.000
COE does not homogenously cause GDP	0.003	0.998
FID does not homogenously cause COE	2.614	0.009
COE does not homogenously cause FID	1.778	0.075
REN does not homogenously cause COE	2.088	0.037
COE does not homogenously cause REN	2.029	0.043
RNE does not homogenously cause COE	2.669	0.008
COE does not homogenously cause RNE	1.670	0.095

Statistical significance at 1%. Source: authors' estimation act as an economical and environmentally friendly solution to mitigate CO_2 emissions.

As seen from the results, the renewable energy consumption helps in minimizing the CO_2 emissions so it is suggested that the government have to pay the keenest attention in investing in clean technology as this will help to protect the environment and also help the economies to increase their competitiveness. Strict environmental regulations and ISO standards should be implemented which induce the domestic operating companies to opt to go-green products and switch themselves to renewable energy. The economics should also ensure that the new companies get an entry in the market only if they come up with cleaner environmental technologies.

The policymakers should also take a keen interest in reducing the CO_2 emissions and should initiate clean energy projects by using the FDI inflows and stock markets money in creating such projects. As the CO_2 emissions reduction is at its early stage, the government should give a safe and healthy business environment to the investors, and encourage the domestic and international investors both to develop clean energy projects. The tax benefits can be one of the strategies which can be given to the investors that build clean energy industries.

The government should provide financial assistance to the investors that launched the environmental friendly ventures in the market. The check and balance should be done while giving loans to the users that they should be utilized in the purchasing of energy efficient products. Furthermore, the quality of the environment can be better by investing in the activities of research and development so economies need to finance greatly in the sector of research and development. Also, collaboration would be beneficial for the society; therefore, economies should cooperate with each other as it will assist them in sharing ideas, financial resources, and innovation of technology on the shared issues. Also, it should bring a certain solution for CO_2 emissions.

Limitations and future recommendations

This study examines the relationship between the variables in BRICS and N-11 countries, so the result cannot be generalized; however, this opens the direction for future research to contribute to the literature by doing the same study by taking individual country, or on the basis of the country's contribution in CO_2 emissions or on a comparative basis. Secondly, this study has examined the impact of residential energy consumption; comprehensive research can be done, which along with this energy consumption can use all the patterns of energy consumption and analyze their impact on carbon emissions. This study has only used three control variables so the other factors can also be considered in future research. The study has used the FMOLS technique; the future research can analyze the same association by using the more advanced econometric technique.

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