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# Relationships among carbon emissions, economic growth, energy consumption and population growth: Testing Environmental Kuznets Curve hypothesis for Brazil, China, India and Indonesia

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ABSTRACT

This study examines the impacts of income, energy consumption and population growth on $CO_2$ emissions by employing an annual time series data for the period 1970–2012 for India, Indonesia, China, and Brazil. The study used the Autoregressive Distributed Lag (ARDL) bounds test approach considering both the linear and non-linear assumptions for related time series data for the top $CO_2$ emitter emerging countries in both the short run and long run. The results show that $CO_2$ emissions have increased statistically significantly with increases in income and energy consumption in all four countries. While the relationship between $CO_2$ emissions and population growth was found to be statistically significant for India and Brazil, it has been statistically insignificant for China and Indonesia in both the short run and long run. Also, empirical observations from the testing of environmental Kuznets curve (EKC) hypothesis imply that in the cases of Brazil, China and Indonesia, $CO_2$ emissions will decrease over the time when income increases. So based on the EKC findings, it can be argued that these three countries should not take any actions or policies, which might have conservative impacts on income, in order to reduce their $CO_2$ emissions. But in the case of India, where $CO_2$ emissions and income were found to have a positive relationship, an increase in income over the time will not reduce $CO_2$ emissions in the country.


## 1. Introduction

Energy is considered as the basic input used in the production process and it is used as widely as capital and labour. Since energy consumption is so extensive among the industries, continuous energy supply is needed for maintaining and improving the current production level and standard of living in any countries, whether they are developing, emerging, developed or industrialized. As any shortfall in energy supply affects economic growth, energy consumption in the process of production is considered as a precondition of sustainable economic development. Environmental scientists argue that energy consumption is responsible for carbon dioxide ($CO_2$) emission, which is one of the major causes of creating Green House Gas (GHG) in the atmosphere and resulting global warming and climate change. Global warming and climate change are evident from melting of snow and ice, raising the sea level, changing pattern of rainfall, raising temperature in air and ocean, worsening the agricultural productivity and wild life and reducing the productivity of labour force. Thus, the threat of global warming and climate change got more attention among the environmentalists in last few decades. Consequently, economists and environmentalists became more aware of the environmental consequences of economic growth, which shifted the attention from simple economic growth to the ecology (environment) friendly economic growth.

But there exist conflicting opinions around environment protection and economic growth. Meadows et al. (1972) argued in their book "The Limits to Growth" that economic growth degenerates environmental sustainability and environment protection requires to limit economic growth. However, Dasgupta and Heal (1979) provided evidence in their book "Economic Theory and Exhaustible Resources" that the relationship between economic growth and environment protection is complementary. On the other hand, in

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early 1990s Grossman and Krueger (1994) revealed that there is a nonlinear relationship between economic growth and environmental degeneration. They also argued that the inverted U-shaped relationship between per capita income and income inequality that is shown in Kuznets (1955) is also applicable in the per capital income and environment degeneration. The relationship between economic growth and environment degeneration can be presented though a bell-shaped curve, which is known as Environmental Kuznets Curve (EKC).

The EKC hypothesis explains that the environmental degeneration rises at the first stage with increasing economic growth and then turns to decline at the last stage after reaching at a threshold level given high level of income. That is, EKC hypothesis shows economic growth brings welfare for the environment in the long term. The hypothesis has been tested in recently in both single country and cross country studies considering its policy implication for solving environmental degeneration issue, keeping economic growth sustainable (see Dinda, 2004). But, empirical evidence from the environmental degeneration-growth nexus did not reach at any conclusive consensus. One group of studies (Baek and Kim, 2013; Esteve and Tamarit, 2012b; He and Richard, 2010; Kanjilal and Ghosh, 2013; Narayan and Narayan, 2010; Nasir and Ur-Rehman, 2011; Saboori et al., 2012a,b; Sephton and Mann, 2013; Xuemei et al., 2011) found nonlinear inverted U-shaped relationship in both long run and short run between $CO_2$ emissions and economic growth and supported EKC hypothesis. But other group of studies (Nasir and Ur-Rehman, 2011; Shahbaz et al., 2012) found evidence of EKC hypothesis in long term, and not in short term. On the other hand, some studies (Arouri et al., 2012; Esteve and Tamarit, 2012a; Fodha and Zaghdoud, 2010) found that the relationship between $CO_2$ emissions and economic growth is linear. Additionally, another bunch of studies (Akbostancı, Türüt-Aşık, and Tunç, 2009; Musolesi et al., 2010; Ozturk and Acaravci, 2010) did not find any evidence of U-shape relationship between $CO_2$ emissions and economic growth; rather they found that the relationship between the two variables is N-shape.

The conflicting evidence from EKC hypothesis is found in both single country and cross country studies. For example, in the time-series single country studies, Saboori et al. (2012a,b) for Malaysia, Esteve and Tamarit (2012a) for Spain, Nasir and Ur-Rehman (2011) for Pakistan, He and Richard (2010) for Canada, Xuemei et al. (2011) for Shandong province of China and Baek and Kim (2013) for Korea, and Kanjilal and Ghosh (2013) for India found the evidence of EKC hypothesis in between carbon emissions and economic growth. However, Ozturk and Al-Mulali (2015) for Cambodia, Al-Mulali et al. (2015b) for Vietnam, Akbostancı et al. (2009) for Turkey, and Fodha and Zaghdoud (2010) and Mhenni, (2005) for Tunisia did not find the existence of EKC hypothesis in between environmental degeneration and economic growth. Cross sectional or Panel data analysis in cross country study did also have lack of consensus of EKC hypothesis. For example, Narayan and Narayan (2010) tested EKC hypothesis for 43 developing countries and they found the support of the hypothesis. In addition, Apergis and Ozturk (2015) tested EKC hypothesis and confirmed it for 14 Asian countries. However, Ben Jebli et al. (2016) for 25 OECD countries, Arouri et al. (2012) for 12 Middle East and North African countries, Musolesi et al. (2010) for 106 developed and developing countries and Jaunky (2011) for 36 high income countries did also not find any evidence supporting the EKC hypothesis. Coondoo and Dinda (2002) present the results of a study of income–$CO_2$ emission causality based on a Granger causality test to cross-country panel data on per capita income and the corresponding per capita $CO_2$ emission data. Their results indicate three different types of causality relationship holding for different country groups

Recent literatures, however, provide some explanations for the contradiction of the empirical result of the environment protection and economic growth nexus. For example, Toman and Jemelkova (2003) found divergent climate condition and pattern of carbon emissions of the country under investigation. In addition, Ewing et al. (2007) revealed that heterogeneous financial structure of the studied countries could be one of the reasons behind that contradiction since every country is at a particular phase of expansion. Moreover, Ozturk (2010) drew attention to the methodological flaws and omitted variable bias as the reason of conflicting results; whereas, Smyth (2013) highlighted on the use of different data set in different time span. The major limitation of using aggregated data is that it is quite difficult to identify associations between particular types of pollution proxy and economic growth as the issues like change of output composition, adoption of clean production technology, environmental awareness and policies influence the relationship between environment protection and economic growth (Panayotou, 1997). In addition, Saboori et al. (2012a,b) suggested that besides economic growth some other influential variables were needed to consider as exploratory variables that could potentially influence $CO_2$ emissions. Therefore, environmental degeneration and economic growth nexus should be investigated in multivariate setting instead of bi-variate setting including some other influential variables that may cause $CO_2$ emissions. On the other hand, Karanfil (2008) argued that policy makers should consider the use of different set of data and methodology as insufficient unless the result is robust and consistent.

However, the lack of profound conclusive evidence of EKC hypothesis and aforementioned explanations of the mixed existing empirical evidence motivate us to reinvestigate empirically the nexus between environment degeneration and economic growth. The study is an attempt to reinvestigate the nexus in multivariate setting. In selecting appropriate sample following the suggestion of Saboori et al. (2012a,b), the authors plan to incorporate energy consumption as it is responsible for 36 percent energy related GHG emissions (Tanaka, 2011). Moreover, IEA (2013) reported that world energy consumption is projected to grow by 56 percent in 2040 and IEA (2008) also reported that industrial GHG emissions continuing to increase by 1.7 times by 2030 for which $CO_2$ emissions are mostly responsible. Furthermore, some recent studies in multivariate setting included energy consumption with economic growth and $CO_2$ emissions to validate EKC hypothesis but they found conflicting result. Ang (2007) found that energy consumption maintains long run relationship with $CO_2$ and that validated EKC hypothesis for France. Ang (2008) also found the evidence of similar finding for Malaysia and Shahbaz et al. (2012) for Pakistan and Kanjilal and Ghosh (2013) for India also found the same result. But Ghosh (2010) did not find any long run relationship between energy consumption and $CO_2$ emissions for India and thus could not validate EKC hypothesis for the country. Also EKC hypothesis is not confirmed in the case of Portugal in the study of Shahbaz et al. (2015). On the other hand, Arouri et al. (2012) found the long run relationship between energy consumption and $CO_2$ emissions but with poor evidence to support EKC hypothesis for Middle Eastern and North African countries.

We conduct our study exclusively on Brazil, China, India and Indonesia due to some distinct features of these countries. According to WDI data set, these four countries were responsible for 34.9 percent global $CO_2$ emission, whereas they account for 13.1 percent of global GDP in 2011. In addition, only these four countries contain 43.3 percent of global population. In the past three decades these countries have been enjoying higher economic growth by transforming their economies from primary agricultural sector to energy-led industrial sector. Thus, we consider population size as an additional exploratory variable as Nasir and Ur-Rehman (2011) pointed out that largely populated countries are more responsible for $CO_2$ emissions. However, to the best of our knowledge population is not considered as exploratory variable for $CO_2$ emis-

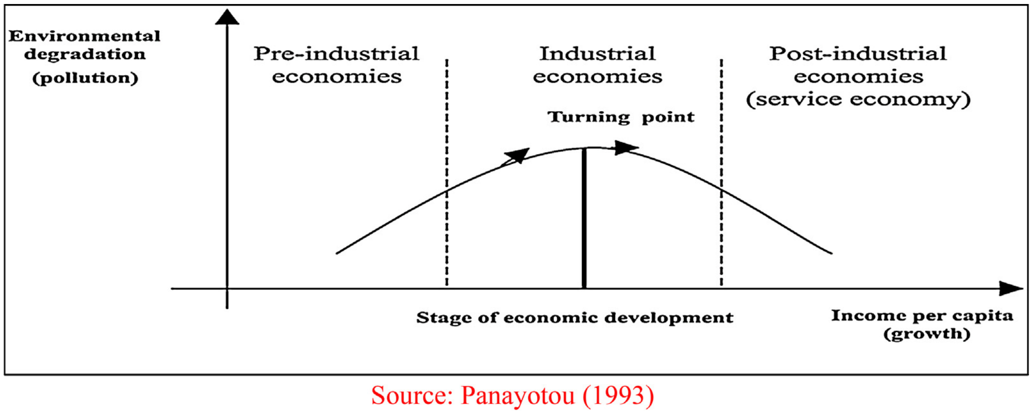


**Fig. 1.** Relationship between economic growth and pollution.

Source: Panayotou (1993)

sions in previous studies. On the other hand, $CO_2$ emissions rate of developing countries is higher as they are not obliged to comply with Kyoto protocol. In selecting appropriate sample, the study selects four emerging countries based on both population size of more than 200 million as of June 2014 and $CO_2$ emissions of those countries. According to Carbon Dioxide Information Analysis Centre (CDIAC) of 2010[1] of US Department of Energy, among the developing countries top $CO_2$ emitting country is China (8286892 t, which is 6.195% of total world $CO_2$ emissions) followed by India (2008823 t, which is 5.98% to total emissions), Indonesia (433989 t, which is 1.29% of total emissions) and Brazil (419754 t, which is 1.25% of total emissions). Moreover, in terms of population size the top four developing countries are China (1356 millions), India (1236 millions), Indonesia (254 millions) and Brazil (203 millions[2]). Therefore, the study aims to reinvestigate the environmental degeneration and growth nexus in multivariate setting for China, India, Indonesia and Brazil based on these countries' $CO_2$ emissions and population growth.

The study contributes to the environmental economics literature both empirically and contextually. The study for the first time investigates dynamic relationship among $CO_2$ emissions, economic growth, energy consumption and population size for China, India, Indonesia and Brazil for the period of 1970–2012. It uses autoregressive distributed lag (ARDL) test in order to assess the long run relationships and dynamics of the key variables for valid reason discussed in the methodology section. The study also conducts some diagnosis tests for checking the reliability of the model such as serial correlation, functional form, normality and heteroscedasticity. In addition, the study also conducts stability test such as cumulative sum and cumulative sum square test based on recursive regression residuals. The paper is designed as follows. Section 2 designates the data and methodology followed by the results and analysis in Section 3 and discussion and policy recommendation are respectively in Sections 4 and 5. Finally, the Section 6 deliberates the study's concluding remarks.

## 2. Methodology

### 2.1. Data and variables

This study investigates the impacts of income, energy consumption and population growth on $CO_2$ emissions. To conduct the empirical test, this study considered four developing countries which are highly populated as well as top $CO_2$ emitters. The study employs an annual time series data for the period of 1970–2012 for India, Indonesia, China, and Brazil. The data were collected from the World Development Indicator (WDI) 2013 dataset. The variables of interest included carbon dioxide emissions in metric tons per capita ($CO_2$) as dependent variable and explanatory variables included GDP per capita (constant at 2005 (GDPC)), energy consumption (kg of oil equivalent per capita (EUC)), and population growth (POPG) (Appendix A). We considered population growth in our model because the concentration of greenhouse gases in the atmosphere is increasing as a consequence of various human activities. Therefore, population growth is the core factor in explaining $CO_2$ emission dynamics (Bongaarts, 1992) in these four countries. There is a common belief that population growth has been fostering greenhouse gas emissions by burning energy, urbanization, deforestation and so on. The functional form of the relationships among the variables for the linear model is as follows:

$$CO_2 = f(GDPC, EUC, POPG) \qquad (1.0)$$

We re-estimate the Eq. (1.0) by considering GDP square in contention with the theoretical essence of Grossman and Krueger (1994). In addition, we consider GDP square for checking the robustness of Eq. (1.0) and following anecdotal fact as numerous empirical studies found the presence of non-linear relationship between $CO_2$ emission and GDP, for instance Ahmed et al., 2016; Begum et al., 2015; Al-Mulali et al., 2015a,b,c; Shahbaz et al., 2015; Saboori et al., 2012a,b.

$$CO_2 = f(GDPC, GDPCS, EUC, POPG) \qquad (2.0)$$

The regression form follows

$$\ln CO_{2t} = \beta_0 + \beta_1 \ln GDPC_t + \beta_2 \ln GDPC^2{}_t + \beta_3 \ln EU_t + \beta_4 \ln POPG_t + \varepsilon_t$$

Where, $\ln CO_{2t}$ = log of carbon emission per capita; $\ln GDPC_t$ = log of GDP per capita (real based on 2005); $\ln GDPC^2$ = long GDP per capita square; $\ln EU$ = log of energy use per capita; $\ln POPG_t$ = log of trade openness; and $\varepsilon_t$ = error term

For the validity the EKC theory requires $\beta_1$ to be positive and significant while $\beta_2$ has to be negative and significant. The EKC hypothesis argues that the initial phase of economic growth has negative consequences to the environment, but the negative consequences diminish as the growth rate surpasses a certain point (Fig. 1).

[1] List of countries by carbon dioxide emissions (http://en.wikipedia.org/wiki/List_of_countries_by_carbon_dioxide_emissionss)

[2] Usage and population statistics (http://www.internetworldstats.com/stats8.htm)

### 2.2. Specification of econometric models

The standard approaches to the co-integration are Engle and Granger and Johansen. Engle and Granger is a bi-variate technique so multivariate analysis is ruled out under the technique of Engle and Granger co-integration test. Another shortcoming of this method is that of estimating long-run equilibrium relationship using Ordinary Least Square (OLS) approach without making the variables stationary. This procedure is subject to generating a substantial bias owing to the omission of dynamics and undermining the performance of the estimator Banerjee et al. (1986). Conversely, Johansen technique is known as system-based approach to co-integration, which is more efficient than the Engle and Granger approach as it offers multiple co-integrating vectors. Unlike Engle & Granger, Johansen approach lessens the omitted lagged variables bias by taking the lag into the estimation. However, this approach also is a subject of criticism as the approach is highly sensitive with the number of lags included in the test (Gonzalo, 1994). Moreover, in the case of existing more than one cointegrating vectors in the model, it is often hard to interpret each implied economic relationship and find the most appropriate vector for the subsequent test (Ang, 2010). Both the Engle-Granger and Johansen techniques have been criticized on the ground of the validity being presence in mix order of integration in the regression, which refers that these techniques are only valid in the case of same order of integration.

This study employs autoregressive distributed lag (ARDL) technique developed by Pesaran et al. (2001) in order to assess the long run relationships and the changing nature of the key variables. This methodology also has some key important characteristics, including (i) co-integration relationship basically estimated using OLS, and this estimation was done after choosing the respective lag order of the model used. (ii) Apart from Johansen and Juselius approach, this applied technique remains statistically significant irrespective of the nature of the variables either being I(0) or I(1) or mutually co-integrated. This situation typically explains the position that unit root test may not be necessary. (iii) In another dimension, it is imperative to mention that the test is necessary and valid in small and finite data size, but in essence, this assessment procedure will not hold if an I(2) series exists within the model.

However, following Khan et al. (2005) and Fosu and Magnus (2006), the ARDL version of the vector error correction model (VECM) can be specified as:

The linear model:

$$\Delta \ln CO_2 = \beta_0 + \beta_1 \ln CO_{2t-1} + \beta_2 \mathrm{LGDPC}_{t-1} + \beta_3 \mathrm{LEUC}_{t-1} + \beta_4 POPG_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta \ln CO_{2t-i} + \sum_{j=1}^{q} \delta_j \Delta LGDPC_{t-j} + \sum_{m=1}^{q} \eta_m LEUC_{t-m} + \sum_{r=1}^{q} \xi_r \mathrm{POPG}_{t-r} + \varepsilon_t \quad (1.1)$$

The quadratic model:

$$\Delta \ln CO_2 = \beta_0 + \beta_1 \ln CO_{2t-1} + \beta_2 \mathrm{LGDPC}_{t-1} + \beta_3 LGDPC^2{}_{t-1} + \beta_4 LEUC_{t-1} + \beta_5 POPG_{t-1} + \sum_{i=1}^{p} \gamma_i \Delta \ln CO_{2t-i} + \sum_{j=1}^{q} \delta_j \Delta LGDPC_{t-j} + \sum_{l=1}^{q} \varphi_l \Delta LGDPC^2{}_{t-l} + \sum_{m=1}^{q} \eta_m LEUC_{t-m} + \sum_{r=1}^{q} \xi_r \mathrm{POPG}_{t-r} + \varepsilon_t \quad (2.1)$$

### 2.3. Estimation procedure

Firstly, we estimated Eqs. (1.1) and (2.1) employing OLS approach and then, we conducted the Wald Test or F-test for determining the joint significance of the coefficients of lagged variables for the purpose of examining the existence of long run relationship among the variables. The purpose of using Wald Test is to explore whether the respective data series collectively follow the stationary process in the long run, where each data series is individually not stationary. The null hypothesis ($H_0$) is: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = 0$, which assumes that there is no conintregration among the variables, while the alternative hypothesis ($H_a$) assumes just the opposite: $\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 \neq 0$.

The F statistics was then compared with the critical value (upper and lower bound) given by Pesaran et al. (2001). If the F-statistic is to be found above the upper critical value, the null hypothesis of no co-integration can be rejected, which indicates that long-run relationship exists among the variables. Conversely, if the F-statistic is found to be smaller than the lower critical value the null hypothesis cannot be rejected implying no co-integration among the variables. However, if the F-statistic lies between lower and upper critical values, the test is inconclusive.

At the second step, after establishing co-integration relationship among the variables, long-run coefficient of the ARDL model can be estimated as follows:

The linear model:

$$\ln CO_2 = \beta_0 + \sum_{i=1}^{p} \gamma_i \ln CO_{2t-i} + \sum_{j=0}^{q1} \delta_j LGDPC_{t-j} + \sum_{m=0}^{q3} \eta_m LEUC_{t-m} + \sum_{r=0}^{q4} \psi_r lnPOPG_{t-r} + \varepsilon_t \quad (1.2)$$

The quadratic model:

$$\ln CO_2 = \beta_0 + \sum_{i=1}^{p} \gamma_i \ln CO_{2t-i} + \sum_{j=0}^{q1} \delta_j LGDPC_{t-j} + \sum_{l=0}^{q2} \varphi_l LGDPC^2{}_{t-l} + \sum_{m=0}^{q3} \eta_m LEUC_{t-m} + \sum_{r=0}^{q4} \psi_r POPG_{t-r} + \varepsilon_t \quad (2.2)$$

In this process, we used Schwarz Information Criteria (SIC) for selecting the appropriate lag length of the ARDL model for all respective variables under study. Finally, we used the error correction models of Eqs. (1.3) and (2.3) to estimate short run dynamics, as shown below:

The linear model:

$$\Delta \ln CO_2 = \beta_0 + \sum_{i=1}^{p} \gamma_i \Delta \ln CO_{2t-i} + \sum_{j=1}^{q} \delta_j \Delta \mathrm{LGDPC}_{t-j} + \sum_{m=1}^{q} \eta_m \Delta LEUC_{t-m} + \sum_{r=1}^{q} \psi_r \Delta lnPOPG_{t-r} + \vartheta emc_{t-1} + \varepsilon_t \quad (1.3)$$

The quadratic model:

$$\Delta \ln CO_2 = \beta_0 + \sum_{i=1}^{p} \gamma_i \Delta \ln CO_{2t-i} + \sum_{j=1}^{q} \delta_j \delta LGDPC_{t-j} + \sum_{l=1}^{q} \varphi_l \Delta LGDPC^2{}_{t-l} + \sum_{m=1}^{q} \eta_m \delta LEUC_{t-m} + \sum_{r=1}^{q} \psi_r \delta POPG_{t-r} + \vartheta emc_{t-1} + \varepsilon_t \quad (2.3)$$

## 3. Empirical results and analysis

### 3.1. Descriptive statistics

Table 1 provides a snapshot of descriptive statistics of the variables used for examining the nexus among carbon emission, economic growth, energy consumption, and population growth for the countries of interest such as India, Brazil, Indonesia and China during 43 years from 1970 to 2012. The table shows that the countries are more fragmented in environment degeneration where, China is the most carbon emitted country with an annual average of 2.726 t per capita emission followed by Brazil (1.592 t per capita emission), Indonesia (1.023 t per capita emission) and India (0.885 t per capita emission). Conversely, in terms of patterns of economic growth, energy consumption and population growth, the counties are more adjacent. For example, Brazil has the highest economic growth with an annual average of 8.322 percent GDP per capita followed by Indonesia (6.701 percent GDP per capita), China (6.349 percent GDP per capita) and India (6.104 percent GDP per capita). Moreover, in terms of energy consumption, Brazil also consumes more energy with an annual average of 6.901 kg of oil equivalent per capita followed by China (6.716), Indonesia (6.271) and India (5.933). In addition, considering the population growth rates, India is the highest among the counties with 1.914 percent per annum followed by Indonesia (1.855 percent per annum), China (1.230 percent per annum) and Brazil (1.023 percent per annum)

**Table 1**
Descriptive statistics of the variables.

| | VARIABLE | OBS | MEAN | STD. DEV. | MIN | MAX |
|---|---|---|---|---|---|---|
| India | LGDPC | 43 | 6.104 | 0.445 | 5.575 | 7.009 |
| | $CO_2C$ | 43 | 0.885 | 0.420 | 0.351 | 1.811 |
| | LEUC | 43 | 5.933 | 0.250 | 5.619 | 6.474 |
| | POPG | 43 | 1.914 | 0.366 | 1.264 | 2.336 |
| Brazil | LGDPC | 43 | 8.322 | 0.187 | 7.772 | 8.652 |
| | $CO_2C$ | 43 | 1.592 | 0.300 | 0.976 | 2.216 |
| | LEUC | 43 | 6.901 | 0.167 | 6.564 | 7.248 |
| | POPG | 43 | 1.747 | 0.537 | 0.870 | 2.477 |
| Indonesia | LGDPC | 43 | 6.701 | 0.477 | 5.807 | 7.457 |
| | $CO_2C$ | 43 | 1.023 | 0.479 | 0.314 | 1.908 |
| | LEUC | 43 | 6.271 | 0.371 | 5.702 | 6.778 |
| | POPG | 43 | 1.855 | 0.441 | 1.248 | 2.556 |
| China | LGDPC | 43 | 6.349 | 0.995 | 4.974 | 8.116 |
| | $CO_2C$ | 43 | 2.726 | 1.628 | 0.943 | 7.087 |
| | LEUC | 43 | 6.716 | 0.424 | 6.143 | 7.691 |
| | POPG | 43 | 1.230 | 0.597 | 0.479 | 2.762 |

Note: LGDPC stands for log of GDP per capita, $CO_2C$ stands for carbon dioxide emission in metric ton per capita, LEUC stands for log of energy consumption in kg of oil equivalent per capita and POPG indicates population growth. OBS stands for number of observations, MEAN indicates annual mean value of the variables, and STD. DEV., MIN and MAX shows standard deviation, minimum value and maximum value of the variables, respectively.

**Table 2**
DF-GLS unit-root test output.

| | India | Indonesia | China | Brazil |
|---|---|---|---|---|
| Level | | | | |
| $LCO_2$ | 1.576 | 0.991 | 1.263 | 0.725 |
| LGDPC | −0.096 | 0.673 | 0.368 | 0.496 |
| LEUC | 0.292 | 1.146 | 1.337 | 1.418 |
| POPG | −1.627* | −3.271** | 0.315 | −0.556 |
| 1st Difference | | | | |
| $\Delta$ $LCO_2$ | −4.031*** | −7.094*** | −2.051** | −5.610*** |
| $\Delta$ LGDPC | −4.364*** | −4.728*** | −3.393*** | −2.270** |
| $\Delta$ LEUC | −2.390*** | −5.991*** | −3.423*** | −5.425*** |
| $\Delta$ POPG | 0.522 | −1.506 | −3.422*** | −1.840* |

* Indicates significant at 10% level.
** Indicates significant at 5% level.
*** Indicates significant at 1% level.

### 3.2. Analysis of unit root

Regression analysis based on time series data assumes that the underlying time series are stationary. It is a well-known empirical fact that many macroeconomic time series are typically non stationary, as indicated by the serial correlation between successive observations, particularly when the sampling interval is very small. This implies that the classical $t$ and F-tests are not appropriate and will result in misleading conclusions. The studies which do not account for the presence of unit root non-stationarity may suffer from (i) spurious regression problem often characterized by a high $R^2$ and a low value of the Durbin–Watson statistic (Granger and Newbold, 1974; Philips, 1986); and (ii) inconsistent and less efficient ordinary least squares (OLS) parameter estimates unless the variables are co-integrated (Engle and Granger, 1987).

Also, the analysis of co-integration starts with the determination of the univariate properties of the time series. The concept of co-integration requires that the set of variables should be integrated of the same order and their linear combinations must be stationary. If the series do not follow the same order of integration, then there can be no meaningful relationship among them. If the series are integrated of the same order, it is reasonable to proceed to the co-integration test.

However, the data used in the study are time series data and all the series were not found to be stationary at levels with constant for all four countries. Unit root tests for stationarity were performed both at levels and first differences for all the variables. Although ADF test results (Table 2) confirm the existence of unit roots, and therefore non-stationarity, at the levels for all the variables except population growth rate for India and Indonesia, however, the rest of the variables show stationarity at first differencing level. The results of Dicky Fuller generalized least square test (DF-GLS) are reported in Table 2.

It is also being noted that in order to conduct ARDL bound test under Pesaran et al. (2001) methodology, there is no necessity to check the order of integration of the respective variables. However, we have conducted the unit root test to make sure no variable surpasses the order of integration I(1) and to justify the appropriateness of applying ARDL approach rather than using other standard cointegration approaches. From the unit root test it was found mixed order of integration and all of the variables were found to be stationarity at either I(0) or I(1), which endorses to employ ARDL bounds test rather than Johansen or Engle and Granger approaches.

### 3.3. Analysis of Co-integration

In order to examine the co-integration relationship among the variables, the F-statistics under the Wald Test measures the join

**Table 3**
ARDL Bounds test output.

| Country | Equation | F-Stat | P-Value | Outcome |
|---|---|---|---|---|
| India | $F_{CO2}(CO_2$\|LGDPC, LEUC, POPG) | 4.223** | 0.007 | Co-integration |
| Indonesia | $F_{CO2}(CO_2$\|LGDPC, LEUC, POPG) | 4.894*** | 0.003 | Co-integration |
| China | $F_{CO2}(CO_2$\|LGDPC, LEUC, POPG) | 5.756*** | 0.002 | Co-integration |
| Brazil | $F_{CO2}(CO_2$\|LGDPC, LEUC, POPG) | 5.121*** | 0.003 | Co-integration |
| Critical Value | | I(0) | I(1) | Method |
| *** | 1 percent significance level | 3.29 | 4.37 | Pesaran et al. (2001) |
| ** | 5 percent significance level | 2.56 | 3.49 | |
| * | 10 percent significance level | 2.20 | 3.09 | |
| *** | 1 percent significance level | 3.892 | 5.173 | Narayan (2005) |
| ** | 5 percent significance level | 2.850 | 3.905 | |
| * | 10 percent significance level | 2.402 | 3.345 | |

**Table 4**
Estimated long run coefficients using the ARDL approach.

| Model | Variable | India | Indonesia | China | Brazil |
|---|---|---|---|---|---|
| Linear Model | | | | | |
| | LGDPC | 0.279** | 0.208 | 0.328*** | 0.012 |
| | | (0.143) | (0.869) | (0.119) | (0.018) |
| | LEUC | 1.5481*** | 2.101** | 0.681*** | 0.106 |
| | | (0.209) | (1.007) | (0.278) | (0.94) |
| | POPG | 0.21887* | 0.47 | 0.157 | (0.541** |
| | | (0.113) | (0.703) | (0.157) | (0.234) |
| | C | −10.403 | −3.451 | 7.806*** | 12.672 |
| | | (1.014) | (6.165) | (1.351) | (6.915) |
| Quadratic Model | | | | | |
| | LGDPC | −0.664 | 0.027* | 1.732*** | 28.693*** |
| | | (0.523) | (0.015) | (0.164 | (5.817) |
| | LGDPCS | 0.063* | −0.005*** | −0.125*** | −1.852*** |
| | | (0.034) | (0.001) | (0.014) | (0.358) |
| | LEUC | 1.652*** | 2.173*** | 1.371*** | 4.350*** |
| | | (0.201) | (0.646) | (0.106) | (0.487) |
| | POPG | 0.114 | 0.698 | 0.049 | 0.062 |
| | | (0.114) | (0.55) | (0.031) | (0.053) |
| | C | −7.455*** | −13.758*** | −0.319 | −138.925 |
| | | (1.778) | (5.062) | (1.049) | (25.034) |

* Indicates significant at 10% level Approach ARDL (1,0,0,0,0,0) selected based on Schwarz Bayesian Criterion: $CO_2$ is Dependent Variable *Slandered errors* are in the parenthesis.
** Indicates significant at 5% level.
*** Indicates significant at 1% level.

effect of all regressors. The calculated F-statistics ($F_{co2}(CO_2$|LGDPC, LEUC, POPG)) for India was found to be 4.223, which is within the range of Pesaran critical value, and hence it indicates that null hypothesis of no co-integration is under inconclusive zone (Table 3). The calculated F-statistics ($F_{co2}(CO_2$|LGDPC, LEUC, POPG)) for Indonesia, China, and Brazil were found to be 4.89, 5.76, and 5.12, respectively, which are all higher than the Pesaran critical value of 4.37. So, it indicates that null hypothesis of no co-integration is rejected at 1% significant level (Table 4). In the case of India, the calculated F-statistics of 4.223 is higher than the Pesaran critical value of 3.49, and thus it indicates that null hypothesis of no co-integration is rejected at 5% significant level.

Furthermore, we have also compared the calculated F-statistics value with the critical value of Narayan (2005), which is considered as better than Pesaran critical value, as it was developed through applying stochastic simulations specific to the sample size based on 40,000 replications. According to the critical value mentioned by Narayan (2005), India and Indonesia were found con-integrated at 5% level while China and Brazil were found con-integrated at 1% level.

### 3.4. Assessment of long run scenario

Table 4 depicts the long run elasticity of the respective variables on the $CO_2$ emissions. According to the linear model, real GDP has a positive and statistically significant influence on $CO_2$ emissions in long run in the cases of both India and China, but no significant relationship was found for both Indonesia and Brazil. But while considering the presence of *Environmental Kuznets Curve* for the income and $CO_2$ emissions, the quadratic model shows different results. Now, except India, for other three countries, real GDP shows a positive and statistically significant influence on $CO_2$ emissions in long run.

On the other hand, the energy consumption (EUC) shows statistically significantly positive relationship with $CO_2$ emissions for India, Indonesia and China in both models, but Brazil is found to have the same relationship only in the quadratic model. The population growth (POPG) does not show statistically significant relationship with $CO_2$ emissions for any countries in quadratic model, but in the linear model, India shows significantly positive relationship and Brazil shows significantly negative relationship.

In the quadratic model, the coefficients of LGDPC and LGDPCS in the long-run co-integrated equation were found to be statistically significant for Indonesia, China, and Brazil (Table 4). Since $\delta > 0$ and $\varphi < 0$ (Eq. (2.2)), there is found an inverted U-shape relationship between per capita $CO_2$ emissions and per capita real GDP, which is just confirming the carbon Kuznets Curve for Indonesia, China, and Brazil. The finding of this study is sensible in the respect of anecdotal issue. For instance, Indonesia adopted a strategic long term development plan (2005–2025) targeting to achieve a “green and everlasting Indonesia” through implementing various environmental policies. Moreover, the growth paradigm of Indonesia still

**Table 5**
Error correction representation using the ARDL approach.

| Model | Variables | India | Indonesia | China | Brazil |
|---|---|---|---|---|---|
| Linear Model | Δ LGDPC | 0.170* | 1.0581*** | 0.530*** | 0.001 |
| | | (0.088) | (0.300) | (0.146) | (0.001) |
| | Δ LEUC | 0.944*** | 0.540** | 0.994*** | 1.069*** |
| | | (0.205) | (0.239) | (0.129) | (0.190) |
| | Δ POPG | 0.133** | 0.121 | 0.022 | −0.054*** |
| | | (0.068) | (0.202) | (0.017) | (0.022) |
| | Δ C | −6.347*** | −0.888 | 1.133** | 1.286*** |
| | | (1.163) | (1.719) | (0.517) | (0.490) |
| | ECM(-1) | −0.610*** | −0.257** | −0.145** | −0.101** |
| | | (0.112) | (0.120) | (0.057) | (0.050) |
| Quadratic Model | Δ LGDPC | −0.429 | 0.006** | 0.906*** | 16.189*** |
| | | (0.339) | (0.003) | (0.227) | (4.100) |
| | Δ LGDPCS | 0.041* | −0.001*** | 0.042* | −0.9948*** |
| | | (.022) | (.317) | (0.024) | (0.251) |
| | Δ LEUC | 1.069*** | 0.535** | 1.174*** | 2.486*** |
| | | (0.210) | (0.22) | (0.120) | (0.297) |
| | Δ POPG | 0.074 | 0.172 | 0.025 | 1.363*** |
| | | (.073) | (.147) | (0.014) | (0.300) |
| | Δ C | −4.824*** | −3.391** | −0.167 | −78.381*** |
| | | (1.778) | (1.59) | (0.556) | (18.939) |
| | ECM(-1) | −0.647*** | −0.246*** | −0.523*** | −0.564*** |
| | | (1.402) | (0.0697) | (0.1114) | (0.110) |

* Indicates significant at 10% level.

largely follows primary sector, for instance agriculture, forestry, and mining contribute about 25% to Indonesia's GDP, whereas Al-Mamun et al. (2014) profoundly argued that the agriculture dominating countries are less responsible for $CO_2$ emission than industrial dominating countries. Similarly, Brazil experienced a great success over the last decade at shielding its forests and averting deforestation. More startling, even with these regulations to improve environmental degradation, Brazil has had a dramatic increase in food output. Thus, Brazil is an example that a country can attain environmental and economic gains simultaneously. In the case of China, the national government has undertaken a number of measures to curb pollution in China and improve the country's environmental situation. Those measures included cleaner energy, green technology, carbon taxing and so on. However, India did not propose to reduce its $CO_2$ emissions. Thus proponents speculate $CO_2$ emissions would still triple by 2030. According to the BP Statistical Review, India emits the third most $CO_2$ emissions in the world. In 2014, India emitted 2088 million metric tons of $CO_2$. If India triples its emissions by 2030, it will be emitting 13 percent more $CO_2$ emissions than the emissions that the Energy Information Administration (EIA) expects the United States to emit in that year.[3]

### 3.5. Assessment of short run scenario

Similar to long run scenario, the four countries show mixed results in short run (Table 5). The linear model shows real GDP has a positive and statistically significant influence on $CO_2$ emissions in short run in the cases of India, Indonesia, and China, but no significant relationship was found for Brazil. But while considering the quadratic model, except India the real GDP of other three countries show a positive and statistically significant influence on $CO_2$ emissions in short run.

In the short run, however, the energy consumption (EUC) shows statistically significantly positive relationship with $CO_2$ emissions for all four countries in both linear and quadratic models. The population growth (POPG) does not show statistically significant relationship with $CO_2$ emissions in short run for Indonesia and China in both linear and quadratic model. However, the population growth (POPG) of India shows statistically significantly positive relationship only in the linear model. The population growth (POPG) of Brazil shows significantly negative relationship in the linear model, but positive relationship in quadratic model.

In the quadratic model, the coefficients of ΔLGDPC and ΔLGDPCS in the short-run co-integrated equation were found to be statistically significant for Indonesia, China, and Brazil (Table 5). Since $\delta > 0$ and $\varphi < 0$ (Eq. (2.3)), there is found an inverted U-shape relationship between per capita $CO_2$ emissions and per capita real GDP, which is just confirming the carbon Kuznets Curve for Indonesia and Brazil in short-run. However, in the short-run, China is found to have the U-shape relationship between per capita $CO_2$ emissions and per capita real GDP as its estimated $\delta > 0$ and $\varphi > 0$ (Eq. (2.3)).

But it is most important to mention that in both linear and quadratic models, the lag error correction term (ECM(-1)) shows negative sign for all of the four countries, which indicates both the long run equilibrium and short run disequilibrium. The coefficients of ECM were found to be −0.61 and −0.647 for India, which indicate that any deviation from the long-run equilibrium between variables will be corrected about 61–64.7 percent for each year and that it takes about 1.55–1.64 years to return to the long-run equilibrium level. The coefficients of ECM were found to be −0.257 and −0.246 for Indonesia, which indicate that adjustment takes place 24.6–25.7 percent per year towards the long run equilibrium. The coefficients of ECM were found to be −0.145 and −0.523 for China, which indicate that adjustment takes place 14.5–52.3 percent per year towards the long run equilibrium. The coefficients of ECM were found to be −0.101 and −0.564 for Brazil, which indicate that adjustment takes place 10.1–56.4 percent per year towards the long run equilibrium.

### 3.6. Diagnostic tests

#### 3.6.1. Efficiency test of models

The models have passed through several diagnostic tests as summarized in Table 6. The values of $R^2$ and adjusted $R^2$ were estimated to be above 99 percent, which indicate that the model is strongly good fitted. In the case of India, the quadratic model was found to be

[3] Energy Information Administration, Annual Energy Outlook 2015, http://www.eia.gov/forecasts/aeo/pdf/tbla18.pdf.

**Table 6**
ARDL-VECM diagnostic tests.

| Model | Type of Tests | India | Indonesia | China | Brazil |
|---|---|---|---|---|---|
| Linear Model | $R^2$ | 0.997 | 0.992 | 0.998 | 0.996 |
| | Adjusted $R^2$ | 0.997 | 0.991 | 0.998 | 0.996 |
| | Serial Correlation | 0.060[0.805] | 2.218[0.136] | 0.029[0.865] | 3.482*[0.062] |
| | Functional Form | 0.673[0.412] | 5.628**[0.018] | 2.995*[0.084] | 1.001[0.317] |
| | Normality | 19.924***[0.000] | 1.633[0.442] | 1.227[1.227] | 0.263[0.877] |
| | Heteroscedasticity | 5.574**[0.018] | 0.495[0.481] | 0.509[0.509] | 0.073[0.786] |
| Quadratic Model | $R^2$ | 0.999 | 0.992 | 0.999 | 0.991 |
| | Adjusted $R^2$ | 0.998 | 0.991 | 0.999 | 0.990 |
| | Serial Correlation | 0.139[0.709] | 1.094[0.168] | 0.064[0.800] | 2.256[.133] |
| | Functional Form | 6.393**[0.011] | 3.483*[0.062] | 0.353[0.552] | 0.990[.320] |
| | Normality | 5.418*[0.067] | 2.053[0.358] | 1.636[0.441] | 1.408[.495] |
| | Heteroscedasticity | 0.494[0.482] | 0.683[0.408] | 0.372[0.542] | 0.043[.834] |

* Indicates significant at 10% level *p*-values are given in the parenthesis.
** Indicate significant at 5% level.
*** Indicate significant at 1% level.

more appropriate as it could solve the heteroscedasticity problem. Although, there is still a functional error in the quadratic model, but it could be disregarded since the $R^2$ is substantially high. In addition, the quadratic model for Indonesia could reduce the functional error from 5 percent significant to 10 percent significant level. If we consider the maximum 5 percent significant level, the quadratic model for all the four countries is considered well fitted than the linear one. However, at 5 percent significant level, the diagnostic tests confirm that there are found no serial correlation, no abnormality problem, and also no heteroscedasticity problem in the quadratic model for all four countries.

### 3.6.2. *Structural stability test*

Since the stability of the $CO_2$ emissions function is vital for an effective economic and environmental policy, testing whether the estimated models have shifted over time is an important part of our empirical analysis. So, there were conducted CUSUM test and CUSUM Square tests (Figs. 2 and 3) of parameter stability, which indicates that the parameters are found to be stable during the sample period considered for both the linear and quadratic models, except India. In the case of India, the quadratic model is found to have more stability than the linear model.

### 3.6.3. *Robustness check: under the assumption of structural Break*

We apply Gregory- Hansen (1996a and 1996b) framework for cointegration that considers the single endogenous structural breaks. Our labour productivity model is as follows:

$$CO_{2t} = \alpha + \beta_1 LGDPC_t + \beta_2 LGDPC2_t + \beta_3 LEU_t + \beta_4 LPG_t + \varepsilon_t \ldots\ldots\ldots(3)$$

Gregory and Hansen (1996a,b) propose three different models with variant assumptions, as follows:

Model 1: Level shift with trend

$$Y_t = \mu_1 + \mu_2 f_{tk} + \beta_1 t + \alpha_1 X_t + \varepsilon_t \ldots\ldots\ldots \quad (4)$$

Model 2: Regime shift where intercept and slope coefficients change

$$Y_t = \mu_1 + \mu_2 f_{tk} + \beta_1 t + \alpha_1 X_t + \alpha_2 X_t f_{tk} + \varepsilon_t \ldots\ldots\ldots \quad (5)$$

Model 3: Regime shift where intercept, slope coefficients and trend change

$$Y_t = \mu_1 + \mu_2 f_{tk} + \beta_1 t + \beta_2 t f_{tk} + \alpha_1 X_t + \alpha_2 X_t f_{tk} + \varepsilon_t \ldots\ldots\ldots \quad (6)$$

In the above equations, $Y$ is the dependent variable while $X_t$ are independent variables. Moreover, k is the break date while $\phi$ is dummy variable such that,

$$f_{tk} = 0 if t \langle k and f_{tk} = 1 if t \rangle k$$

The above frameworks endogenously determine a single break and provide the predicted time of break within the sample. The framework selects break date where the test statistic is the least vis-à-vis the absolute ADF test statistic is the highest. Finally, we compare the calculated value of this approach with MacKinnon (1996) critical value to ensure breaks.

Our sample year consists of the changes in both political regime and significant economic policies in these four respective countries. We apply Gregory–Hansen cointegration approach and Tables 7–10 present the result. ADF and $Z_t$ tests confirm the existence of cointegration between $CO_2$ emission and GDP per capita and other controls under the assumption of regime, and regimen and trend change in the context of China where the break points are 1993, 1997, and 1998. In the context of Indonesia, $Z_t$ and ADF statistic confirm the presence of cointegration under the assumption of level, and regime and trend change where the break points are 2006 and 1998. However, Gregory Hansen test denies the existence of cointegration under any assumption in the context of Brazil. On the other hand, ADF and $Z_t$ statistic profoundly confirm the presence of cointegration under the assumption of Zt and ADF test in the case of India where the break points are 1984 and 1996. During the break point, the growth paradigm of the respective countries might change from agriculture to industrial economy.

## 4. Discussion

As observed from empirical findings, in the case of India, both in the long run and short run, energy consumption per capita has a significantly positive relationship with per capita $CO_2$ emissions in both the linear and quadratic models, but population growth and GDP per capita show a significantly positive relationship with $CO_2$ emissions only in the linear model. The results also suggest that if there is any deviation from the long-run equilibrium, it will take about 1.55–1.64 years to return to equilibrium level. Our observations also suggest that the theory of EKC for $CO_2$ emissions does not significantly hold for India, but the sign of the output indicates the level of per capita $CO_2$ emissions initially goes down but eventually goes up with the rise of GDP per capita over time. Apparently, this finding supports the one obtained earlier by Ghosh (2010) for India using ARDL bound testing approach. Ozturk and Uddin (2012) also found the same dynamic positive relationship between $CO_2$ and GDP growth for India using VECM. This finding, however, contradicts with the one obtained by Kanjilal and Ghosh (2013), as they found EKC supportive for India using the approach of ARDL bound test during 1971–2008. On the other hand, the finding also contradicts with Govindaraju and Tang (2013) who did not find any long run nexus between energy consumption, output growth and $CO_2$ emissions in India using VECM and VAR model during

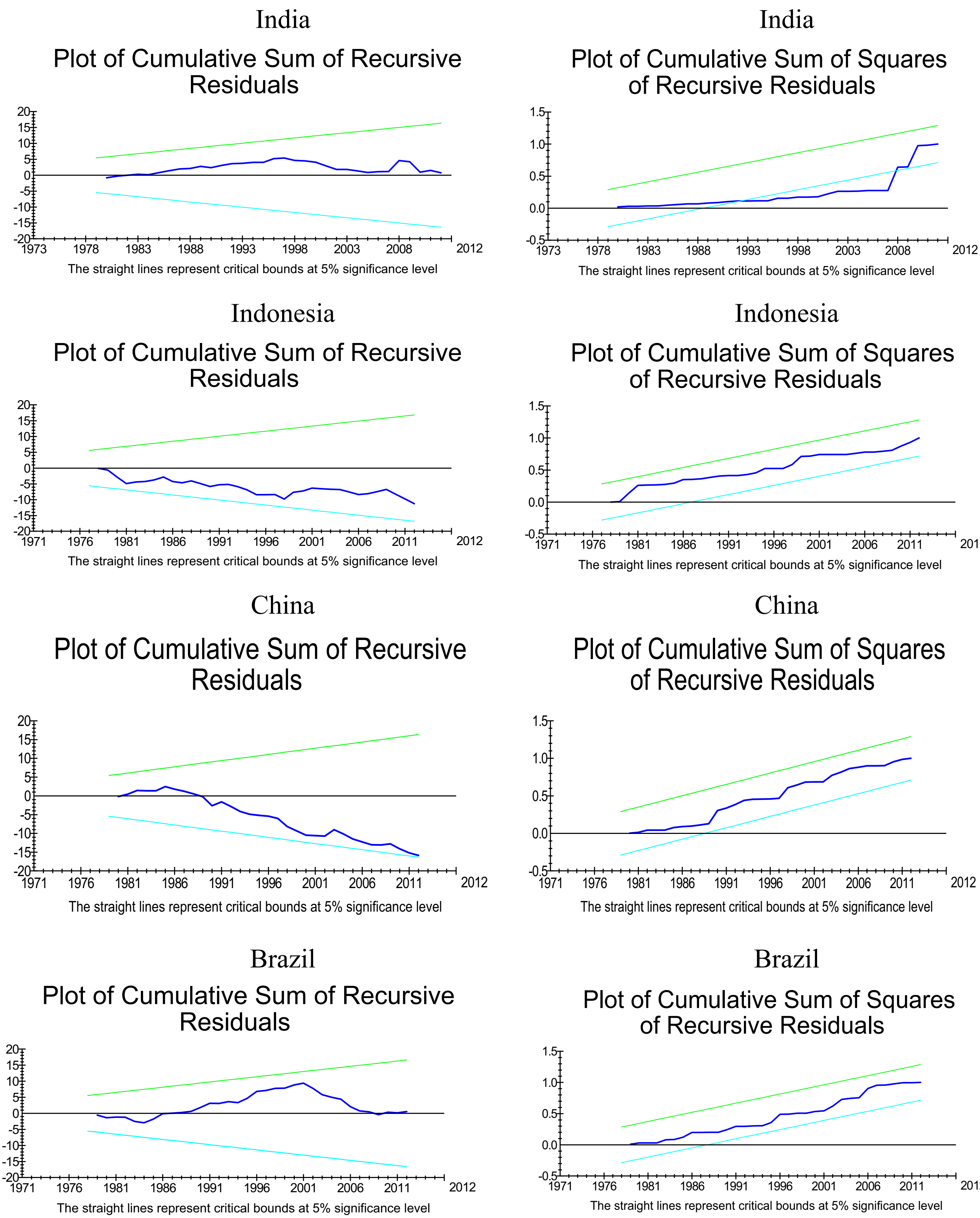


**Fig. 2.** CUSUM and CUSUM Square tests for linear model.

1965–2009. Our study provides evidence that energy consumption and economic growth degenerate environment in both short and long run and that the attempt to cut $CO_2$ emissions will hurt economic growth of India. While India requires sustainable economic growth of 8–10% to alleviate poverty and improve standard of living of the people, developed nations have been continuously giving pressure to India for reducing $CO_2$ emissions. While that being the

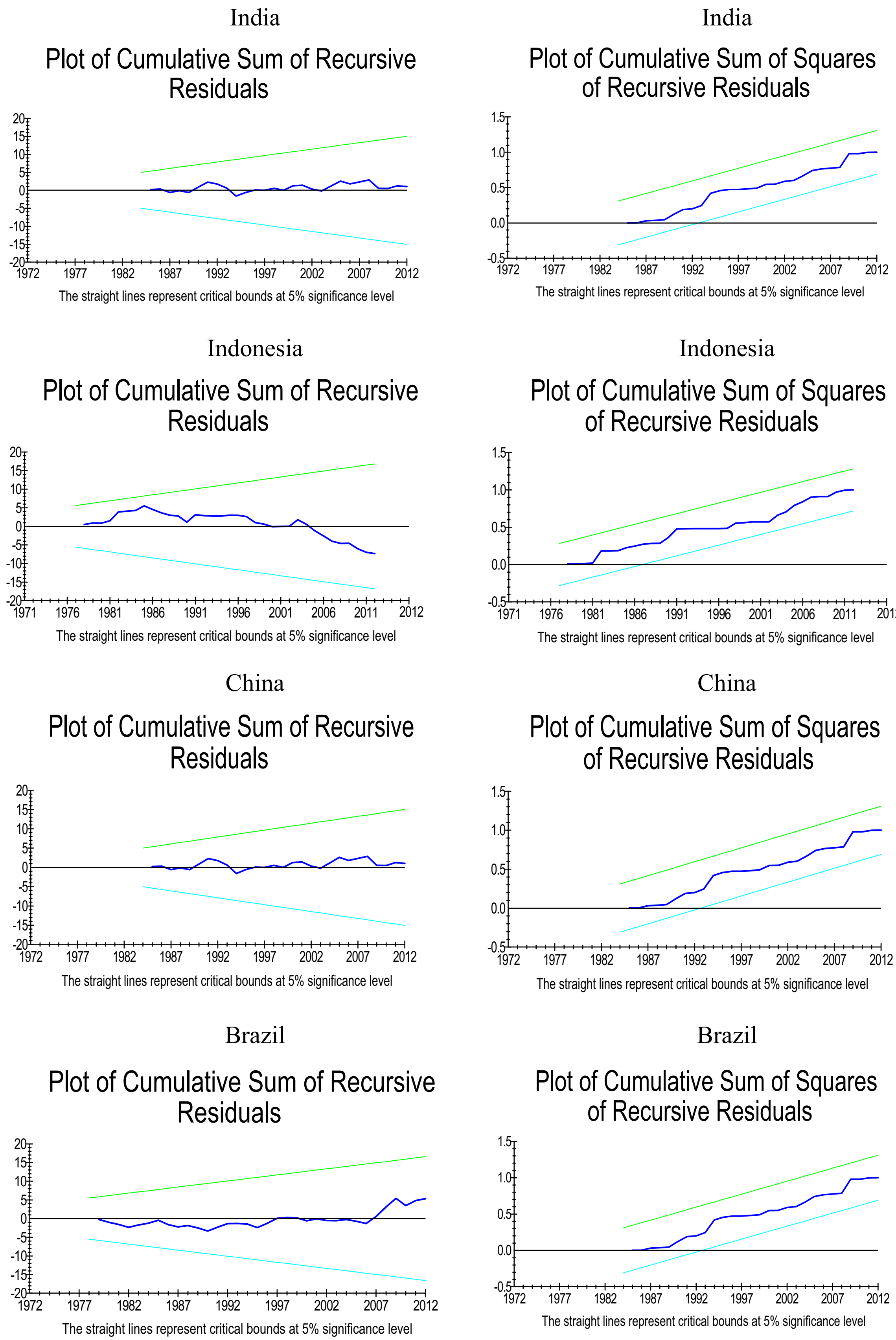


**Fig. 3.** CUSUM and CUSUM Square tests for quadratic model.

**Table 7**
Gregory-Hansen Test for Cointegration: China.

| | Change in level | | Critical Value | | | |
|---|---|---|---|---|---|---|
| | Statistic | Break point | Date | 1% | 5% | 10% |
| ADF | −4.15 | 26 | 1995 | −5.77 | −5.28 | −5.02 |
| $Z_t$ | −4.97 | 14 | 1983 | −5.77 | −5.28 | −5.02 |
| $Z_a$ | −28.11 | 14 | 1983 | −63.64 | −53.58 | −48.65 |
| Change in regime | | | | | | |
| ADF | −5.86[c] | 24 | 1993 | −6.51 | −6.00 | −5.75 |
| $Z_t$ | −5.94[c] | 24 | 1993 | −6.51 | −6.00 | −5.75 |
| $Z_a$ | −38.12 | 24 | 1993 | −80.15 | −68.94 | −63.42 |
| Change in regime and trend | | | | | | |
| ADF | −7.39[a] | 28 | 1997 | −6.89 | −6.32 | −6.16 |
| $Z_t$ | −7.48[a] | 29 | 1998 | −6.89 | −6.32 | −6.16 |
| $Z_a$ | −46.72 | 29 | 1998 | −90.84 | −78.87 | −72.75 |

**Table 8**
Gregory-Hansen Test for Cointegration: Indonesia.

| | Change in level | | Critical value | | | |
|---|---|---|---|---|---|---|
| | Statistic | Break point | Date | 1% | 5% | 10% |
| ADF | −5.70[b] | 37 | 2006 | −5.77 | −5.28 | −5.02 |
| $Z_t$ | −5.77[a] | 37 | 2006 | −5.77 | −5.28 | −5.02 |
| $Z_a$ | −38.36 | 37 | 2006 | −63.64 | −53.58 | −48.65 |
| Change in regime | | | | | | |
| ADF | −5.44 | 29 | 1998 | −6.51 | −6.00 | −5.75 |
| $Z_t$ | −5.15 | 20 | 1989 | −6.51 | −6.00 | −5.75 |
| $Z_a$ | −33.88 | 20 | 1989 | −80.15 | −68.94 | −63.42 |
| Change in regime and trend | | | | | | |
| ADF | −6.21[c] | 29 | 1998 | −6.89 | −6.32 | −6.16 |
| $Z_t$ | −6.09 | 38 | 2007 | −6.89 | −6.32 | −6.16 |
| $Z_a$ | −40.24 | 38 | 2007 | −90.84 | −78.87 | −72.75 |

**Table 9**
Gregory-Hansen Test for Cointegration: Brazil.

| | Change in level | | Critical value | | | |
|---|---|---|---|---|---|---|
| | Statistic | Break point | Date | 1% | 5% | 10% |
| ADF | −3.46 | 23 | 1992 | −5.77 | −5.28 | −5.02 |
| $Z_t$ | −4.10 | 20 | 1989 | −5.77 | −5.28 | −5.02 |
| $Z_a$ | −20.71 | 20 | 1989 | −63.64 | −53.58 | −48.65 |
| Change in regime | | | | | | |
| ADF | −5.44 | 23 | 1992 | −6.51 | −6.00 | −5.75 |
| $Z_t$ | −5.02 | 22 | 1991 | −6.51 | −6.00 | −5.75 |
| $Z_a$ | −32.88 | 22 | 1991 | −80.15 | −68.94 | −63.42 |
| Change in regime and trend | | | | | | |
| ADF | −5.11 | 23 | 1992 | −6.89 | −6.32 | −6.16 |
| $Z_t$ | −5.26 | 20 | 1989 | −6.89 | −6.32 | −6.16 |
| $Z_a$ | −33.95 | 20 | 1989 | −90.84 | −78.87 | −72.75 |

**Table 10**
Gregory-Hansen Test for Cointegration: India.

| | Change in level | | Critical value | | | |
|---|---|---|---|---|---|---|
| | Statistic | Break point | Date | 1% | 5% | 10% |
| ADF | −5.40[b] | 15 | 1984 | −5.77 | −5.28 | −5.02 |
| $Z_t$ | −5.47[b] | 15 | 1984 | −5.77 | −5.28 | −5.02 |
| $Z_a$ | −35.80 | 15 | 1984 | −63.64 | −53.58 | −48.65 |
| Change in regime | | | | | | |
| ADF | −5.47 | 13 | 1982 | −6.51 | −6.00 | −5.75 |
| $Z_t$ | −4.60 | 6 | 1975 | −6.51 | −6.00 | −5.75 |
| $Z_a$ | −27.11 | 6 | 1975 | −80.15 | −68.94 | −63.42 |
| Change in regime and trend | | | | | | |
| ADF | −8.32[a] | 27 | 1996 | −6.89 | −6.32 | −6.16 |
| $Z_t$ | −8.42[a] | 27 | 1996 | −6.89 | −6.32 | −6.16 |
| $Z_a$ | −54.69 | 27 | 1996 | −90.84 | −78.87 | −72.75 |

case, the Indian government has been continuously ignoring the advice.

In the case of Indonesia, in the long run, energy consumption per capita has a significantly positive relationship with per capita $CO_2$ emissions in both the linear and quadratic models, but GDP per capita shows a significantly positive relationship with $CO_2$ emissions only in the quadratic model. In the short run, both energy consumption per capita and GDP per capita have a significantly positive relationship with per capita $CO_2$ emissions in both the linear and quadratic models. The results also suggest that if there is any deviation from the long-run equilibrium, it will take about 3.89–4.07 years to return to equilibrium level. Empirical results also suggest that the theory of EKC for $CO_2$ emissions does hold for Indonesia both in the long run and short run. This indicates that the level of per capita $CO_2$ emissions initially goes up but eventually declines with the rise of GDP per capita over time. This finding is consistent with Shahbaz et al., 2013 who, using VECM and ARDL approach during 1975Q1 to 2011Q4, found that both energy consumption and economic growth increase $CO_2$ emissions in Indonesia in both the short term and long term. Similarly, this findings is also consistent with Rahman et al. (2016) who found long run nexus between output growth and $CO_2$ emissions in Indonesia using Toda-Yamamoto approach during 1971–2011. But this finding contradicts with Jafari et al., 2012 who did not find any long-run relationship between economic growth and $CO_2$ emissions for Indonesia using Toda-Yamamoto approach during 1971–2007.

In the case of China, both in the long run and short run, GDP per capita and energy consumption per capita show a significantly positive relationship with per capita $CO_2$ emissions in both the linear and quadratic models. Results also suggest that if there is any deviation from the long-run equilibrium, it will take about 1.91–6.9 years to return to equilibrium level. Our empirical findings also suggest that the theory of EKC for $CO_2$ emissions does hold for China only in the long run. This indicates that the level of per capita $CO_2$ emissions initially goes up but eventually declines with the rise of GDP per capita in the long run. But EKC does not significantly hold for China in short run, so it indicates that the level of per capita $CO_2$ emissions goes up with the rise of GDP per capita in the short run. This finding supports the findings of those obtained by Lin et al. (2014) using ARDL approach for China during 1980–2012, Govindaraju and Tang (2013) using VECM and VAR for China during 1965–2009 and Chang (2010) using VECM during 1981–2006 for China.

In the case of Brazil, in the long run, only population growth shows a significantly negative relationship with per capita $CO_2$ emissions in the linear model, but GDP per capita and energy consumption per capita show a significantly positive relationship with $CO_2$ emissions in the quadratic model. In the short run, energy consumption per capita has a significant positive relationship with per capita $CO_2$ emissions in both the linear and quadratic models, population growth has a significant negative relationship with per capita $CO_2$ emissions in the linear models and positive relationship in the quadratic model, but GDP per capita shows a significantly positive relationship with $CO_2$ emissions only in the quadratic model. Our findings also suggest that if there is any deviation from the long-run equilibrium, it will take about 1.77–9.9 years to return to equilibrium level. Also the empirical findings suggest that the theory of EKC for $CO_2$ emissions does hold for Brazil both in the long run and short run. This implies that the level of per capita $CO_2$ emissions initially goes up but eventually declines with the rise of GDP per capita over time. Similar findings were found by He and Richard (2010) for Canada using partial regression method, Kanjilal and Ghosh (2013) for India using ARDL approach and Saboori et al. (2012a,b) for Malaysia using ARDL approach.

## 5. Policy recommendations

Overall, the study provides evidence that energy consumption and economic growth negatively affect the environment both in the short run and long run. Having said that it is not feasible to undertake any conservative economic policy in order to reduce $CO_2$ emissions, as achieving economic growth is vital for and one of the public mandates in these countries. Thus, it creates a controversy of whether or not the emerging economies should take more care of the environment while achieving their higher economic growth objectives. If they essentially want to care the environment more than what they are doing now the convergence of the economic positions among emerging and developed nations will be uncertain and the inequality will be widening. Furthermore, empirical observations from the testing of EKC hypothesis imply that in the cases of Brazil, China and Indonesia, $CO_2$ emissions will decrease over the time when income increases. So relying upon the EKC findings it can be recommended that these three countries should not take any economic and/or environmental policies, which might have conservative impacts on income, to reduce their $CO_2$ emissions. But in the case of India, where $CO_2$ emissions and income were found to have a positive relationship, an increase in income over the time will not reduce $CO_2$ emissions in the country. Therefore, for India, a conservative economic policy to reduce $CO_2$ emissions might be effective. But in both the situations, policy makers need to be highly careful while prioritizing between caring the environment and promoting the economic growth.

But in real sense, however, it is not easy to formulate economic and environmental policies simultaneously promoting economic growth and addressing environmental problem or protecting environment from pollution effectively. That is why the emerging economies like Brazil, China, India and Indonesia, as they are experiencing the dilemma of promoting economic growth and at the same time addressing environmental problems, should primarily consider energy saving and switching to non-fossil fuel and carbon tax. As effective policies these countries should also consider converting energy source to natural gas, developing both traditional and high-tech clean coal technology, establishing mechanisms of strategic oil reserve, developing fuel cell and hydrogen vehicle, promoting desulfurization, improving environmental monitoring and management, among others. We simply understand that promoting economic growth and at the same time reducing environmental pollution is possible, if not fully, by undertaking some sorts of conservative economic and environmental policies.

## 6. Conclusion

In this study we investigated the impacts of income, energy consumption and population growth on $CO_2$ emissions. We also investigated the presence of EKC based on $CO_2$ emotions in the four highly populated and top $CO_2$ emitter developing/emerging countries, such as Brazil, China, India and Indonesia. Economic growth and the environment are the two distinct phenomena but their relationship in both the shorn run and long run is undeniable, as evidenced by numerous studies including this. Also, the impacts of other mediating variables such as energy consumption and population growth on $CO_2$ emissions in all four countries are noticeable, as evidenced by numerous studies, including this one. While considerable relationships among the key variables are apparent in all these countries, as explained earlier through ARDL approaches and EKC hypotheses, the possible remedies to the already identified economic and environmental problems lie in a greater part, if not fully, in the recommendations provided in the previous section. Policy makers are therefore to exercise caution in their efforts to promote economic growth and at the same time reduce environmental degradation keeping in mind the sustainability of both the economy and the environment.

## Appendix A.

| Variable | Definition | Source |
|---|---|---|
| $CO_2$ emission | Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport. | WDI |
| GDPC | GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in constant 2005 U.S. dollars. | WDI |
| EUC | Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport. | WDI |
| POP | Annual population growth rate. Population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship–except for refugees not permanently settled in the country of asylum, who are generally considered part of the population of the country of origin. | WDI |

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