Does GDP and GDP Growth Rates affect Energy Consumption: A Panel Study of Some Developed, Developing and Transition Economies

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Abstract

The present study is an attempt to test the relationship between energyconsumption, energy efficiency, CO_2 Emissions and economic growth for aset of some developed, transition and developing counties. For thispurpose, panel data on various factors of GDP growth has been taken for 18developing, 16 transition and 18 developed countries from 1980-2013.The paper uses the variant of Solow model to provide the economic justification behind the econometric estimation of regression model whichincludes energy consumption per capita, CO_2 emissions and energyefficiency as one of the independent variables affecting GDP growth of acountry, among others.To estimate the regression model, the study uses various panel dataestimation *methodologies such as: panel data cointegration, panelcausality (assuming homogeneous and heterogeneous panels), panel VECM,panel VAR and panel data ARDL and SURE. The results help us to find out he short run and long-run relationship between the policy variables.The paper also tests the direction of causality between energy consumptionand GDP and per capita GDP growth by working on the following hypotheses:(a) Neutrality Hypothesis, which holds that there is no causality (neither direction) between these two variables; (b) Energy conservationhypothesis, which holds that there is evidence of unidirectional causalityfrom GDP growth to energy consumption; (c)Growth hypothesis, energy consumption drives GDP growth; and (d) Feedback hypothesis, which suggestsa bidirectional causal relationship between energy consumption and GDPgrowth.S-shaped relationship between energy consumption and per capita GDP isalso tested by hypothesizing that with high GDP, first energyconsumption increases at an increasing rate and then increases at adecreasing rate.The overall conclusion emerges from the analysis is that per capita energy consumption has a negative impact on growth of per capita GDP in developing countries and transition economies but positive impact in case of developed countries. This may be due to the fact that in developed nations, the energy consumption expenditures may be more devoted to technological progress in alternative source of oil like shell gas or in expenditures related to renewable energy intensive technological products. The developing and transition countries although trying to put efforts in increasing expenditures in alternative energy sources like non-renewable, oil consumption still seem to not have many alternatives sources of energy. Therefore, reducing oil expenditures tend to promote growth among developing countries. Growth, Energy Conservation and Feedback hypotheses tend to work for developed, transition and developing countries. Also, the direction of causality may run from growth per capita to energy consumption depicting aS-shaped relation signifying that as society matures energy consumption increases but at a decreasing rate.*

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JEL Classification Codes: O13, O47, C33

1. Introduction

Energy is the engine that drives the economy of any nation. In the absence of reliable energy supply, efforts at socio-economic and technological development cannot yield any positive result. It is essential to the production of all goods and services and hence vital to the industrial development of any nation. Energy plays an essential role in an economy on both demand and supply sides. On the demand side, in the form of electricity, itis one of the products which consumer decides to buy to maximize his/her utility. On the supply side, energy is a key factor of production in addition to capital, labor and materials. Being a key factor, it plays a vital role in increasing country's economic growth and living standards through industrial and economic development. However, energy consumption and growth per capita do have an impact on carbon emissions and possibly is responsible for higher carbon emissions and climate change. Our paper goes on to understand the two way relationship between energy consumption and growth per capita, FDI/GDP, Trade/GDP and CO_2 emissions, among other variables for set of developed, developing and transition economies.

There exist various studies that examined the relationship between economic growth and energy consumption. The results of the studies provide mixed conclusions about the direction of causality between energy consumption and economic growth. In the earlier studies, Kraft and Kraft (1978) using the time-series data from 1947-1974 for the USA study the causal relationship between gross energy consumption and GNP. They found the uni-directional relationship flowing from GNP to energy. This study was followed by many other studies such as Akarca and Long II (1980), Abosedra and Baghestani (1991), Masih and Masih (1997) and Soytas and Sari (2003). These studies employ data for single country/countries and find varied results. In addition to these, Chiang (2005) uses panel data for developing countries and finds short-run and long-run uni-directional causality flowing from energy to GDP. His result suggests that energy conservation may harm economic growth in the short-run and in the long run. However, there also exist some studies which support bi-directional causality between energy consumption and GDP growth. Those studies are: Glasure (2002), Erdal*et al.* (2008), Belloumi (2009) among others. Further, Squalli (2007), Ozturk (2010) and Magazzino (2011) in their studies club all directions of causality between energy consumption and economic growth into the following four categories which can be used as research hypotheses in the research focused on studying the relationship between these two variables. Those hypotheses are:

- **Neutrality Hypothesis**: which holds that there is no causality (in either direction) between these two variables;

- **Energy Conservation Hypothesis**: which holds that there is evidence of unidirectional causality from GDP growth to energy consumption;
- **Growth Hypothesis**: which assumes energy consumption drives GDP growth; and
- **Feedback Hypothesis**: which suggests a bidirectional causal relationship between energy consumption and GDP growth

Howland, Derek Murrow, Lisa Petraglia and Tyler Comings (2009)show that when energy efficiency is implemented only at individual state level, it has comparatively weaker impact than when implemented over all states simultaneously. This happens because efficient use of energy leads to energy savings, increasing comparative national competitiveness, boosting GDPs and real household income. Increased spending on efficiency measures and decreased spending on energy go hand in hand. They also show that energy savings leads to lower energy costs which takes the economy to a more competitive state leading to a higher per capita GDP growth rate.

A report prepared by the Climate Institute on Energy efficiency and economic growth (2013) considers energy as a factor of production and shows that given higher real energy prices, efficiency in use of energy contributes positively to economic growth. They go on to show that empirical evidence on whether energy consumption leads to growth is mixed (mainly due to model specification and country). They show that energy productivity has increased over time (GDP per unit of energy used) and efficient use of energy leads to greater economic growth by reducing energy requirement per unit of output - hence demand and prices fall - competitive cost advantage appears in trading scenario. The authors go on to estimate energy efficiency and define energy productivity being determined by energy efficiency, prices and social and sectoral factors. The analysis of relation between energy efficiency and growth shows a positive relation.

NarendraNathDalei (2016) establishes a non-linear sigmoid relation between energy consumption and GDP. The study shows that initially energy consumption increases at an increasing rate with rise in GDP and after a point in time, it increases at a decreasing rate with further rise in GDP. The study suggests use of alternative or renewable sources of energy instead of conventional sources is the main reason for this turn of relation. Taking the clue from the above study , we also test for S-shaped relationship between energy consumption per capita and growth per capita GDP, FDI/GDP,Trade/GDP and CO_2 emissions. Theempirics of S-shaped relationship below indicate that as society matures, energy consumption increases at a decreasing rate across the sample.

The authors try to understand the relationship between energy consumption and growth of an economy, among other growth factors, including CO_2 emissions, under the framework of a growth model. If energy consumption and efficiency of energy consumption may be considered as proxies for the level of technology used for production, then an econometric analysis may be conducted based on the model specified by Solow for capturing growth of an economy and variables affecting it. By testing the model for developed, developing and transition countries, we may be able to pin down the differences with respect to the growth model relations for the two sets of economies considered. Such a study may be able to bring to limelight how energy consumption may promote (or not) GDP growth depending on which phase of development the economy is enjoying during the time period considered. The economy's phase of development would prompt different policy implications. Also, the relationship may work from growth per capita GDP to energy consumption per capita, in particular, mimicking the S-shape relationship, signifying that as growth increases, energy consumption increases at an increasing rate and then after the inflection point has been attained, energy consumption increases at a decreasing rate. The same relationship is tested in the paper for set of developing, developed and transition economy. Further, the S-shaped relationship is also tested between energy consumption per capita with CO_2 emissions, FDI/GDP and Trade/GDP variables.

For this purpose, the study is divided into five sections including the present introductory one. Section 2 presents the objectives and rationale of the study. Section 3 provides the derivation of the economic model which is used as the base for defining the regression equation for empirical results, the sources of database and methodology used for the empirical analysis in detail. It also explains the steps of estimation using panel data analysis. In Section 4, empirical results pertaining to the estimation of regression models have been presented and discussed. Section 5 concludes the whole study and provides some noteworthy policy implications obtained from the results.

2. Objectives and Rationale of the study

2.1Objectives

On the basis of mixed results obtained in the literature, the present study tries to evaluate the relationship between country's energy consumption and its economic growth by taking the sample of 18 developed,18 developing countries and 16 transition economies (see appendix Table A1 for country names). The main objective of the study is to confirm one of the hypotheses given in the previous section mentioning the direction of relationship between energy consumption and economic growth. The study also evaluates the type of relationship between these two variables by specifying an economic model behind this, including other variables affecting economic growth of a country and energy consumption per capita. The study also tests for the S-shape relationship running from growth per capita to energy consumption per capita. The study has utilized panel data estimation approach to evaluate the short run and long run relationships.

2.2 Rationale

A glance through the literature reveals various studies related to the topic at hand throwing light on various aspects. However, a study of comparative analysis among developing, transition and developed countries over a time period of thirty three years (1980-2013) has not been attempted. The authors are curious to understand not only the relationship among the variables mentioned earlier, but also to examine whether the three groups of countries display similar behavior or not. The authors believe that this analysis and its peculiar results would help in carving out more efficient policies for developed, transition and developing nations.

3. Empirical Model, Database and Methodology

3.1 Empirical Model

The study follows the variant of the Solow model with technical progress given in Mankiw*et al.* (1992) and Jones (2002). With labor augmenting technological progress (A), the Cobb-Douglas production function becomes:

$$Y_t = K_t^{\alpha}\left(A_t L_t\right)^{1-\alpha} \quad 0<\alpha<1 \qquad ...(1)$$

Where Y is level of output; K is capital; and L is labor which is assumed to grow exogenously at rate n which is equal to:

$$n = \frac{\dot{L}}{L}$$

$$\Rightarrow L_t = L_0 e^{nt}$$

A_t grows endogenously at rate g and presented as follows:

$$A_t = A_o e^{gt} T^{\beta_4} H^{\beta_5} I^{\beta_6} E^{\beta_7} ...(1.1)$$

The level of technology in (1.1) above is explained by trade openness (T), human capital (H), share of industry in GDP of the country (I) and expenditure on energy consumption or energy efficiency (E)[1]. Further, capital grows at $\dot{K} = sY - \delta K$. Assuming that a proportion of income is saved and invested (s) and the level of output per unit of effective labor and stock of capital per unit of effective labor as $\tilde{y} = \frac{Y}{AL}$ and $\tilde{k} = \frac{K}{AL}$ respectively, then the dynamic equation for $\tilde{k}$ is given as:

$$\dot{\tilde{k}} = s\tilde{y}_t - (n+g+\delta)\tilde{k}_t$$

$$\Rightarrow \dot{\tilde{k}} = s\tilde{k}_t^{\alpha} - (n+g+\delta)\tilde{k}_t$$

Where δ is the constant rate of depreciation and it is evident that $\tilde{k}$ converges to its steady state value $\left(\dot{\tilde{k}} = 0\right)$.

$$\tilde{k}^* = \left(\frac{s}{n+g+\delta}\right)^{\frac{1}{1-\alpha}}$$

The steady state output per effective labor is:

$$\tilde{y}^* = \left(\frac{s}{n+g+s}\right)^{\frac{\alpha}{1-\alpha}}$$

The steady state output per laboris:

$$y^* = \left(\frac{s}{n+g+\delta}\right)^{\frac{\alpha}{1-\alpha}} A_t \qquad ...(2)$$

The formulation in (2) can explain why steady state per capita income levels differ among countries. They differ because countries have different savings rate, technology levels and rate of growth of population among others.

3.1.1Dynamism around the Steady State

It is possible to utilize a more general framework that examines the predictions of the Solow model for behavior of per capita income out of steady state. Such a framework allows estimation of the effect of various explanatory variables on per-capita growth rates as well as the speed at

[1] The trade openness and human capital are known to be major vehicles for international knowledge and technology spillovers; technology plays a major role in increasing productivity and growth in the industrial sector; whereas, energy consumption expenditure is linked with increase in investments in technological advances in energy resources and more advancement also lead to invent energy efficient resources.

which actual income per capita reaches the steady state level of income per-capita. Assuming other terms zero, the expansion of log $\tilde{y}$ around log $\tilde{y}^*$ using Taylor's expansion provides:

$$\log_e \tilde{y} = \log \tilde{y}^* + \frac{\tilde{y} - \tilde{y}^*}{\tilde{y}^*}$$

$$\Rightarrow e^{\log \tilde{y}^* + \frac{\tilde{y}-\tilde{y}^*}{\tilde{y}^*}} = \tilde{y}$$

$$\Rightarrow e^{\left(\frac{\tilde{y}-\tilde{y}^*}{\tilde{y}^*}\right)} = \frac{\tilde{y}}{\tilde{y}^*}$$

Similarly,

$$\frac{\tilde{k}}{\tilde{k}^*} = e^{\left(\frac{\tilde{k}-\tilde{k}^*}{\tilde{k}^*}\right)}$$

Also, the rate of growth of income per effective labor is α times the rate of growth of capital per effective labor.

$$\frac{\dot{\tilde{y}}}{\tilde{y}} = \alpha \frac{\dot{\tilde{k}}}{\tilde{k}}$$

$$\frac{\dot{\tilde{y}}}{\tilde{y}} = \alpha \left[\frac{\dot{K}}{K} - \frac{\dot{L}}{L} - \frac{\dot{A}}{A} \right]$$

$$\Rightarrow \frac{\dot{\tilde{y}}}{\tilde{y}} = \alpha \left[s \frac{\tilde{y}_t}{\tilde{k}_t} - (n + g + \delta) \right]$$

$$\Rightarrow \frac{\dot{\tilde{y}}}{\tilde{y}} = \alpha \left[s \frac{e^{\frac{\tilde{y}-\tilde{y}^*}{\tilde{y}^*}} . \tilde{y}_t^*}{e^{\frac{\tilde{k}-\tilde{k}^*}{\tilde{k}^*}} . \tilde{k}^*} - (n + g + \delta) \right]$$

In steady state:

$$s\tilde{y}^* = (n + g + \delta)\tilde{k}^*$$

So

$$\Rightarrow \frac{\dot{\tilde{y}}}{\tilde{y}} = \alpha \left[\frac{(n + g + \delta) e^{\frac{\tilde{y}-\tilde{y}^*}{\tilde{y}^*}}}{e^{\frac{\tilde{k}-\tilde{k}^*}{\tilde{k}^*}}} - (n + g + \delta) \right]$$

$$\Rightarrow \frac{\dot{\tilde{y}}}{\tilde{y}} = \alpha \left[(n + g + \delta) \left\{ \frac{e^{\frac{\tilde{y}-\tilde{y}^*}{\tilde{y}^*}}}{e^{\frac{\tilde{k}-\tilde{k}^*}{\tilde{k}^*}}} - 1 \right\} \right]$$

$$\Rightarrow \frac{\dot{\tilde{y}}}{\tilde{y}} = \alpha\left[(n+g+\delta)\left\{\frac{e^{\frac{\tilde{y}-\tilde{y}^*}{\tilde{y}^*}} - e^{\frac{\tilde{k}-\tilde{k}^*}{\tilde{k}^*}}}{e^{\frac{\tilde{k}-\tilde{k}^*}{\tilde{k}^*}}}\right\}\right]$$

Asper the Taylors expansion:

$$\log_e m = \log n + \frac{m-n}{n}$$

$$e^{\frac{m-n}{n}} \approx \frac{m}{n}$$

$$\Rightarrow \frac{m-n}{n} \simeq \log\frac{m}{n}$$

Using the above, we get

$$\Rightarrow \frac{\dot{\tilde{y}}}{\tilde{y}} = \alpha\left[(n+g+\delta)\left\{\frac{\frac{\tilde{y}}{\tilde{y}^*} - \frac{\tilde{k}}{\tilde{k}^*}}{\frac{\tilde{k}}{\tilde{k}^*}}\right\}\right]$$

$$\Rightarrow \frac{\dot{\tilde{y}}}{\tilde{y}} = \alpha\left[(n+g+\delta)\left(\log\left\{\frac{\tilde{y}}{\tilde{y}^*} / \frac{\tilde{k}}{\tilde{k}^*}\right\}\right)\right]$$

$$\Rightarrow \frac{\dot{\tilde{y}}}{\tilde{y}} = \alpha\left[(n+g+\delta)\left\{\log\ \tilde{y} - \log\ \tilde{y}^* - \log\ \tilde{k} + \log\ \tilde{k}^*\right\}\right]$$

By using $\log\ \tilde{y} = \alpha\ \log\ \tilde{k}\ \mathit{and}\ \log\ \tilde{y}^* = \alpha\ \log\ \tilde{k}^*$

$$\frac{\dot{\tilde{y}}}{\tilde{y}} = (1-\alpha)(n+g+\delta)\left[\log\ \tilde{y}^* - \log\ \tilde{y}\right]$$

$$\Rightarrow \frac{\dot{\tilde{y}}}{\tilde{y}} = \lambda\left[\log\ \tilde{y}^* - \log\ \tilde{y}\right] \qquad ...(3)$$

Where $\lambda = (1-\alpha)(n+g+\delta)$ is the speed of convergence.Barro and Martin (1995) defined speed of convergence as rate at which the level of income per effective worker approaches its steady state which is given as:

$$-\frac{d\left(\frac{\dot{\tilde{y}}}{\tilde{y}}\right)}{d(\log\ \tilde{y})} = \lambda$$

The speed of convergence coefficient (λ) is the proportionate change in growth rate caused by change in initial income per effective labor. Equation (3) shows that growth rate of income per effective labor is equal to the speed of convergence multiplied by the gap between steady state and actual level of incomes. Higher the gap, higher would be the growth rates. If the countries/regions have the same steady state growth and level of incomes, country/regions which are far away from its steady state will grow at faster rate and catch up with the relatively rich partner (absolute convergence).Solving the differential equation (3) we get

$$\log\,\tilde{y}_t = \log\,\tilde{y}_0 e^{-\lambda t} + \left(1 - e^{-\lambda t}\right)\log\,\tilde{y}^*$$

Where $\log\,\tilde{y}_0$ is log of initial level of income per effective labor.

$$\Rightarrow \log\,\tilde{y}_t - \log\,\tilde{y}_0 = -\left(1 - e^{-\lambda t}\right)\log\,\tilde{y}_0 + \left(1 - e^{-\lambda t}\right)\log\,\tilde{y}^*$$

To find growth of income per capital we substitute the value of log A_t which is equal to:

$$\log\,A_0 + + gt + \beta_4 \log T + \beta_5 \log\,H + \beta_6 \log\,I + \beta_7 \log\,E$$

and

$$\tilde{y} = \frac{Y}{AL}$$

$$\Rightarrow \tilde{y} = \frac{y}{A}$$

We get

$$\log\,y_t - \log\,y_0 = \left(1 - e^{-\lambda t}\right)\left(\log\,y^* - \log\,y_0\right)$$

$$\Rightarrow \log\,y_t - \log\,y_0 = -\left(1 - e^{-\lambda t}\right)\log\,y_0 + c_i \qquad ...(4)$$

Where

$$c_i = \left(1 - e^{-\lambda t}\right)\log\,y^* + e^{-\lambda t}\left[gt + \beta_4 \log\,T + \beta_5 \log H + \beta_6 \log I + \beta_7 \log E\right]$$

In Equation (4) average per capita growth is found by dividing by time period *t* on both sides. Non-linear least squares can be used to estimate equation (4) using cross sectional data. It is to be noted that if we assume that all economies here have the same steady state level of per capita income, which in turn implying same structural parameters of the economy, and steady state growth, then Constant$c_i$becomes c. Further, equation (4) would then imply absolute convergence, if the coefficient $(1 - e^{-\lambda t}) = \beta \; of \; \log\,y_0 \; is > 0$ (implying negative relationship between average growth rate and initial level of GDP per capita).However, the diversities among the economies are quite apparent,conditional convergence is the likely proposition. For conditional convergence, we can derive growth rate of per capital income after substituting values of steady state income from (2). Therefore, we get:

$$\begin{aligned}\log\, y_t - \log\, y_0 = &-\left(1-e^{-\lambda t}\right)\log\, y_0 + \frac{\alpha}{1-\alpha}\left(1-e^{-\lambda t}\right)\log\, s \\ &-\left(1-e^{-\lambda t}\right)\frac{\alpha}{1-\alpha}\log(n+g+\delta)+gt+\beta_4\log T \\ &+\beta_5\log\, H+\beta_6\log\, I+\beta_7\log\, E+\left(1-e^{-\lambda t}\right)\log\, A_0\end{aligned}$$

For cross-sectional study average growth can be found by dividing by time period *t*

$$\begin{aligned}\frac{\log\, y_t - \log\, y_0}{t} = D &- \frac{\left(1-e^{-\lambda t}\right)}{t}\log\, y_0 + \frac{\alpha}{1-\alpha}\frac{\left(1-e^{-\lambda t}\right)}{t}\log\, s \\ &-\frac{\left(1-e^{-\lambda t}\right)}{t}\frac{\alpha}{1-\alpha}\log(n+g+\delta)+g+\beta_4'\log T \\ &+\beta_5'\log\, H+\beta_6'\log\, I+\beta_7'\log\, E+\varepsilon \qquad \text{... (5)}\end{aligned}$$

Where $\log\, A_0 = D + \varepsilon$ where D is a constant and ε is the country specific shift or shock term. Time component captures the rate of growth of technology in a panel setup. If the coefficient of log y_0 is > 0 we have conditional beta convergence.However, for empirical analysis, the following linear equation is estimated using country-wise data over the years. As per the nature of the data, the study has used the panel data estimation technique to estimate the following model to show the impact of energy consumption on economic growth.

$$\begin{aligned}Y_{it}^{PCGr} = &\, a + b_1\log(Intial_i^{PC}) + b_2\log(Savings_{it}^{Ratio}) + b_3\log(Pop_{it}^{Gr}) + b_4\log(Trade_{it}^{Ratio}) + b_5\log(LifeExp_{it}) \\ &+ b_6\log(Industry_{it}^{Ratio}) + b_7\log(Energy_{it}^{PC}) + b_8\log(FDI_{it}^{Ratio}) + b_9\log(CO_{it}) \\ &+ b_{10}\log(CO_{it}\times Energy_{it}^{PC}) + \varepsilon_{it} \qquad \text{... (6)}\end{aligned}$$

$$\begin{aligned}Y_{it}^{PCGr} = &\, a + b_1\log(Intial_i^{PC}) + b_2\log(Savings_{it}^{Ratio}) + b_3\log(Pop_{it}^{Gr}) + b_4\log(Trade_{it}^{Ratio}) + b_5\log(LifeExp_{it}) \\ &+ b_6\log(Industry_{it}^{Ratio}) + b_7\log(Efficiency_{it}^{Energy}) + b_8\log(FDI_{it}^{Ratio}) \\ &+ b_9\log(CO_{it}) + b_{10}\log(CO_{it}\times Energy_{it}^{PC}) + \varepsilon_{it} \qquad \text{... (6.1)}\end{aligned}$$

Where Y_{it}^{PCGr} is annual growth rate of GDP per capita; $\log(Intial_i^{PC})$ is the log of initial level of GDP per capita; $\log(Savings_{it}^{Ratio})$ is log of ratio of gross domestic savings to GDP; $\log(Pop_{it}^{Gr})$ is the log ofthe growth rate of population growth (n) +rate of growth of technology(g)which is assumed to be constant at 3 percent +rate of depreciation(δ) assumed to be constant at 2 percent; $\log(Trade_{it}^{Ratio})$ log of the trade to GDP ratio as a proxy for trade openness; $\log(LifeExp_{it})$ is the log of life expectancy at birth, a proxy for healthy labor force; $\log(Industry_{it}^{Ratio})$ is the log of share of industry value added in GDP; $\log(Energy_{it}^{PC})$ is the log of energy consumption per capita; $\log(Efficiency_{it}^{Energy})$ is the log of efficiency scores plus one of electricity producing energy industry by using various renewable and non-renewable resources; and $\log(FDI_{it}^{Ratio})$ is the log of share of net FDI inflows in GDP[2]. We have added CO_2 emissions and an interactive term of CO_2 emissions and energy consumption per capita(both in log form) in (6) and (6.1) hypothesizing that CO_2 emissions entails use of sophisticated technology to develop renewable, which in turn increases growth per capita. The interactive term is also hypothesized to have a positive impact on growth per capita.

3.2 Database

To estimate the regression model given in equation (6), panel data of 18 developed, 16 transition and 18 developing countries on the required variables has been used over the period 1980-2013. Country-wise data on all variables has been culled from World Development Indicators (WDI) provided by the World Bank.Data on all the variables of the regressions are easily available in the WDI database except the efficiency scores of energy industry. The efficiency scores of energy industry is calculated using input-oriented technical efficiency[3]with constant returns to scale assumption. Year-wise technical efficiency scores of 18 developed and 18 developing countries have been calculated by using three outputs and one input. Due to the restriction of data availability, the study has taken one input of energy use per capita and three outputs as electricity production from nuclear sources, renewable sources, excluding hydroelectric and electricity production from oil, gas and coal sources. The data on all three outputs is in percentage terms of total electricity production and data on input is at kilogram of oil equivalent provided by WDI.

3.3 Methodology

As per the nature of the data, the study has used the panel data estimation methodology to find the relationship between energy consumption and economic growth. Following sub-sections

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[2] In the study, two different models have been estimated: One with energy consumption per capita (Model given in equation 6) and other with energy efficiency (Model given in equation 6.1) as a one of the independent variable in place of each other. The study has also included share of FDI in GDP as one of the independent variable which is not present in the equation (5) as derived from the economic model. The last four factors in both of the models determine the level of technology in the model.

[3] See Cooper *et al.* (2007).

show the panel data estimation methodology utilized to answer the research questions defined in section 1.

3.3.1 Panel Data Unit-Root Tests for Two Variable Analysis

The study has employed panel data unit root tests to check whether the variables are stationary or not. Several statistical methods (Levin, Lin and Chu 2002; Im, Pesaran and Shin, 2003; Choi, 2001; Breitung, 2000; and Hadri, 2000) are constructed to test for unit roots in panel data. Among those the study has employed Levin-Lin-Chu test and Im-Pesaran-Shin tests to check for stationarity in the variables.

I) Levin-Lin-Chu (LLC) Test

The model is: $y_{i,t} = \alpha_i + \rho_i y_{i,t-1} + \varepsilon_{it}$ $t = 1, 2, . . . , T; i = 1, 2, . . . , N$

It proposes a panel based ADF test which restricts ρ_i by keeping them identical across cross sections as follows:

$$\Delta y_{i,t} = \alpha_i^* + \rho_i^* y_{i,t-1} + \sum_{j=1}^{\rho_i} \theta_{ij} \Delta y_{i,t-j} + \varepsilon_{it}$$

The null and alternative hypotheses are defined as:

$H_0 : \rho_i = \rho = 0$ for all i, against

$H_A: \rho_1 = \rho_2 = \cdots = \rho < 0$ for all i, with test based on statistics: $t_\rho = \hat{\rho}/SE(\hat{\rho})$

The LLC unit root test suggests that both the variables are stationary at first difference in the case of developing as well as developed countries.

II) Im-Pesaran-Shin (IPS) Test

The model is: $y_{i,t} = \alpha_i + \rho_i y_{i,t-1} + \varepsilon_{it},$ $t = 1, 2, . . . , T$

The null and alternative hypotheses are defined as:

$H_0 : \rho_i = 1$, i = 1, 2, . . . , N i.e. each series in the panel contains a unit root for all *i*

$H_A : \rho_i < 1$, for at least one *i*

They use separate unit root tests for the N cross-section units.

The DF regression: $y_{i,t} = \alpha_i + \rho_i y_{i,t-1} + \varepsilon_{it}$ or

The ADF regression: $\Delta y_{i,t} = \alpha_i + \rho_i y_{i,t-1} + \sum_{j=1}^{\rho_i} \theta_{ij} \Delta y_{i,t-j} + \varepsilon_{it}$

is estimated and the *t*-statistic for testing $\rho i = 1$ is computed. Let $t_{i,T}$(i = 1, 2, . . . , N)denote the *t*-statistic for testing unit roots in individual series *i*, and let $E(t_i, T) = \mu$ and $V(t_i, T) = \sigma^2$.

Then, $\bar{t}_{N,T} = \frac{1}{N}\sum_{j=1}^{N} t_i, T$ and $\overline{W} = \sqrt{\frac{N(\bar{t}_{N,T}-\mu)}{\sigma}} \Longrightarrow N(0,1)$

$\overline{W}$ converges in distribution to a standard normal variate sequentially, as $T\rightarrow\infty$ first and then $N\rightarrow\infty$.The IPS test is a way of combining the evidence on the unit root hypothesis from *N* unit root tests performed on *N* cross-section units. The test assumption is that *T* is the same for all cross-section units and hence *E(ti,T)* and *V(ti,T)* are the same for all *i*, so the IPS test is applied only for balanced panel data. In the case of serial correlation, IPS test proposes using the ADF *t*-test for individual series.

3.3.2 Panel Cointegration Analysis for Two Variables

I) Pedroni's Residual Cointegration Test

To test the cointegration relationship,Pedroni's method (1999,2004) which extends the idea of residual based cointegration, proposed by Engle and Granger (1987) is used. Pedroni's formulation allows for the heterogeneity across the cross-sections by permitting individual specific fixed effect, slopes and deterministic time trend for each cross-section.To test the cointegration, following bi-variate regression equation is estimated:

$$Y_{jt} = a_j + \delta_{jt} + b_t + \beta_j X_{jt} + e_{jt}$$

Under the null hypothesis of no cointegration in heterogeneous panels i.e. e_{it} is non-stationary,Pedroni develops seven different test statistics based on the estimated error term e_{it} in equation. These are divided in two groups. The first group, "within dimensions" contains four test statistics termed as *panel-v*, *panel-p*, *panel-t* non parametric (*PP*) and *panel-t* parametric (*ADF*). The second group "between dimensions" contains three test statistics termed as *group-p*, *group-t* non parametric (*PP*) and *group-t* parametric (*ADF*).

The estimated statistic will be the average of the individual statistics. The rejection of null of no cointegration indicated that the cointegration holds at least for one individual. After the calculation of the panel cointegration test statistics, Pedroni shows that the standardized statistic is asymptotically normally distributed as follows:

$$K = \frac{\left(K_{N,T} - \mu(N)^{\frac{1}{2}}\right)}{(V)^{\frac{1}{2}}} \Rightarrow N(0,1)$$

He reports the critical values for μ and v for different values of number of regressors in cointegration relationship.

II) Johansen CointegrationTest for Two Variables (Fischer-type test)

Johansen (1988) proposes two different approaches; one of them is the likelihood ratio trace statistics and the other one is maximum eigenvalue statistics, to determine the presence of cointegration vectors in non-stationary time series. The trace statistics and maximum eigenvalue statistics have shown in equation below:

$$\lambda_{trace}(r) = -\mathrm{T}\sum_{i=r+1}^{N} \ln\left(1-\hat{\lambda}_i\right)$$

$$\lambda_{max}(r, r+1) = -\mathrm{T}\ln\left(1-\hat{\lambda}_{r+1}\right)$$

Where, T is the sample size. For the trace test tests the null hypothesis of at most *r* cointegration vector against the alternative hypothesis of full rank *r=n* cointegration vector, the null and alternative hypothesis of maximum eigenvalue statistics is to check the r cointegrating vectors against the alternative hypothesis of r+1 cointegratingvectors.UsingJohansens (1988) test for cointegration, Maddala and Wu (1999) consider Fisher's (1932) suggestion to combine individual tests, to propose an alternative for testing for cointegration in the full panel by combining individual cross-sections tests for cointegration.

If π_i is the p-value from an individual cointegration test for cross-section i, then under the null hypothesis for the whole panel,

$$-2\sum_{i=1}^{N} ln(\pi_i)$$

is distributed as χ^2_{2N}.A big benefit is that the test can handle unbalanced panels.EViews reports χ^2-value based on MacKinnon-Haug-Michelis (1999) p-values for Johansen's cointegration trace test and maximum eigenvalue test.

Further, to estimate the long run relationship between the heterogeneous cointerated panels in case of developing countries, Panel Fully Modified Least Square (FMOLS) method is used. This methodology allows consistent and efficient estimation of cointegrating vector and also addresses the problem of simultaneous bias. The cointegrated regression for estimation is:

$$Y_{it} = a_i + bX_{it} + e_{it}; \quad X_{it} = X_{i,t-1} + e_{it}$$

3.3.3 Panel Causality between GDP Per Capita and Energy Consumption Per Capita

Granger causality is checked in both the panels to analyze the causality hypotheses explained in section 1. In case of long-run relationship, panel Vector Error Correction Model

(VECM) is used while panel Vector Auto Regression (VAR) method is used in case of no cointegration.The conventional Granger causality tests raise two critical issues for a panel data case, both dealing with the potential heterogeneity of the individual cross sections. The first source of heterogeneity is cross sectional variation due to the distinctive intercepts; such heterogeneity may be addressed with a fixed effects model (i.e. it is controlled by introduction of individual effects in the model). The more crucial case is where heterogeneous slope coefficients should be considered (i.e. should be controlled by introducing individual dimension for regression slopes in the model). The second source of heterogeneity affects the causality relationships. For instance, for some individuals the introduction of past values of may improve the forecast on, whereas for others there may be no improvement. Therefore, we should distinguish two subgroups of individuals according to the causality relationships between and. If this heterogeneity is not considered, the test of causality hypothesis may lead to a fallacious conclusion concerning the relative size of the two subgroups. In a nutshell, the Granger causality for panel data sets should consider the different sources of heterogeneity of the data-generating. A newly suggested theory of Granger Causality in Panel by HurlinandVenet (2001) is used here to test causality which controls for both sources of heterogeneity. The procedure has three main steps, which are related to the homogeneous non-causality (HNC), homogeneous causality (HC) and heterogeneous non-causality (HENC) hypotheses.Following model is estimated:

$$\Delta \ln energy_{it} = \sum_{k=1}^{p} a_k \Delta \ln energy_{i,t-k} + \sum_{k=1}^{p} b_k \Delta \ln gdp_{i,t-k} + \lambda_i + \mu_{it}$$

$$\Delta \ln gdp_{it} = \sum_{k=1}^{p} a_k \Delta \ln gdp_{i,t-k} + \sum_{k=1}^{p} b_k \Delta \ln energy_{i,t-k} + \lambda_i + \mu_{it}$$

Homogeneous Non Causality hypothesisrefers to the case in which there is no linear causality between dependent variable and explanatory variable for any cross section (the null hypothesis states non-existence of causal relationships across all cross sections, *N*).

$$H_0 : b_k^i = b_k^j = 0 \;\; \forall_i \epsilon [1, N], \;\; \forall_k \epsilon [1, p]$$

$$H_1 : b_k^i \neq 0 \; \exists [1, k]$$

To test these Non-linear restrictions, the following Wald statistic is computed:

$$F_{HNC} = \frac{(RSS_1 - RSS_\mu)/N_p}{RSS_\mu/[NT - N(1+p) - p]}$$

Where, RSS_1 denotes the sum of squared residuals obtained under the null hypothesis, RSS_udenotes the sum of squared residuals produced by unrestricted model.If the HNC hypothesis is not accepted, Homogeneous Causality hypothesis is tested which says that there exists causality between per capita GDP and per capita energy consumption for all cross sections (the null hypothesis states existence of causal relationships across all cross sections, *N*).

$$H_0 : b_k^i = b_k^j \forall_i \epsilon [1, N], \ \forall_k \epsilon [1, p]$$

$$H_1 : b_k^i \neq b_k^j \exists [i, j, k]$$

With the F-statistic being:

$$F_{HNC} = \frac{(RSS_2 - RSS_\mu)/[(N-1)p]}{RSS_\mu/[NT - N(1+p) - p]}$$

Where RSS_2 denotes the sum of squared residuals under the null hypothesis.If the HC hypothesis is also rejected, Heterogeneous Non Causality hypothesis is tested which means that least one cross section unit does not indicate a causality relationship between two variables (the null hypothesis states non-existence of causal relationship for each cross section unit).

$$H_0 : b_k^i = 0 \ \forall_i \epsilon [1, N], \ \forall_k \epsilon [1, p]$$

$$H_1 : b_k^i \neq 0 \ \forall_i \epsilon [1, N], \ \forall_k \epsilon [1, p]$$

With the F-statistic being:

$$F_{HENC} = \frac{(RSS_{3,i} - RSS_\mu)/p}{RSS_\mu/[NT - N(1+2p) - p]}$$

Where$RSS_{3,i}$denotes the sum of residual squares obtained from model when one imposes$b_k^i = 0$ *for all* $k \epsilon [1,p]$, for each *i*.These *N* cross-sectional tests allow to us to identify the individuals for which there are no causality relationships.

3.3.3.1 Panel Vector Error Correction Model (VECM) for a Two VariableModel

In case of long-run relationship, panel VEC method is used to get the direction of causality between the variables. Following are the steps to conduct this analysis:

Step1: Estimate $lnEnergy_{i,t} = a_i + b_t + \beta_i lngdp_{it} + e_{it}$and obtain residuals;

Step2: Estimate Granger causality model with a dynamic error correction term (residuals obtained from step 1)

$$\Delta \ln gdp_{it} = a_{1j} + \sum_{k=1}^{m} a_{11ik} \Delta \ln gdp_{it-k} + \sum_{k=1}^{m} a_{12ik} \Delta \ln energy_{it-k} + b_{1i} ect_{it-1} + \mu_{it} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (A)$$

$$\Delta \ln energy_{it} = a_{2j} + \sum_{k=1}^{m} a_{21ik} \Delta \ln energy_{it-k} + \sum_{k=1}^{m} a_{22ik} \Delta \ln gdp_{it-k} + b_{2i} ect_{it-1} + \mu_{it} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (B)$$

Where Δis first difference, m is the lag length, e_{it-1} is error correction term and *b* is speed of convergence parameter for each individual.Sources of causation can be identified by testing for significance of the coefficients on the lagged variables in Equations (A) and (B). First, by testing H0: a_{12ik}=0for all *i*in Equation (A) or H0: a_{22ik}=0 for all *i*in Equation (B), Granger weak causality is evaluated. Masih and Masih(1996) and Adjaye (2000) interpreted the weak Granger causality as 'short run' causality in the sense that the dependent variable responds only to short-run shocks to the stochastic environment. Another possible source of causation is the *Error Correction Term (ECT)*in Equations (A) and (B). In other words, through the *ECT*, an error correction model offers an alternative test of causality (or weak exogeneity of the dependent variable). The coefficients on the *ECTs* represent how fast deviations from the long run equilibrium are eliminated following changes in each variable. If, for example, $b_{1i}$is zero, then lngdpdoes not respond to a deviation from the long run equilibrium in the previous period. It is also desirable to check whether the two sources of causation are jointly significant, in order to test Granger causality. This can be done by testing the joint hypotheses *H0:* $a_{12ik}=0$ and $b_{1i}= 0$ for all *i*in Equation (A) or *H0:* $a_{22ik}=0$ and $b_{2i}=0$ for all *i*in Equation (B). This is referred to as a strong Granger causality test. The joint test indicates which variable(s) bear the burden of short run adjustment to re-establish long run equilibrium, following a shock to the system (Adjaye, 2000). If there is no causality in either direction, the 'neutrality hypothesis' holds.

3.3.3.2 Panel Vector Auto Regression (VAR) for a Two Variable Model

To check for causality in case of no long-run relationship, panel VAR is used. Following fixed effects model is estimated:

$$\Delta \ln gdp_{it} = \sum_{k=1}^{p} a_k \Delta \ln gdp_{i,t-k} + \sum_{k=1}^{p} b_k \Delta \ln energy_{i,t-k} + \lambda_i + \mu_{it}$$

$$\Delta \ln energy_{it} = \sum_{k=1}^{p} a_k \Delta \ln energy_{i,t-k} + \sum_{k=1}^{p} b_k \Delta \ln energy_{i,t-k} + \lambda_i + \mu_{it}$$

Where, p= lag length, λ_i: country fixed effects-controls the potential heterogeneity of cross sections.

3.3.4 Panel ARDL Approach: Multivariate Analysis

To test for panel unit roots in multivariate analysis, the study have used LLC and IPS tests again to check whether the variables are stationary or not. Let us consider the following AR(1) processfor panel data:

$$y_{it} = \rho_i y_{i(t-1)} + X_{it}\delta_i + \varepsilon_{it}$$

Where *i=1,2,…N* cross-section units or series, that are observed over periods *t=1,2,…T*.The X_{it} represent the exogenous variables in the model, including any fixed effects or individualtrends, ρ_i are the autoregressive coefficients, andε_{it} the errors are assumed to bemutually independent idiosyncratic disturbance. If $|\rho_i| < 1$, $y_i$is said to be weakly (trend)stationary. On the other hand, if$|\rho_i| = 1$ then y_i contains a unit root.For purposes of testing, there are two assumptions that we can make about the ρ_i .First, one can assume that the persistence parameters are common across cross-sections sothat $\rho_i = \rho$for all i. The Levin-Lin-Chu (LLC), Breitung and Hadri tests all employthis assumption. Alternatively, one can allow p_i to vary freely across cross-sections. The Im-Pesaran-Shin (IPS), and Fisher-ADF and Fisher-PP tests are of this form.

After determining the level of integration of all variables, the study proceeds to the application of panel ARDL to estimate the long-run and short-run relationships between regression variables. Autoregressive Distributed Lag (ARDL) models are standard least squares regressions which include lags of both the dependent variable and independent variables as regressors (Greene, 2008). Although, ARDL models have been used in econometrics for decades,they have gained popularity in recent years as a method of examining long-run and cointegratingrelationships between variables (Pesaran and Shin, 1999).In panel settings with individual effects, standard regression estimation of ARDL models isproblematic due to bias caused by correlation between the mean-differenced regressors andthe error term. This bias only vanishes for large numbers of observations T, and cannot becorrected by increasing the number of cross-sections, *N* . To address this problem, a number of small *T*–large *N*, dynamic panel data GMM estimators have been developed (for example, Arellano-Bond, 1991). In large datasets, these assumptions underlying dynamic GMM are often inappropriate, and the estimator breaks down. In these cases, a popular alternative is the Pooled MeanGroup (PMG) estimator of Pesaran, Shin and Smith (PSS, 1999). This model takes the cointegrationform of the simple ARDL model and adapts it for a panel setting by allowing theintercepts, short-run coefficients and cointegrating terms to differ across cross-sections.The model can be written as:

$$\Delta y_{i,t} = \phi_i EC_{i,t} + \sum_{j=0}^{q-1} \Delta X_{i',t-j'} \beta_{i,j} + \sum_{j=1}^{p-1} \lambda_{i,j} \Delta y_{i,t-j} + \varepsilon_{i,t}$$

Where

$$EC_{i,t} = y_{i,t-1} - X_{i,t'}\theta$$

It is assumed that both the dependent variable and the regressors have the same number of lags in each cross-section. For notational convenience, it is also assumed that theregressors *X*, have the same number of lags$q$ in each cross-section, but this assumption isnot strictly required for estimation. The following log-likelihood function is then derived:

$$l_t(\varphi) = -\frac{\mathrm{T}_i}{2} \sum_{i=1}^{N} \log(2\pi\sigma_i^2) - \frac{1}{2} \sum_{i=1}^{N} \frac{1}{\sigma_i^2} (\Delta Y_i - \phi_i EC_i)' H_i (\Delta Y_i - \phi_i EC_i)$$

Where

$$\Delta Y_i = \left(\Delta y_{i,1}, \Delta y_{i,2}, \ldots \ldots . \Delta y_{i,T_i}\right)'$$

$$EC_i = \left(EC_{i,1}, EC_{i,2}, \ldots \ldots . EC_{i,T_i}\right)'$$

$$H_i = \left(I_{T_i} - W_i (W'^{W_i})^{-1} W_i'\right)^{-1}$$

$$W_i = \left(\Delta Y_{i,-1}, \Delta Y_{i,-p+1}, \Delta X_1, \Delta X_{i,-1} \ldots \ldots . \Delta X_{i,-q+1}\right)$$

$$\Delta X_i = \left(\Delta X_{i,1}, \Delta X_{i,2}, \ldots \ldots . \Delta X_{i,T_i}\right)'$$

where the *j*thlags of ΔY_i and ΔX_i as $\Delta Y_{i,-j}$ and $\Delta X_{i,-j}$, respectively.This log-likelihood can be maximized directly. However, there exists an iterative procedure. Initial least squares estimates of θ based on the regression $Y_t = \theta X_t$ (where Y_t and $X_t$are the stacked forms of $y_{i,t}$ and $x_{i,t}$) are used to compute estimates, using the first-derivative relationships, of Φ_i and σ_i^2. These estimates are then used to compute new estimates of θ, and the process continues until convergence. Given the final estimates of θ ,Φ_i and σ_i^2, estimates of $\beta_{i,j}$ and$\lambda_{i,j} *$ may be computed.

Panel Causality through Panel Granger Test

In the pairwise causality tests with the stationarised data, the bivariate regressions in a panel data context take the following form:

$$y_{i,1} = \alpha_0 + \alpha_{1,i}y_{i,t-1} + \cdots + \alpha_{l,i}y_{i,t-1} + \beta_{1,i}x_{i,t-1} + \cdots + \beta_{1,i}x_{i,t-1} + \varepsilon_{i,t}$$

$$x_{i,1} = \alpha_0 + \alpha_{1,i}x_{i,t-1} + \cdots + \alpha_{l,i}x_{i,t-1} + \beta_{1,i}y_{i,t-1} + \cdots + \beta_{1,i}y_{i,t-1} + \varepsilon_{i,t}$$

Where t denotes the time period dimension of the panel, and i denotes the cross-sectionaldimension.The different forms of panel causality test differ on the assumptions made about the homogeneityof the coefficients across cross-sections.The first is totreat the panel data as one large stacked set of data, and then perform the Granger Causalitytest in the standard way, with the exception of not letting data from one cross-section enterthe lagged values of data from the next cross-section. This method assumes that all coefficientsare same across all cross-sections, i.e.:

$$\alpha_{0,i} = \alpha_{0,j}, \alpha_{1,i} = \alpha_{1,j}, \dots\dots.. \;\; \alpha_{l,i} = \alpha_{l,j} \forall i, j$$

$$\beta_{1,i} = \beta_{1,j}, \dots\dots\dots\dots \beta_{l,i} = \beta_{l,j} \forall i, j$$

A second approach adopted by Hurlin and Dumitrescu (2012) makes an extreme opposite assumption, allowing all coefficients to be different across cross-sections:

$$\alpha_{0,i} \neq \alpha_{0,j}, \alpha_{1,i} \neq \alpha_{1,j}, \dots\dots.. \;\; \alpha_{l,i} \neq \alpha_{l,j} \forall i, j$$

$$\beta_{1,i} \neq \beta_{1,j}, \dots\dots\dots\dots \beta_{l,i} \neq \beta_{l,j} \forall i, j$$

This test is calculated by simply running standard Granger Causality regressions for eachcross-section individually. The next step is to take the average of the test statistics, which are termed the $\overline{W}$ statistic. They show that the standardized version of this statistic, appropriately weighted in unbalanced panels, follows a standard normal distribution. This istermed the $\overline{Z}$ statistic. The authors have relied on the first version of the test. The p-values of the statistic are reported below.

4. Analysis

The empirical results have been explained in following two sub-sections. In the first sub-section, the short-run and long-run relationship between per capita energy consumption and growth rate of GDP per capita has been presented using appropriate panel data estimation techniques. In the second sub-section, the regression equation derived from the Solow model of economic growth (see equation 6 and 6.1) has been estimated and the effect of per capita energy consumption on growth rate of GDP per capita has been shown by including other variables effecting growth of per capita income. S shaped regression results are also provided in this section.

4.1 Energy Consumption and Economic Growth: A Two Variables Analysis

In the first step, variables have been tested for the presence of unit-roots using LLC and IPS tests. The results of these two tests are given in Table 1. The results in Table 1 show that both of the variables are stationary at first difference i.e. both are integrated of order 1.

Table 1: Unit-Root Test Results

Variable	LLC Test	IPS Test
Per Capita GDP	*I(1)*	*I(1)*
Per Capita Energy Use	*I(1)*	*I(1)*

Notes: *I(1)*: Indicated integrated of order one; Due to lack of space, instead of giving figures, only the decision has been shown on the basis of these tests. Authors' can provide all the results on demand.

Source: Authors' Elaboration from Unit-Root Results.

As explained in the previous section that if both variables are stationary at first difference,then there may exist long-run relationship between them. To check for that, cointegration results are given in Table 2 for developing and developed countries separately.

Table 2: Cointegration Test Results

Name of the Test	Developing Countries		Developed Countries	
	Test Statistic	P-value	Test Statistic	P-value
Panel 1: Pedroni Residual Cointegration Tests				
Panel *v*-Statistic	-499.1275	1.0000	45.3818*	0.0000
Panel *rho*-Statistic	1.0909	0.8623	1.6115	0.9465
Panel *PP*-Statistic	0.9804	0.8633	1.0632	0.8562
Panel *ADF* Statistic	1.6361	0.9491	0.9808	0.8367
Group *rho*–Statistic	0.7852	0.7378	2.4550	0.9930
Group *PP* Statistic	0.0992	0.5395	1.1799	0.8810
Group ADF-Statistic	0.2990	0.6195	2.0750	0.9810
Panel 2: Kao Residual Cointegration Test				
ADF Statistic	2.0573*	0.0198	-0.4018	0.3439
Panel 3: Johansen Fischer Panel Cointegration Test				
Fischer Statistics from Trace Test	101.100*	0.0000	24.33	0.9305
Fischer Statistics from Max-Eigen value test	94.30*	0.0000	24.33	0.9305

Notes: * represents the value is significant at 1percent level of significance.

Source: Authors' Calculations.

The results show that per capita GDP and per capita energy use are cointegrated and have a long-run relationship in case of developing countries' panel. However, in developed countries' panel, cointegration does not exist. Further, to estimate the long-run relationship between the heterogeneous cointegrated panels in case of developing countries, Panel Fully Modified Least Square (FMOLS) method is used. The long-run relationship using FMOLS is given as:

$$\log(Energy_{it}^{PC}) = 0.5369(GDP_{it}^{GrPC}) + C$$

The above relationship explains that if per capita GDP would increase by 1 percent then it will lead to increase the energy consumption by 0.54 percent approximately(correlations below show that negative relationship holds between the two variables, of course assuming homogeneous panels, unlike FMOLS which assumes heterogeneous panes).

Checking for Causality

After establishing that the variables in question arecointegratedin developing countries' panel and not cointegrated in developed countries' panel, Granger causality is checked in both the panels to analyze the causality hypotheses explained above. In case of the presence of long-run relationship in developing countries' panel, the results of panel VECM are reported in Table 3 to show the causality between two variables. However, to show the causality between non-cointegrated variables in developed countries' panel, the results of panel VAR is reported in Table 4.

Table 3: Panel VECM Results for Developing Countries

	Short-Run Causality (F-Statistic)		Long-Run Causality (F-Statistic)	
Hypothesis	**PC_Energy →PC_GDP**	**PC_GDP →PC_GR_Energy**	**PC_Energy → PC_GDP**	**PC_GDP →PC_GR_Energy**
Homogeneous Non-Causality	0.22 (0.81)	16.03* (0.00)	3.01** (0.03)	13.73* (0.00)
Heterogeneous Non-Causality	--	2.80** (0.01)	1.59 (0.20)	6.93* (0.00)

Notes: PC_Energy: Per Capita Energy Use; PC_GDP: Per Capita GDP; * and **: represents the level of significance at 1 and 5 percent respectively; Figures in parenthesis of type ( ) are the p-value of the respective coefficient.

Source: Authors' Calculations.

Table 3 shows that there is no homogeneous causality found from energy consumption to GDP per capita in developing countries in short-run but it exists in the long-run. Further, the evidence of causality from GDP per capita to energy consumption exists both in short-run as well as in long-run. Under heterogeneous causality check, it exists from GDP per capita to energy consumption both in short-run as well as in long-run. It shows the evidence of energy conservation hypothesis(we reject the null hypothesis of no causality when p-value is less than the level of significance). Table 4 shows the panel VAR results for developed countries' panel in which case long-run relationship does not exist as per the cointegration test statistics.The results show that in case of developed countries, no causality exists in both the direction (since the p-values are greater than level of significance).

Table 4: Panel VAR Results for developed Countries' Panel		
Hypothesis	**PC_Energy →PCGDP**	**PC_GDP →PC_GR_Energy**
Heterogeneous Non-Causality	2.19 (0.11)	1.54 (0.21)
Notes: PC_Energy: Per Capita Energy Use; PC_GDP: Per Capita GDP;Figures in parenthesis of type ( ) are the p-value of the respective coefficient.		
Source: Authors' Calculations.		

Checking for Panel Causality

We also perform below short run panel causality(assuming homogeneous and heterogeneous panels) between log of GDP per capita and log of energy consumption per capita and growth per capita and log of energy consumption per capita for set of developed, developing and transition economies.The results in Table 5 show that:

In case of Developing Countries,

- Relationship works in one way from growth per capita GDP to log of energy consumption per capita under homogeneous panel assumption;
- Relationship works both ways under heterogeneous panel assumptions. This gives justification for understanding the explanatory factors determining log of energy consumption per capita and also growth per capita GDP;
- Further, the relationship between log of energy consumption per capita and log of GDP per capita has been evaluated. The relationship works from GDP per capita to energy consumption per capita based on homogeneous panels but works two way based on heterogeneous panels;
- The correlation between growth per capita and energy consumption per capita, turned out be negativebut is positive for log of GDP per capita and log of energy consumption per capita.

In case of Developed Countries,

- Using similar approach, we perform panel granger causality test on data for developed nations by following up with correlation exercise. The variables first we take are growth per capita GDP and log of energy consumption per capita and then log of GDP per capita and log of energy consumption per capita;

- In the first case, the study found both way robust relationships between the variables assuming homogeneous panels. However, we do find insignificant statistical relationship between the variables(both ways) assuming heterogeneous variables, indicating neutrality hypothesis working for developed nations;
- Negative correlation between the variable suggest that higher growth per capita GDP leads to lower energy consumption per capita. The correlation between, energy consumption and GDP per capita is also negative.

In case Transition Economies,

- A very strong statistical relationship exists for transition economies between log of energy consumption per capita and growth per capita GDP based on homogeneous and heterogeneous panels. Also, the relationship is quiet robust both ways for GDP per capita and log of energy consumption per capita using panel causality and assuming heterogeneous panels;
- As in case for developing countries, GDP per capita growth has negative relationship with energy consumption per capita and for transition economies, log of GDP per capita pulls up energy consumption per capita.

Table 5: Pair-wise Granger Causality Test					
Developing Countries					
Hypotheses	**Homogeneous Panel**		**Heterogeneous Panel**		
	F Value	**P Value**	**W Statistic**	**Zbar Statistic**	**P Value**
Energy Consumption Per Capita does not Granger Cause Per Capita GDP Growth	0.7066	0.4938	4.2324	3.6794	0.0002
Per Capita GDP Growth does not Granger Cause Energy Consumption Per Capita	20.1295	0.0000	3.3763	2.1479	0.0317
Energy Consumption Per Capita does not Granger Cause Per Capita GDP	0.2305	0.7942	3.5899	2.5328	0.0113
Per Capita GDP does not Granger Cause Energy Consumption Per Capita	16.7559	0.0000	6.0356	6.9073	0.0000
Developed Countries					
Hypotheses	**Homogeneous Panel**		**Heterogeneous Panel**		
	F Value	**P Value**	**W Statistic**	**Zbar Statistic**	**P Value**
Energy Consumption Per Capita does not Granger CausePer Capita GDP Growth	10.2021	0.0000	2.8028	1.1631	0.2448
Per Capita GDP Growth does not Granger Cause Energy Consumption Per Capita	7.1666	0.0008	2.9869	1.4967	0.1347
Energy Consumption Per Capita does not Granger	1.5161	0.2205	1.6320	-0.9692	0.3324

Cause Per Capita GDP					
Per Capita GDP does not Granger Cause Energy Consumption Per Capita	2.3229	0.0990	3.3095	2.0313	0.0422
Transition Economies					
Hypotheses	**Homogeneous Panel**		**Heterogeneous Panel**		
	F Value	**P Value**	**W Statistic**	**Zbar Statistic**	**P Value**
Energy Consumption Per Capita does not Granger CausePer Capita GDP Growth	24.8476	0.0000	7.5881	9.2777	0.0000
Per Capita GDP Growth does not Granger Cause Energy Consumption Per Capita	4.9492	0.0074	5.7977	5.8757	0.0000
Energy Consumption Per Capita does not Granger Cause Per Capita GDP	2.0963	0.1244	9.9076	11.6157	0.0000
Per Capita GDP does not Granger Cause Energy Consumption Per Capita	21.9035	0.0000	8.5394	9.5339	0.0000
Source: Authors' Calculation					

The above analysis indicates that two type of regression analysis is worth exploring. Growth regressions explaining growth per capita depending on host of explanatory variables, where in energy consumption, energy efficiency and CO_2 emissions are important explanatory variables, among other control variables. Also, it would be interesting to understand the S-shaped relationship between log of energy consumption(dependent variable) and growth per capita GDP in its reciprocal form, among other explanatory variables(reciprocals).

4.2 Energy Consumption and Economic Growth: A Multi-Variate Analysis

In the present section, the regression model defined in section 2 given by equation (6) and (6.1), have been estimated using appropriate panel data estimation methodology to find out the effect of various factors affecting economic growth with special focus on energy variable. To start with, the results of unit-root tests have been given in the Table 6.The results show that some variables are *I(0)*(stationary in level)and some are *I(1)*(stationary at first difference) implying that any form of regression would be invalid. Hence, the study employed panel ARDL to estimate equation (6) and (6.1) in various combinations. The study also quotes the results of SURE regression in panel which is based on the assumption that there exists autocorrelation in the error term with cross sectional dependence.

Table 6: Unit-Root Test Results

Variable	Developing Country	Developed Country
Y_{it}^{PCGr}	*I(0)*	*I(0)*
$\log(Savings_{it}^{Ratio})$	*I(1)*	*I(0)*
$\log(Pop_{it}^{Gr})$	*I(0)*	*I(0)*
$\log(Industry_{it}^{Ratio})$	*I(1)*	*I(1)*

$\log(LifeExp_{it})$	*I(0)*	*I(1)*
$\log(Trade_{it}^{Ratio})$	*I(1)*	*I(0)*
$\log(FDI_{it}^{Ratio})$	*I(1)*	*I(0)*
$\log(Efficiency_{it}^{Energy})$	*I(0)*	*I(1)*
$\log(Energy_{it}^{PC})$	*I(1)*	*I(1)*
Notes: *I(0)* and *I(1)*: Integrated of Order zero and one respectively.		
Source: Authors' Calculations.		

4.2.1 Panel ARDL Regression Results

The study has estimated five models to show the relationship between energy consumption and economic growth for 18 developing and 18 developed countries. Table 7 presents the results of all five models estimated using panel ARDL.

Table 7: Results of ARDL					
Variable	**Developing**		**Developed**		
Long-Run Relationships					
Model	**I**	**II**	**III**	**IV**	**V**
$\log(Savings_{it}^{Ratio})$	1.0663*** (0.0634)	0.7432 (0.1862)	--	--	--
$\log(Pop_{it}^{Gr})$	-2.5335* (0.0006)	-2.8353* (0.0002)	-0.2637* (0.0053)	-0.1901** (0.0446)	-0.2954* (0.0051)
$\log(Trade_{it}^{Ratio})$	0.8075 (0.2051)	0.8182 (0.1845)	2.0417* (0.0035)	-0.2236 (0.4245)	0.2839 (0.4706)
$\log(LifeExp_{it})$	2.7074 (0.6012)	8.5634*** (0.0773)	4.4048 (0.7704)	-5.4693* (0.0000)	-4.5936* (0.0000)
$\log(Industry_{it}^{Ratio})$	2.6010*** (0.0511)	3.3384** (0.0146)	3.7572* (0.0020)	4.1325* (0.0000)	5.6483* (0.0000)
$\log(Energy_{it}^{PC})$	-3.7081* (0.0013)	--	0.9532 (0.2492)	1.4576* (0.0000)	--
$\log(Efficiency_{it}^{Energy})$	--	4.1842* (0.0000)	--	--	1.8674*** (0.0562)
$\log(FDI_{it}^{Ratio})$	-0.1299 (0.1946)	-0.1024 (0.2542)	0.2119** (0.0186)	0.0771 (0.3620)	0.0317 (0.7379)
Time Trend	0.0743** (0.0120)	0.0118 (0.6558)	-0.0725*** (0.0904)	--	--
Error Correction Term					
COINTEQ	-0.9076* (0.0000)	-0.8478* (0.0000)	-0.6867* (0.0000)	-0.6300* (0.0000)	-0.5911* (0.0000)
Notes: *, ** and *** represent the coefficient is significant at 1, 5 and 10percent respectively; Figures in parenthesis of type ( ) are the p-value of respective coefficient.					
Source: Authors' Calculations.					

Model 1: In this model, using the panel of 18 developing countries, growth rate of GDP per capita is regressed on host of other factors including per capita energy consumption as one of the independent variables among others. The long-run relationship in model 1 shows that rate of

growth of population and per capita energy consumption has a negative and significant impact on per capita GDP growth and the share of industry to GDP has a positive and significant impact on per capita GDP growth. In addition to this, the significant time component imply that growth rate of technologyhas significant impact on growth of per capita GDP in developing countries. Further, the error correction term (the coefficient cointeq) in the short term equation signifies that the speed of adjustment of growth of per capita GDP is at the rate 90 percent towards its long-run equilibrium value.

Model 2: In this model, in place of energy consumption per capita, energy efficiency has been considered as a one of the independent variables among others. The results from the long-run equation show that considering all right hand side factors, rate of growth of population is inversely related to growth and is statistically significant. The share of industry to GDP has a positive and significant impact on growth of per capita income and energy efficiency pulls up the growth process (as shown by positive and significant coefficient of energy efficiency variable). The significant error correction term explains that around 85 percent of the disequilibrium in rate of growth of per capita income of developing countries is being adjusted annually towards its final equilibrium.

Model 3: In this model, panel of 18 developed countries has been considered for estimating equation (6). It depicts from the results that rate of growth of population, share of industry to GDP, trade to GDP ratio and FDI to GDP ratio are significant factors explaining growth of per capita GDP. The second short term equation again shows that adjustments take place at the rate of 68 percent towards the final equilibrium value. The coefficient of savings to GDP is missing in the specification as we find trade to GDP and Savings to GDP interchange their importance (seems to be substitutable) in explaining growth process of the developed nations.

Model 4: In this model, time trend has not been included with per capita energy consumption taken as one of the independent variable among others. It seems from the results that when we dispense with time trend from the panel ARDL model, energy consumption per capita tend to have positive impact on growth per capita. This may be due to the fact that in developed nations, the energy consumption expenditures may be more devoted to technological progress in alternative source of oil like shell gas or in expenditures related to renewable energy intensive technological products. For developing countries reduction in energy consumption leads to higher growth but for developed nations higher energy consumption expenditures lead to higher growth.The developing countries although trying to put efforts in increasing expenditures in alternative energy sources like non-renewable, oil consumption still seem to not have many alternatives sources of energy. Therefore, reducing oil expenditures tend to promote growth among developing countries.

Model 5: In this model, energy efficiency has been taken as one of the independent variables in place of energy consumption per capita with no time trend. In this estimated model, rate of growth of population, industry to GDP, life expectancy at birth and energy efficiency hassignificant impact on the dependent variable. Life expectancy at birth tends to have a negative impact on growth of per capita GDP. Negative and significant error correction term implies adjustments towards equilibrium and signifying long term cointegratingrelationship between variables with short run adjustments and long-run panel causality among the variables.

Panel Causality Through Panel Granger Test

Homogenous panel causality results for developing and developed countries are shown in Table 8 and 9. The null hypothesis for each test is that of no causality. So a p-value less than the level of significance forces us to reject the null hypothesis and accept the alternative of existence of causality. The pair-wise causality results for developing countries shows that rate growth of population and savings to GDP ratio have two way relationships with rate of growth of per capita GDP. The industry to GDP ratio, life expectancy and Trade to GDP ratio have one way relationship with rate of growth of per capita GDP while FDI to GDP and energy efficiencies have no relationship as shown in the Table 8.

Table 8: Panel Causality Test Results for Developing Countries

S.N.	Hypothesis	Observations	F-Statistics	P-Value
1.	$\log(Savings_{it}^{Ratio})$ does not Granger Cause Y_{it}^{PCGr}	557	4.9185*	0.0076
	Y_{it}^{PCGr} does not Granger Cause $\log(Savings_{it}^{Ratio})$		3.1747**	0.0426
2.	$\log(Pop_{it}^{Gr})$ does not Granger Cause Y_{it}^{PCGr}	562	3.9560**	0.0197

	Y_{it}^{PCGr} does not Granger Cause $\log(Pop_{it}^{Gr})$		4.0663**	0.0177
3.	$\log(Industry_{it}^{Ratio})$ does not Granger Cause Y_{it}^{PCGr}	555	10.7810*	3.E-05
	Y_{it}^{PCGr} does not Granger Cause $\log(Industry_{it}^{Ratio})$		1.1342	0.3224
4.	$\log(LifeExp_{it})$ does not Granger Cause Y_{it}^{PCGr}	564	2.5400***	0.0798
	Y_{it}^{PCGr} does not Granger Cause $\log(LifeExp_{it})$		0.2063	0.8136
5.	$\log(Trade_{it}^{Ratio})$ does not Granger Cause Y_{it}^{PCGr}	564	11.1089*	2.E-05
	Y_{it}^{PCGr} does not Granger Cause $\log(Trade_{it}^{Ratio})$		2.1560	0.1167
6.	$\log(FDI_{it}^{Ratio})$ does not Granger Cause Y_{it}^{PCGr}	564	1.8165	0.1635
	Y_{it}^{PCGr} does not Granger Cause $\log(FDI_{it}^{Ratio})$		1.4275	0.2408
7.	$\log(Energy_{it}^{PC})$ does not Granger Cause Y_{it}^{PCGr}	564	0.0185	0.9816
	Y_{it}^{PCGr} does not Granger Cause $\log(Energy_{it}^{PC})$		0.6278	0.5341
8.	$\log(Efficiency_{it}^{Energy})$ does not Granger Cause Y_{it}^{PCGr}	564	2.4075***	0.0910
	Y_{it}^{PCGr} does not Granger Cause $\log(Efficiency_{it}^{Energy})$		0.7556	0.4702
Notes: *, ** and *** represent the coefficient is significant at 1, 5 and 10 percent respectively.				
Source: Authors' Calculations.				

Further, the panel causality results in Table 9 show that rate of growth of per capita GDPimpacts the savings to GDP ratio, and energy efficiency in one way. Rate of growth of population, industry to GDP ratio, life expectancy at birth, trade to GDP ratio, FDI to GDP ratio have two way relationships with rate of growth of per capita GDP. Energy consumption and per capita GDP don't have any causality in either direction.

Table 9: Panel Causality Test Results for Developed Countries

S.N.	Hypothesis	Observations	F-Statistics	P-Value
1.	$\log(Savings_{it}^{Ratio})$ does not Granger Cause Y_{it}^{PCGr}	535	1.5688	0.2092
	Y_{it}^{PCGr} does not Granger Cause $\log(Savings_{it}^{Ratio})$		4.3781**	0.0130

2.	$\log(Pop_{it}^{Gr})$ does not Granger Cause Y_{it}^{PCGr}	572	2.9139***	0.0551
	Y_{it}^{PCGr} does not Granger Cause $\log(Pop_{it}^{Gr})$		4.5869**	0.0106
3.	$\log(Industry_{it}^{Ratio})$ does not Granger Cause Y_{it}^{PCGr}	528	2.7550***	0.0645
	Y_{it}^{PCGr} does not Granger Cause $\log(Industry_{it}^{Ratio})$		5.6245*	0.0038
4.	$\log(LifeExp_{it})$ does not Granger Cause Y_{it}^{PCGr}	575	10.549*	3.E-05
	Y_{it}^{PCGr} does not Granger Cause $\log(LifeExp_{it})$		3.7109**	0.0250
5.	$\log(Trade_{it}^{Ratio})$ does not Granger Cause Y_{it}^{PCGr}	575	6.4461*	0.0017
	Y_{it}^{PCGr} does not Granger Cause $\log(Trade_{it}^{Ratio})$		22.693*	3.E-10
6.	$\log(FDI_{it}^{Ratio})$ does not Granger Cause Y_{it}^{PCGr}	465	2.4745***	0.0853
	Y_{it}^{PCGr} does not Granger Cause $\log(FDI_{it}^{Ratio})$		11.9632*	9.E-06
7.	$\log(Energy_{it}^{PC})$ does not Granger Cause Y_{it}^{PCGr}	575	0.0566	0.9449
	Y_{it}^{PCGr} does not Granger Cause $\log(Energy_{it}^{PC})$		1.5766	0.2076
8.	$\log(Efficiency_{it}^{Energy})$ does not Granger Cause Y_{it}^{PCGr}	575	0.6662	0.5140
	Y_{it}^{PCGr} does not Granger Cause $\log(Efficiency_{it}^{Energy})$		9.0974*	0.0001
Notes: *, ** and *** represent the coefficient is significant at 1, 5 and 10 percent respectively.				
Source: Authors' Calculations.				

4.2.2 GLS Regression:Cross Sectional SURE and AR(1)

To get the flavor of our results obtained through panel ARD, we employ SURE regression after finding cross sectional dependence with auto-corelationof order 1. To present the results, four models have been estimated and the results are given in Table 10. Model 1 and 2 presents the EGLS results for panel of developing countries' with per capita energy consumption and energy efficiency as one of the independent variables in place of each other, respectively. Further, Model 3 and 4 pertains to the panel of developed countries.

Model 1: The estimated results of model 1 show that all varibles, except trade to GDP ratio and life expectancy at birth have significant impact on growth of per capita GDP and come up with the usual sign. Savings to GDP ratio and trade to GDP ratio seem to be substitutable in impacting growth. Threfore, one may not find two variables to be significant factor taken together in the model. Energy consumption per capitahas a negative impact on growth of per capita GDP defying the energy conservation hypothesis for developing countries, a result we got with two variables anlaysis. Therefore, reducing energy consumption expenditures promotes growth. We also find that initial level of incomepromotes growth giving evidence of beta convergence[4]. FDIto GDP ratio also promotes growth for developing countries. The value of R^2becomes 0.53 shows much improved model when OLS is applied without taking into account cross sectional dependence and AR(1) structure. However, all these results do not take into account the unit root problem. The latter is dealt with panel ARDL models already discussed.

Table 10: Results of Panel EGLS (SUR)

Variable/ Model	Developing		Developed	
	I	II	III	IV
$\log(Intial_{i}^{PC})$	-0.8631* (0.0014)	-1.2602* (0.0000)	-2.5404* (0.0000)	-2.1120* (0.0000)
$\log(Savings_{it}^{Ratio})$	1.1057* (0.0003)	1.0769* (0.0003)	3.3897* (0.0000)	3.5385* (0.0000)
$\log(Pop_{it}^{Gr})$	-0.6831* (0.0076)	-0.6545** (0.0100)	-0.2401* (0.0008)	-0.2051* (0.0044)
$\log(Trade_{it}^{Ratio})$	-0.0037 (0.9876)	-0.2112 (0.3366)	0.4194** (0.0381)	0.2560 (0.1686)
$\log(LifeExp_{it})$	2.1295 (0.3176)	2.7977 (0.1873)	-28.212* (0.0000)	-34.581* (0.0000)
$\log(Industry_{it}^{Ratio})$	3.1348* (0.0000)	2.6140* (0.0000)	0.4454 (0.3514)	0.2918 (0.5316)
$\log(Energy_{it}^{PC})$	-0.6623** (0.0440)	--	0.7607** (0.0127)	--
$\log(Efficiency_{it}^{Energy})$	--	0.3693 (0.5398)	--	-0.6942 (0.3528)
$\log(FDI_{it}^{Ratio})$	0.3386* (0.0000)	0.3399* (0.0000)	0.0524 (0.3274)	0.0597 (0.2681)
Time Trend	0.0372*** (0.0576)	0.0365*** (0.0548)	0.0422*** (0.0766)	0.0678* (0.0030)
AR(1)	0.3353* (0.0000)	0.3389* (0.0000)	0.4116* (0.0000)	0.4066* (0.0000)
Constant	-84.2053** (0.0298)	-84.5565** (0.0242)	45.0626 (0.1354)	24.9320 (0.3916)
R^2	**0.53**	**0.54**	**0.42**	**0.42**

Notes: *, ** and *** represent the coefficient is significant at 1, 5 and 10 percent respectively; Figures in parenthesis of type () are the p-values.

Source: Authors' Calculations.

Model 2:Further, if we take energy efficiency in place of energy consumption per capita, the variable becomes statistically insignificant. Life expectancy at birth and trade to GDP ratio are

[4] The correct concept of economic convergence in panel setting is given by Evans and Karras(1996). According to them one would see panel convergence if each income series (log of y_{it}at constant international and common prices) of the group(*N*) is integrated of order one and any deviations of any individual income series from cross sectional average(sum of y_t divided by *N*) are stationary. Convergence is said to be absolute if the mean of all the series y_{it} (cross sectional average) are equal to zero and relative otherwise. The economies are said to diverge if the deviation series are non stationary.

insignificant factors. FDI to GDP ratio, savings to GDP ratio, initial level of GDP per capita, rate of growth of population and industry to GDP ratio are important factor in explaining the growth process for developing countries.

Model 3:For developed countries with energy consumption per capita as one of the independent varaibles, the results of this model show that by assuming cross-sectionaldependence and AR(1) structure per capita energy consumption expendituretend to have a positive impact on growth of per capita GDP. Among other variables, life expectancy at birth have negative and significant impact, rate of growth of population, savings to GDP ratio, trade to GDP ratio and initial level of per capita incomehave usual signs and are statistically significant. FDI to GDP ratio, industry to GDP ratio and time component capturing growth rate of technology have insignificant impact at 5% level of significance.

Model 4: Finally, with energy efficiency, the results show that the effect becomes insignificant. Trade to GDP ratio and FDI to GDP ratio also have insignificant impact while life expectancy at birth, rate of growth of populationand initial level of per capita incomehave negative and significant impact on growth.

4.2.3Growth Regressions Including CO_2Emissions and an Interactive Term

Further, growth regressions have been estimated by adding two additional variables such as: CO_2 emissions and an interaction term of CO_2 emmisions and energy consumption per capita. For this purpose, we consider two models. One, panel SURE model with AR(1) structure and another being the panel ARDL model. We use the latter as there is unit root problem in almost all the growth explanatory variables across country groups. Some variables are I(0) and some are (1).

Table 11: Panel SUR Model Results
Developing Countries
Dependent Variable: GDP Growth Per Capita

Variable	Coefficient	P Value
Constant	-11.2111	0.0524
$\log(Intial_{i}^{PC})$	-0.7422	0.0000
$\log(Industry_{it}^{Ratio})$	1.3252	0.0052
$\log(FDI_{it}^{Ratio})$	0.4029	0.0000
$\log(Trade_{it}^{Ratio})$	0.29991	0.1350
$\log(Savings_{it}^{Ratio})$	1.8258	0.0000
$\log(LifeExp_{it})$	3.8591	0.0062
$\log(Efficiency_{it}^{Energy})$	-0.2821	0.5043
$\log(Pop_{it}^{Gr})$	-0.5354	0.0005
*CO_2 * Energy Consumption*	0.4998	0.0446
$\log(Energy_{it}^{PC})$	-1.7556	0.0019
Developed Countries		
Constant	67.2571	0.0005
$\log(Intial_{i}^{PC})$	-2.4423	0.0000
$\log(Industry_{it}^{Ratio})$	0.6492	0.2087
$\log(FDI_{it}^{Ratio})$	0.0119	0.8573
$\log(Trade_{it}^{Ratio})$	0.8166	0.0001
$\log(Savings_{it}^{Ratio})$	3.1606	0.0000
$\log(LifeExp_{it})$	-14.5239	0.0005
$\log(Efficiency_{it}^{Energy})$	0.4501	0.4931
$\log(Pop_{it}^{Gr})$	-0.1987	0.0035
CO_2 * Energy Consumption	0.5979	0.0011
AR(1)	0.4234	0.0000
Transition Economies		
Not Shown due to insignificant results		
Source: Authors' Calculations		

The results in Table 11 show that:

- In case of developing countries, Initial level of GDP per capita is negative and significant in explaining growth per capita of developing countries. Log of industry/GDP, Log of FDI/GDP, Log of Gross Savings/GDP, log of rate of growth of population and log of life expectancyhave significant impact on growth per capita. Log of energy consumption per capita tend to have negative and significant impact on growth per capita. Importantly log of interactive term between energy consumption and co2 emissions tend to have positive impact on growth per capita. The latter implying that as CO_2 emissions increase, also proxy for development in technologies which limit use of oil consumption and promotes alternative use of energy resources like renewable, leads to decrease in the rate of increase in energy consumption per capita, which in turn promotes growth per capita in developing countries.

- In case of developed countries, we apply panel sure with AR(1) structure to data made available for developed nations. Log of initial level of income, log of Trade/GDP, log of Gross Savings/GDP, log of life expectancy, log of rate of growth of population and log of interactive term(Co2 emissions with energy consumption per capita) have significant impacts on growth per capita.
- In case of Transition economies, we are not presentingthe panel SURE model results(with AR(1) structure of errors) as almost all variables in the regression model are insignificant except CO_2 emissions which have a negative impact and log of interactive term which has positive and significant impact on growth per capita. The latter may be due to the fact that transition economies may not have fully developed technologies that can take care of limiting CO_2 emissions. On the other hand interactive term is positive may signify that people's movement may have limited use of energy consumption per capita in such countries, acknowledging that climate change is more due to anthropogenic factors.
- We however reported two way random effects model results in case of transition economies in Table 12. Unit root problem is present in almost all variables used in the regression. We strangely find that in transition economies log of Gross Savings/GDP, log of FDI/GDP and log of Trade/GDP have negative and significant impact on growth per capita. This may be due to unit root and autocorrelation in error term. Also, non-market forces play significant role for transition economies leading to false impact of such variables(FDI, Trade and Savings) on growth per capita. Log of Industry/GDP, log of rate of growth of population,log of energy consumption per capita, log of CO_2 emissionsand log of interactive term have significant impact on growth per capita of transition economies.

Table 12: Random Effect Model Results
Transition Economies
Dependent Variable: GDP Growth Per Capita

Variable	Coefficient	P Value
Constant	390.4623	0.5490
$\log(Intial_{i}^{PC})$	8.4212	0.7677
$\log(Savings_{it}^{Ratio})$	-2.4117	0.0000
$\log(Pop_{it}^{Gr})$	-7.5824	0.0000
$\log(Trade_{it}^{Ratio})$	-91.5996	0.0000
$\log(LifeExp_{it})$	216.1546	0.1329
$\log(Industry_{it}^{Ratio})$	51.3275	0.0005
$\log(Energy_{it}^{PC})$	-171.6387	0.0000
$\log(FDI_{it}^{Ratio})$	-4.8554	0.0000
CO_2 Emission	-159.8203	0.0000
*CO_2 * Energy Consumption*	30.0225	0.0000
Source: Authors' Calculations		

Panel ARDL Results

The panel ARDL is the appropriate mode for studying long term and short term relationship between variables when some variables are I(0) and some are I(1). The Table 13 shows long term cointegrating coefficients along with short term ECM(Error Correction Model) coefficients. The results show that:

- In case of developing countries, the long term results show that log of industry/GDP, log of Trade/GDP, log rate of growth of populationand Log of energy consumption per capitahave significant impact on growth per capita. The interactive coefficient of CO_2 emissions and energy consumption per capita is positive but insignificant. The lagged coefficient term in the ECM model is negative and significant implying that the gap between actual and the long run value of dependent variable would be met at the speed of 82.7 %. The coefficient also indicates that there exists long term causality between energy consumption per capita and the explanatory variables.
- In case of developed countries, The panel ardl results below of developed nations indicate that log of industry value added/GDP, log of Trade/GDP(at 10% level of significance), log of life expectancy(negative impact and significant) and log of rate of growth of population(negative) have significant impact on grwoth per capita of developed nations. Log of Energy consumption per capita and log of energy consumption*CO_2 emissions tend to have positive impact on growth per capita, although both variables are insignificant factors.

- In case of transition economies, it seems that there is long run relationship among growth and its explanatory factors. In this formulation the cointeq term in the short run equation shows that the gap between actual and long run equilibrium value of the dependent variable would be met at the speed of 34.8 %. This term is negative implying long run causality between growth and its determinants. The long run equation shows Log of Gross Savings/GDP, log of rate of growth of population, log of Trade/GDP, log of life expectancy, log of energy consumption per capita, and log of FDI/GDP have significant impact on growth per capita. Log of CO_2 emissions(negative but insignificant) and log of CO_2 emissions * energy consumption per capita have positive impact on growth per capita.

Table 13: Results of ARDL

	Developing		**Developed**		**Transition**	
Long-Run Relationships						
Variable	**Coefficient**	**P-Value**	**Coefficient**	**P-Value**	**Coefficient**	**P-Value**
$\log(Industry_{it}^{Ratio})$	2.7897	0.0368	2.2587	0.0032	0.9790	0.6934
$\log(FDI_{it}^{Ratio})$	0.6269	0.7597	-0.0967	0.3768	0.1947	0.0016
$\log(Trade_{it}^{Ratio})$	1.5558	0.0163	0.6830	0.0930	10.4131	0.0000
$\log(LifeExp_{it})$	2.1036	0.6550	-5.3469	0.0000	-4.8066	0.0803
$\log(Pop_{it}^{Gr})$	-2.4344	0.0002	-0.3853	0.0000	0.5580	0.0175
*CO_2 * Energy Consumption*	1.0834	0.2523	0.4746	0.3948	0.7317	0.3656
$\log(Energy_{it}^{PC})$	-5.8810	0.0154	1.1180	0.2455	-2.9944	0.0795
$\log(Savings_{it}^{Ratio})$	0.2867	0.6230	--	--	-0.7274	0.0002
CO2 Emissions	--	--	--	--	-3.7745	0.5566
Error Correction Term						
COINTEQ	-0.8277	0.0000	-0.6248	0.0000	-0.3487	0.0036
Source: Authors' Calculations.						

4.2.4 S-Shaped Relationship between Energy Consumption Per-Capita and Host of Explanatory Variables

Our panel causality results indicate that the relationship may work the other way. Growth per capita and its factors may impact log of energy consumption per capita. We hypothesize that the relationship is S-shaped between energy consumption per capita and growth per capita GDP. The latter would mean that first energy consumption increases at an increasing rate with an increase in growth per capita and then after the point of inflextion is reached, energy consumption increases but at a decreasing rate. The same relation is hypothesized between energy consumption per capita and FDI/GDP, Trade/GDP and CO_2 emissions(in metrics per tonne). Mathematically, to prove for the S-Shape curve, we will assume the following model. Y is energy consumption per capita while X can be either growth per capita, FDI/GDP or CO_2 emissions or Trade/GDP.

$$Y = \exp(b_1 - \frac{b_2}{\mathrm{X}})$$

$$\log(Y) = b_1 - \frac{b_2}{\mathrm{X}}$$

Taking first order derivative, we would get the following

$$\frac{dY}{dX}\frac{1}{Y} = \frac{b_2}{X^2}$$

$$\frac{dY}{dX} = \frac{b_2}{X^2}Y$$

$$\frac{dY}{dX} = \frac{b_2}{X^2}\exp(b_1 - \frac{b_2}{\mathrm{X}})$$

Taking second order derivative, we would get the following:

$$\frac{d^2Y}{dX^2} = \frac{dY}{dX}\frac{b_2}{X^2} - Y\frac{2b_2}{X^3}$$

$$\frac{d^2Y}{dX^2} = \frac{{b_2}^2}{X^4}\exp(b_1 - \frac{b_2}{\mathrm{X}}) \quad - \exp(b_1 - \frac{b_2}{\mathrm{X}})\frac{2b_2}{X^3}$$

$$\frac{d^2Y}{dX^2} = \exp(b_1 - \frac{b_2}{\mathrm{X}})(\frac{{b_2}^2}{X^4} - \frac{2b_2}{X^3})$$

At the point of inflection, second order derivative would be 0, which would give:

$$X = \frac{b_2}{2}$$

Therefore, any value less than $X=b_2/2$ would give positive value for second order derivative , while for any value greater than $X=b_2/2$, second derivative would be negative. This would imply that the curve chnages its curvature from convexity to concavity implying s shaped relationship between energy consumption per capita and host of its explanatory variables. Therefore, it is hypothesized from step 2 of the above equation that log y is hypothesized to have negative relationship with reciprocal of GDP per capita growth, reciprocal of Co2 emissions, reciprocal of Trade/GDP and reciprocal of FDI/GDP. We first present the results for developing economies, then transition and then finally of developed nations.We have panel data set for 18 developing economies and we use data from 1980-2013 on our dependent variable and set of explanatory variables. Panel unit Root tests(Levin,Lin,Chu and Imm Pesaran and Smith) have been applied(not shown) and there is evidence of the unit root problem across the sample of developed, transition and developed nations. It is assumed and tested that there is presence of panel cross sectional contemporaneous correlations which allows us to use Panel SURE model with error following AR(1) structure. We then finally use Panel ARDL model as all variables are of I(0) and I(1) form. However, Panel ARDL results for S-shaped relationship between energy consumption and its determinants are not robust for all three groups-developing economies, transition economies and developed nations. Therefore, we do not show the panel ardl results. The other results are shown in Table 14. The results show that:

- In case of developing countries, The results(panel SURE with AR(1) structure) indicate that S-shaped relationship holds for CO_2 emissions only for developing economies. Energy Consumption per capita have Inverted S-shaped relationship for growth per capita, FDI/GDP and Trade/GDP for set of developing countries considered in our study. If one removes AR(1) assumption, all variables except FDI/GDP, have an S-shaped relation with energy consumption per capita. Growth, Trade and FDI tend to increase energy consumption at an increasing rate after the point of inflection has reached. Policy makers need to address the issue by limiting energy consumption by focusing on promoting usage of renewable energy.
- For developed nations, CO_2 emissions and Trade/GDP have an S-shaped relation with energy consumption per capita. If one removes the AR(1) structure on errors, all the variables have an S-shaped relation with energy consumption per capita.
- For transition economies S-shaped relation with energy consumption per capita holds with CO_2 emissions only. In case assumption of AR(1) structure is removed we find robust S-shape relation with growth per capita and CO_2 emissions.

Table 14: Results for Looking S-Shaped Relationship			
Dependent Variable: Energy Consumption Per Capita			
Variable	**Developing**	**Developed**	**Transition**

Model	Coefficient	P-Value	Coefficient	P-Value	Coefficient	P-Value
Constant	47.4158	0.8438	9.3047	0.0000	6.7227	0.0000
1/GDP Growth Per Capita	0.0002	0.2826	0.0001	0.0313	0.0003	0.8321
1/FDI to GDP Ratio	2.47E-05	0.0216	5.16E-06	0.2724	-5.13E-16	0.3771
1/Trade to GDP Ratio	0.4415	0.0244	-1.2369	0.0013	-0.2037	0.0000
1/CO_2 Emissions	-0.0258	0.0000	-3.8346	0.0000	0.0005	0.0895
AR(1)	0.9996	0.0000	0.9881	0.0000	0.9695	0.0000
Source: Authors' Calculations.						

All the results(based on panel sure and AR(1) error structure) indicate in common that with high co2 emissions, it seems that there are concerted attempts made by national governments across the countries and regional groups to develop technologies which can limit or reduce the rate at which energy consumption grows in nation states. Panel ARDL results do not show any robust s shape relationship between energy consumption per capita and its determinants**.**

5. Conclusions

The present study is an attempt to evaluate the impact of energy consumption on economic growth and economic growth on energy consumption for a set of developing, transition and developed countries in the world. For this purpose, sample of 18 developing,18 developed and 16 transition countries have been considered to analyze the relationship between variables. To pursue this, the study reports two types of results: one set of results consists of the study of relationship between energy consumption per capita and rate of growth of GDP per capita over the years; among others and in other set of results, S-shaped relationship between energy consumption per capita and its determinants are examined for the set of developing, developed and transition economies. The variables for growth regression are justified on the basis of variant of Solow growth model as explained in the section 2.

Both the variables GDP per capita and energy consumption have unit root at level and are stationary at first difference i.e. are I(1) for developing as well as developed countries panel (which may have panel unit roots implying that despite all variables being I(1), one may not have cointegration among variables in the developed nations). Energy consumption and GDP per capita have a long term relationship in case of developing countries but no cointegrating relationship in case of developed countries. However, as soon as we bring in some control factors impacting growth, energy consumption has positive, significant and long term impact on GDP per capita growth rates of developed nations but negative and significant long term impact on growth per capita of developing countries.The developing countries, although trying to put efforts in increasing expenditures in alternative energy sources (like non-renewable) oil consumption still does not seem have many alternative sources of energy. Therefore, reducing oil expenditure tends to promote growth among developing countries. Conspicuous consumption of oil in cities (through purchase of multiple numbers of cars in one household) may also hinder growth of GDP per capita, atleast in Indian cities. Energy efficiency tend to have positive but insignificant impact on growth of GDP per capita for developed countries but significant impact on growth of GDP per capita for developing countries. Panel ARDL results for studying Cointegrating Relationship between growth and with CO_2 emissions and interactive term,among other variables show that with higher CO_2 emissions, the rate at which energy consumption grows declines which in turn promote growth across nations. The study strongly indicates that CO_2 emissions promotes technology for reducing energy consumption per capita by developing environmentally friendly products which are renewable energy intensive products.

Further, panel VEC model in developing countries suggests that there is no short run causality from per capita energy consumption to GDP per capita (with two variables only). Causality from per capita GDP to energy consumption per capita is present in some of the countries in short run as well as in long run. One possible reason for this result is that since the countries are at different stage of development, some may be in secondary sector (manufacturing), some in tertiary sector (services), they require different amount of energy in their development process and hence growth doesnot really drive energy demand in all the developing countries. Various phases of production and economic activities call for different relations between per capita GDP and energy consumption. It may also be noticed that the relation in question may not be a linear one - the initial phase of a developing country may reflect an increasing relation between energy consumption and per capita GDP (since economic activities are at large and use of consumer durables, particularly cooling machines, is on the rise) but later, as pollution accumulates due to use of non-sophisticated technology, more efficient use of energy and investment of the country in pollution abatement technology leads to energy conservation. Same amount of energy may now produce more output leading to a falling apart of the relation seen in the previous phase.

Moreover, Panel VAR model(based on two variables only) in developed countries suggests that there is homogeneous non-causality in both the directions. This can be supported by the argument that, since developed countries outsource their energy(involve themselves in energy saving policies)to developing countries to meet their requirement of reduction in carbon emission, their GDP increases but energy consumption doesnot. Energy consumption expenditures, promotes growth in developed nations if we bring in all factors impacting growth. It maybe due to the fact that consumption expenditures on oil when implemented with other policies enhances adoption of technologies in increasing renewable resources and is growth enhancing for developed nations.The S-shape regression exercise shows in common that with high CO_2 emissions, it seems that there are concerted attempts made by national governments across the countries and regional groups to develop technologies which can limit or reduce the rate at which energy consumption grows in nation states.

There exists long run relationship among growth and its explanatory factors for transition economies. In this formulation the cointeq term in the short run equation shows that the gap between actual and long run equilibrium value of the dependent variable would be met at the speed of 34.8 %. This term is negative implying long run causality between growth and its determinants. The long run equation shows Log of Gross Savings/GDP(negative impact), log of rate of growth of population(positive impact), log of Trade/GDP(positive impact), log of life expectancy(negative impact), log of energy consumption per capita(negative impact), and log of FDI/GDP(positive impact) have significant impact on growth per capita. log of CO2 emissions(negative but insignificant) and log of (Co2 emissions* energy consumption per capita) have positive impact on growth per capita.

Policy Implications

A definitive policy suggestion cannot be derivedon the basis of empirical results based on two variables because such a decision requires a holistic setting. However, these initial results(based on two variables) give a direction in which more work could be done to determine the nature of causality in each country group. Because of this reason, we end up doing panel ARDL and SURE to establish long-run and short-run relationships between per capita energy consumption, energy efficiency, among other factors affecting growth of per capita GDP. The policy makers of different economies may find it useful to make use of a more widespread array of variables in determining growth-energy consumption relation, as suggested in this study. Policy decisions resting on stand-alone (2-variable) analysis may often be misguiding. Correlations between growth per capita GDP and log of energy consumption across nation groups is negative, while it is positive between GDP per capita and log of energy consumption per capita. This is the only solace coming out of the two variable exercise, besides giving us clue in understanding the direction of causality, which the results show that they run two way(bidirectional causality) for developing and transition economies and only one way for developed nations(from growth to energy consumption per capita), all based on assumption of homogeneous and heterogeneous panels.Correlations between growth per capita GDP and log of energy consumption across nation groups is negative, while it is positive between GDP per capita and log of energy consumption per capita(negative for developed nations).Growth, Energy Conservation (with limited policy intervention) and Feedback hypotheses tend to work for developed and developing countries.

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Appendix Table

Table A1: List of Sampled Countries for the Empirical Analysis

Developing Countries		**Developed Countries**		**Transition Economies**	
Bangladesh	Nigeria	Australia	Japan	Albania	Montenegro
Chile	Pakistan	Austria	Netherland	Armenia	Russian Federation
Colombia	Peru	Belgium	New Zealand	Azerbaijan	Serbia
Ghana	Philippines	Canada	Norway	Belarus	Tajikstan
Hungary	Saudi Arabia	Finland	Spain	Bosnia Herzegovina	Turkmenistan
India	Singapore	France	Sweden	Croatia	Ukraine
Indonesia	Sri Lanka	Hong Kong	Switzerland	Georgia	Uzbekistan
Kenya	Thailand	Ireland	UK	Kazakhstan	
Malaysia	Venezuela	Italy	USA	Kyrgyz Republic	

Source: Authors' Elaboration.