Energy consumption, carbon emissions and economic growth in India

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Abstract

Purpose – The purpose of this paper is to empirically examine the long run and causal relationship between energy consumption, carbon emissions and economic growth in India over the period 1971-2009 within multivariate framework.

Design/methodology/approach – The study uses the Johansen cointegration test to examine the possible long-run equilibrium relationship followed by Granger causality test based on vector error correction model to explore short- and long-run causality between energy consumption, carbon emissions and economic growth in India.

Findings – Cointegration result indicates the long-run equilibrium relationship between economic growth, energy consumption and carbon emissions. Further causality results suggest unidirectional causality running from energy consumption and carbon emissions to economic growth in long run, energy consumption to carbon emissions, carbon emissions to economic growth and economic growth to energy consumption in short run.

Practical implications – There is urgent need of policy development toward boosting energy efficiency, developing alternative carbon-free energy sources like nuclear, renewables and expansion of affordable energy for faster, sustainable and more inclusive growth for India in upcoming years.

Originality/value – India, an energy-dependent economy needs to effectively implement energy efficiency measures, super critical technologies in power plants, and investment in renewable energy resources in order to minimize the dependence on fossil fuels and carbon emissions for faster, more inclusive and sustainable growth.

Keywords Development, Climate change, Sustainable environment

Paper type Research paper

1. Introduction

Greenhouse gas (GHG) emissions especially carbon dioxide emissions through the combustion of fossils fuels, is a major cause of global warming, imposing serious threat to the environment and human life. Acting on this concern, international communities through Kyoto Protocol in 1997 call for reduction of GHG emissions in 37 industrialized countries and European community to 5.20 percent lower than 1990 level during 2008-2012. However, Kyoto Protocol does require monitoring and reporting GHG emissions without reducing GHG emissions for developing economies including India and further notified by Doha conference 2012. The issues of climate change is very critical for developing economies like India which uses mainly fossils fuels[1] (nearly 89.80 percent of gross energy consumption) to meet its energy demand. About 400 million people (almost 34.50 percent of population) do not have access of electricity and 836 million people (almost 72 percent of population) depend upon traditional biomass for cooking (International Energy Agency, 2012) in India. India's per capita energy consumption (585 kilograms of oil equivalent) is still less than one third of world's average (1,802 kilograms of oil equivalent per capita in year 2010). Thus India's energy consumption[2] is expected to increase steadily in the coming years to meet the

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requirement of economic growth and different development objectives resulting in to more carbon emissions also causing global warming. On the other hand, reducing energy consumption and carbon emission control obligations directly may hamper its growth momentum. Therefore, examining the linkage between energy consumption, carbon emissions and economic growth will help the countries in optimal inclusive green growth policy formation for minimize the impact of global warming.

The causal relationship between economic growth and energy consumption, as well as economic growth and GHG emissions has been extensively examined in three different strands over the last two decades. The first strand mainly concentrates on the nexus between economic growth and environmental carbon emissions by examining the validity of environmental Kuznets curve (EKC). EKC postulates an inverted U-shape relationship between the level of environmental pollution and income per capita. That means environmental pollution levels increases as a country develops but begin to decrease as rising income crosses a threshold. However, empirical results (see, Grossman and Krueger, 1991; Shafik and Bandyopadhyay, 1992; Selden and Song, 1994; Shafik, 1994; Unruh and Moomaw, 1998; Heil and Selden, 1999; Friedl and Getzner, 2003; Dinda and Coondoo, 2006; Managi and Jena, 2008; Coondoo and Dinda, 2008; Romero-Avila, 2008) on EKC hypothesis remain debatable and inconclusive till date.

The second strand mainly focusses on the economic growth and energy consumption nexus. This approach investigates whether economic growth stimulates energy consumption or energy consumption spur economic growth. Since the seminal study of Kraft and Kraft (1978) various studies (see, Masih and Masih, 1998; Asafu-Adjaye, 2000; Stern, 2004; Soytas and Sari, 2003, 2006; Ghali and El Sakka, 2004; Lee, 2005, 2006; Akinlo, 2008; Narayan *et al.*, 2008; Apergis and Payne, 2009, 2012a, b; Wolde-Rufael, 2005, 2009; Ozturk, 2010; Payne, 2010; Tang and Tan, 2013; Apergis and Tang, 2013; Baranzini *et al.*, 2013) have analyzed the causal relationship between energy consumption and economic growth using cointegration and Granger causality. However, results remain controversial due to different time period, countries, variable selections, econometric tools employed and level of economic development.

The third strand combines the first two approaches by examining the relationship between environmental carbon emissions, energy consumption and economic growth simultaneously. Soytas and Sari (2007) examined the existence and direction of Granger causality between energy consumption, output and carbon emissions for USA over a period of 1960-2007 using Toda-Yamamoto (TY) procedure after including labor forces and gross fixed capital formation in to model. They found absence of causality between income – carbon emissions and energy use – income and unidirectional causality running from energy consumption to carbon emissions. Using same variables and econometric approaches, Soytas and Sari (2009) found unidirectional causality running from carbon emissions to energy consumption and no causality between income and carbon emissions in either direction for Turkey over the period of 1960-2001. Zhang and Cheng (2009) investigated the causal relationship between energy consumption, output and carbon emissions with TY procedure for China over the period of 1960-2007. They found unidirectional Granger causality running from energy consumption to carbon emissions, and a unidirectional Granger causality running from GDP to energy consumption. Further they suggested no causality between carbon emissions – economic growth and energy consumption – economic growth in either direction in long run. Ghosh (2010) analyzed the dynamic relationship between carbon emissions, energy consumption and income after incorporating real investment and employment for India over the period 1971-2006 using autoregressive distribution lag model of cointegration and causality. Study confirmed the absence of long-run causality between carbon emissions – national income. However, bidirectional causality between carbon emissions – national income, unidirectional causality from national income to energy supply and energy supply to carbon emissions exists in short run. Pao and Tsai (2010) examined the nexus between carbon emissions, energy consumption and income for BRIC countries using panel cointegration and causality over the period 1971-2005. They found bidirectional causality between energy consumption – carbon emissions and energy consumption – output and unidirectional causality from carbon emissions to output. Pao and Tsai (2011) used a tri-variate vector error correction model (VECM) to find the bidirectional Granger causality between energy consumption, carbon emissions and economic growth for Brazil during 1980-2007. Al-Mulali (2011) investigated the relationship between oil consumption, carbon emissions and economic growth for MENA countries using panel cointegration and Granger causality. Results confirmed the presence of bidirectional causality between oil consumption, carbon emissions and economic growth in both the short run and long run.

This study examines the dynamic relationship between energy consumption, carbon emissions and economic growth for India over the period 1971-2009 using Johansen cointegration and Granger causality based on VECM. The choice of India is motivated by the three reasons. First, India is fifth largest consumer of energy after USA, China, Russia and Japan and fourth largest carbon dioxide emitter after USA, China and Russia, though per capita energy consumption and carbon dioxide emission is much below the World's average. Second, recent estimates from Planning Commission indicate that India's energy need is expected to grow by 5.70 and 5.40 percent per annum during 12th and 13th Five-Year Plans, respectively. Current energy import[3] of India is more one third of gross demand and expected to grow further by 6.5 percent per annum, putting serious implication for its energy security to achieve faster, more inclusive and sustainable growth. Third, we prefer country-specific study against a cross-country study because empirical results fails to capture country – specific economic complexities due to difference in geography, culture, market structure and resource – availability. Thus, country-specific analysis provides better insights for policy formulation on specific issues.

The remainder of the paper proceeds as follows. Section 2 presents data and econometric methodology used in the study. Section 3 provides the empirical findings. Section 4 concludes the study.

2. Data and econometric methodology

For the empirical analysis, current study uses annual time series data for India over the period 1971-2009 obtained from World Development Indicators – 2013 published by World Bank. Our study uses total primary energy consumption (kilotons of oil equivalent), real gross domestic product (constant US$2,000) and total carbon dioxide emissions (in kilotons) as a proxy for energy consumption, economic growth and carbon emissions, respectively, based up on the common practices in the literature. Following Soytas *et al.* (2007), study uses total data rather than per capita data as dividing the variables by population will only scale down the variables. Further, as the Kyoto Protocol calls for a reduction in the percentage of emissions, Friedl and Getzner (2003) suggested the use of total emission instead of per capita emissions. The data were converted in to natural logarithmic form so that their first differences approximate their growth rates. Figure 1 shows the data trend of each series for India during 1971-2009.

To examine the causal relationship between the energy consumption, carbon emissions and economic growth, the following function is employed:

$$\mathrm{GDP} = f(\mathrm{EC}, \mathrm{CO_2}) \tag{1}$$

where GDP is the logarithmic real gross domestic product, EC is logarithmic total primary energy consumption and CO_2 is logarithmic gross carbon dioxide (CO_2) emissions.

A three stage econometric procedure is adopted to test the direction of causality. In the first stage, we investigated the order of integration of the natural logarithm of the variables under consideration using the Augmented Dickey Fuller (ADF) and Phillip-Perron (PP) unit root test. For the time series x_t, ADF and PP relationship is expressed as:

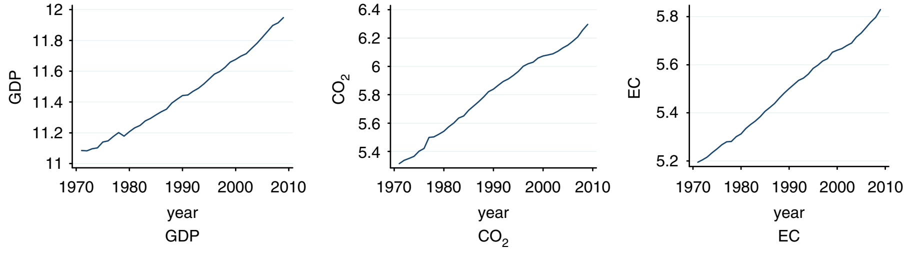
$$\Delta x_t = \alpha_1 + \alpha_2 t + \alpha_3 x_{t-1} + \sum_{i=1}^{p} \beta_i \Delta x_{t-i} + \varepsilon_t \tag{2}$$

where Δ and p is the difference operator and auto-regressive lag length, respectively. When the series at level are found to be non-stationary, we take first difference and apply the ADF test again on the differenced data and so on. Null hypothesis for the ADF and PP test is the presence of unit root (*H0*: $\alpha_3 = 0$) in the series against the alternative of stationary (*H1*: $\alpha_3 \neq 0$).

In the second stage, to examine the long-run relationship among the integrated variables of same orders, we employ maximum likelihood method developed by Johansen (1988, 1991) and Johansen and Juselius (1990). Absence of cointegration means that no long-run equilibrium relationship and in principle, they can wander arbitrarily far away from each other (Dickey *et al.*, 1991). The hypothesis that tests this is the null of non-cointegration against an alternative that cointegration exists. Johansen cointegration test consists of two test statistics, namely trace statistics and the maximum eigenvalue statistics:

$$\lambda_{\mathrm{trace}} = -T \sum_{i=r+1}^{n} \mathrm{Log}\left(1 - \lambda_i^*\right) \tag{3}$$

$$\lambda_{\max} = -T\,\mathrm{Log}\left(1 - \lambda_{r+1}^*\right) \tag{4}$$



Source: World Development Indicators (2013)

Figure 1. Data trends for selected variables

where λ^*_{r+1}, λ^*_n are (*n*-*r*) smallest estimated eigenvalues. T is the maximum time in the time series *t*. If cointegration is present, then the third step is to examine causality by using the appropriate types of causality tests. According to Engle and Granger (1987), cointegrated variables must have an error correction representation in which an error correction term (ECT) must be incorporated in to model. Accordingly, a VECM is formulated to reintroduce the information lost in the differencing process:

$$\Delta GDP_t = \mu_1 + \alpha_{11} ECT_{t-1} + \sum_{j=1}^{P-1} \phi_{1j} \Delta GDP_{t-j} + \sum_{j=1}^{p-1} \theta_{1j} \Delta CO_{2t-j} + \sum_{j=1}^{p-1} \psi_{1j} \Delta EC_{t-j} + \varepsilon_{1t} \tag{5}$$

$$\Delta CO_{2t} = \mu_2 + \alpha_{21} ECT_{t-1} + \sum_{j=1}^{P-1} \phi_{2j} \Delta GDP_{t-j} + \sum_{j=1}^{p-1} \theta_{2j} \Delta CO_{2t-j} + \sum_{j=1}^{p-1} \psi_{2j} \Delta EC_{t-j} + \varepsilon_{2t} \tag{6}$$

$$\Delta EC_t = \mu_3 + \alpha_{31} ECT_{t-1} + \sum_{j=1}^{P-1} \phi_{3j} \Delta GDP_{t-j} + \sum_{j=1}^{p-1} \theta_{3j} \Delta CO_{2t-j} + \sum_{j=1}^{p-1} \psi_{3j} \Delta E_{t-j} + \varepsilon_{3t} \tag{7}$$

where ECT is error correction term – the estimated residual from the cointegration regression. A significant coefficient means that past equilibrium errors play a role in determining the current outcomes. The short-run dynamics are captured through the individual coefficients of the difference terms.

3. Empirical findings

The empirical analysis begins with checking stationarity of the time series variables as a prerequisite for cointegration and causality test. The optimal lag length selection for the unit root tests are restricted to three for the sample size of 39 using a $T^{1/3}$ formula, as suggested by Lutkepohl (1993). The Table I presents the ADF and PP unit root results. Results clearly indicate that no time series variables appear to be stationary at levels, since computed test statistics could not reject the null hypothesis of non-stationarity. But they become stationary after taking the first difference. Hence we conclude that series are integrated of order one, i.e. *I*(1) at the 1 percent level of significance.

Since all the variables GDP, EC and CO_2 are integrated of order one, we proceed to examine the presence of long-run cointegrating relationship among the variables. Since the Johansen cointegration tests are sensitive to the choice of lag length, we use

Table I. Unit root tests results (order of integration)

Variables	Augmented Dickey Fuller test Level	First difference	Phillip-Perron test Level	First difference	Inference
GDP	−1.6445	−7.6842*	−1.5360	−8.1264*	I(1)
EC	−1.6331	−5.3446*	−1.9314	−5.4362*	I(1)
CO_2	−1.6750	−6.147*	−1.7722	−6.1518*	I(1)

Notes: Lag length selection using Schwartz information criterion (SIC) in case of ADF while bandwidth for PP test by using the Newly-West Bartlett Kernel. *Statistically significant at 1 percent level
Source: Author's estimation

the Schwartz information criterion (SIC) to determine the optimal lag lengths. Table II shows the results of trace statistics and maximum eigenvalue statistics, which clearly indicates the presence of cointegrating relationship at 5 percent level of significance. Hence we conclude that there is a long-run equilibrium relationship between energy consumption, carbon emissions and economic growth for India.

Since the variables are integrated of order one and cointegrated, then causal relationship may exist between them in at least one direction (Engle and Granger, 1987). To test the direction of causality, the VECM is used. In Table III, we present the results of causality based on VECM. Beginning with long-run causality results, the statistical significance of the lagged ECT in ΔGDP equation indicates that there is unidirectional Granger causality from energy consumption and carbon emissions to

Table II. Johansen cointegration tests results (eigenvalue and trace test statistics)

Variables	Null hypothesis	Eigenvalue	Trace statistics	5% critical values	Maximum eigenvalue	5% critical values
EC, CO_2, GDP	$H0$: $r = 0$	0.6181	46.684**	42.915	35.625**	25.8232
	$H0$: $r \leqslant 1$	0.2062	11.059	25.872	8.5482	19.38
	$H0$: $r \leqslant 2$	0.0656	2.5108	12.517	2.5108	12.517

Notes: r is the number of cointegrating relations. Optimal lag length selection using Schwartz information criterion (SIC). **Statistically significant at 5 percent level
Source: Author's estimation

Table III. Selected results of Granger causality tests based on VECM

Dependent variables	Short run ΔGDP	ΔEC	ΔCO_2	Long run ECT
ΔGDP	–	0.0014	3.6816**	−0.3409**
ΔEC	3.082***	–	1.5475	−0.0873
ΔCO_2	0.1728	5.1617**	–	−0.009

Notes: **,***Statistically significant at 5 and 10 percent levels, respectively
Source: Author's estimation

real GDP. The presence of unidirectional causality running from energy consumption to economic growth, i.e. growth hypothesis in long run indicates that India is an energy dependent economy for its growth and any reduction in energy supply for economic activities may lead to adverse impact on economic growth. It implies that carbon emissions Granger cause real GDP, implying that any effort to reduce CO_2 emission may lead to fall in GDP. Therefore, there is urgent need to implement the energy efficiency related measures for minimum energy losses and policy reforms for higher investment in carbon-free energy resources (e.g. nuclear and renewable energy sectors) in order to further minimize CO_2 emission.

Now coming to the short-run causality results, carbon emissions is found to be statistically significant at 5 percent level in real GDP equation suggesting that it is not possible to reduce carbon emissions without sacrificing economic growth as reduction in carbon emissions can impact negatively in short run also. Similarly, energy consumption is statistically significant at 5 percent critical level in carbon emissions equation means there is unidirectional causality from energy consumption to carbon emissions in short run. It indicates India's high dependence upon carbon fuels like coal, oil and natural gases to meet its energy needs in the end use sectors like industry, transport, commercial, households and agriculture (almost 89.80 percent of total primary energy supply). These fuels have high carbon emission coefficients, which further pushes up the carbon emission. This implies that reducing dependence on fossils energy by enhancing renewable and nuclear energy without reducing energy consumption may be viable option for India to reduce carbon dioxide emissions. Real GDP is found to be statistically significant at 10 percent level in energy consumption equation indicating the presence of unidirectional causality from real GDP to energy consumption in short run. This implies that energy conservation policies should be implemented without compromising socio-economic developments (as short-run shocks are absorbed in long-run) in short run.

4. Conclusion

In this paper, we examine the long-run and causal relationship between energy consumption, carbon emissions and economic growth within multivariate framework using Johansen cointegration, and Granger causality based on vector error correction method in India during the period 1971-2009. Our analysis reveals the presence of long-term relationship among the variables indicating that carbon emissions and energy consumption are positively correlated to economic growth in long run. The empirical findings of unidirectional causality from real GDP to energy consumption, energy consumption to carbon emissions and carbon emissions to real GDP in short-run and unidirectional causality from carbon emissions and energy consumption to real GDP in long run suggest that India should implement energy efficiency and conservation policies, decreasing reliance on fossils fuels especially coal by promoting cleaner and carbon-free energy (wind, solar, biomass, hydro and nuclear) without reducing the energy consumption.

Notes

1. Coal, oil and natural gas contribute 52.28, 31.75 and 8.07 percent, respectively, of total primary energy consumption in year 2009-2010 (Energy-2011, CMIE).
2. According to the Report of Expert Committee on Integrated Energy Policy (Planning Commission, 2006), India needs to increase the energy supply by almost three to four times by the year 2032-2033 with respect to year 2003-2004 levels to maintain 8 percent growth rate.

3. 36.53 percent in 2010-2011 and expected to reach 37.95 percent in 2016-2017 (source: Approach paper, 12th Five Year Plan, Planning Commission, 2011). Oil, natural gas and LNG, and coal imports constitute 76.4, 19 and 19.8 percent, respectively, of gross demand for year 2010-2011.

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