CAUSALITY AMONG CARBON EMISSIONS, ENERGY CONSUMPTION AND GROWTH IN INDIA

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Abstract

This study attempts to investigate the long-run Granger causality relationship between energy consumption, carbon dioxide emission and economic growth in India over the period 1971-2007. The augmented Dickey–Fuller test (ADF), Phillips-Perron test (PP) and KPSS test are used to test for Granger causality in cointegration models which take account of the stochastic properties of the variables. The most important result is that there is feedback causal relationship between energy consumption and economic growth in India which implies that the level of economic activity and energy consumption mutually influence each other; a high level of economic growth leads to a high level of energy consumption and vice versa. The value of the error correction term confirms the expected convergence process in the long-run for carbon emissions and growth in India which

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implies that emission reduction policies will hurt economic growth in India if there are no supplementary policies which seek to modify this causal relationship.

1 INTRODUCTION

With rapid industrialization, increased population and significant change in life style, the threat of global warming and climate change is increasing for the last two decades. Carbon dioxide (C02) emission is considered as the main cause to the Green House Gases (GHGs). It is responsible at least 60% to the cause of global warming. Since 1990, the link between emission and economic growth has been studied extensively as global warming is raising the concern of environmental quality. In order to reduce the emission of GHGs, there have been several international attempts, of which the Kyoto protocol agreement, signed in 1997 is the most notable one. The Kyoto Protocol is a protocol to the United Nations Framework Convention on Climate Change (UNFCCC) and the key feature of the Kyoto protocol is to reduce the collective emission of GHGs of 39 industrialized countries and the European Union by 5.2% from 1990 level during the period of 2008-2012. As of 2010, 191 countries have signed and ratified the protocol with a view to reduce global emission level.

However, with the pace of development, as suggested by the Environmental Kuznets Curve (EKC) hypothesis, the level of carbon emission is expected to rise for many of the economies, contributing further to global warming. The validity of the EKC, on the other hand is itself a debatable issue and depending on the level of development, countries might differ significantly in terms of their growth-pollution nexus. This linkage of emission and growth is also closely related to the relationship between energy consumption and carbon emission as combating energy use will, on one hand reduce the level of emission and on the other might affect economic growth in a negative manner. In addition, depending on several other factors, e.g. the composition of growth, type of economic activities, intensity of foreign trade etc. this growth-emission-energy consumption nexus is likely to be altered.

In the backdrop of climate change, India has been quite at the focus, since its average annual growth at around 7% for the last ten years has cost the climate substantially, especially through the emissions of carbon dioxide (CO2). India, being a signatory of UNFCC does not have the responsibility to reduce emissions below the current level; however it is committed to slow down the emissions growth. The choice of India, in this paper, is motivated due to the fact that India is the fifth largest consumer of energy after USA, China, Russia and Japan and the fourth largest emitter of CO2 after USA, China and Russia.

Being a key tourist location of Asia and a highly commercialized country, India's demand for energy is also increasing at a tremendously high speed. All such commercial and industrial activities have posed the environment of the country under risk. In addition, Indian economy has historically been integrated to the outside world with labor migration, tourism and export of goods and services, all such activities are expected to contribute significantly to not only high economic growth but also increased energy demand and carbon emission. Especially, India's growth agenda needs that primary energy supply to be increased by at least 3 to 4 times by 2031 with respect to 2003 as the base year, where coal will be the dominant source of energy due to its affordability and availability. But coal is labeled as dirty fuel, owing to its highest CO2 emission coefficient (IEP-India, 2008). Therefore, India faces a challenge to balance between her need for growth and environmental commitment.

India has experienced a significant rise in energy consumption and carbon emissions in recent decades; it is an emerging economy and one of the important countries which has a high carbon emission in the world. The highest direct emissions are due to electricity sector followed by manufacturing, steel and road transportation. Given its ever increasing trend of economic activities and industrialization, coupled with its intensive integration to the global economy, analysis of such inter-linkages of India is expected to offer important implications for not India economy but also for other developing economies with high global integration and rapid industrialization.

Recently, Parikh et. al (2009) investigate the carbon dioxide (CO2) emissions of the Indian economy based on an Input–Output (IO) table and Social Accounting Matrix (SAM) for the year 2003–04 that distinguishes 25 sectors and 10 household classes. Total emissions of the Indian economy are estimated to be 1217 million tons (MT) of CO2, of which 57% is due to the use of coal and lignite. The per capita emissions turn out to be about 1.14 tons. Balachandra et al. (2010) investigate that India has made substantial progress in improving energy efficiency which is evident from the reductions achieved in energy intensities of GDP to the tune of 88% during 1980–2007. Mallah and Bansal (2010) found that exploitation of energy conservation potential and an aggressive implementation of renewable energy technologies lead to sustainable development. Coal and other fossil fuel (gas and oil) allocations stagnated after the year 2015 and remain constant up to 2040. After the year 2040, the requirement for coal and gas goes down and carbon emissions decrease steeply. By the year 2045, 25% electrical energy can be supplied by renewable energy and the CO2 emissions can be reduced by 72% as compared to the base case scenario. However, literatures do not strongly supported time series analysis on India to reveal the relationship between emission, energy consumption and growth.

This paper is an attempt to fill up that research gap. In this paper, we have attempted to examine the long run and causal relationship between economic growth, energy consumption, square of per capita income, trade openness and carbon emissions in India taking 36 years of data, from 1971 to 2007.

The rest of paper is as follows: In section metricconverterProductID2, a2, a brief review of the recent literature is provided whereas section 3 describes the data and outlines the methodology of the analysis. In section 4, econometric analysis is described and finally section 5 concludes the paper.

2 LITERATURE REVIEW

There has been basically three research strands in empirical literature to examine the relationship between economic growth, energy consumption and environmental quality (of which CO2 emission is an important variable). The first strand focuses on the environmental pollutants and economic growth nexus. The literature on environmental quality and economic growth study mainly focuses on the testing of the existence of environmental Kuznet's curve (EKC). The pioneering work of Kuznet (1955) which claimed for an inverted U-shaped relationship between economic growth and income inequality has been later reformulated to test similar inverted U relationship between economic growth/income and environmental quality. In this context, Grossman and Krueger (1991), Shafiq (1994), Heil and Selden (1999), Friedl and Getzner (2003), Dinda and Coondoo (2006), Ang (2007), Acaravci and Ozturk (2010), Pao and Tsai (2011) among others attempted to test the existence of EKC for different economies. The results of such research are however contradictory and in many cases researchers failed to establish the inverted U-shaped relationship with real life data.

A second strands looks at the link between energy consumption and output, suggesting that energy consumption and output may be jointly determined and the direction of causality between these two variables needs to be tested. Following the seminal work of Kraft and Kraft (1978), several others including Masih and Masih (1996), Yang (2000), Wolde-Rufael (2006), Narayan and Singh (2007), Narayan et al. (2008), Apergis and Payne (2009), Ozturk et al., (2010), Lau et al. (2011) tested the energy consumption and economic growth nexus with a variety of techniques and for different panel of countries. Ozturk (2010) provides a detailed literature survey on the empirical studies of energy-GDP nexus.

Finally, a third stream of research has emerged, which combines earlier two approaches by examining dynamic relationship between carbon emissions, energy consumption and economic growth. Some of the recent studies using this approach are as follows: Soytas et al. (2007), Akbostanci et al. (2009), Soytas and Sari (2009), Zhang and Cheng (2009), Jalil and Mahmud (2009), Ozturk and Acaravci (2010), Apergis and Payne (2010), Acaravci and Ozturk (2010), Pao and Tsai (2011), and Alam et al. (2011). The recent study of Alam et al. (2011) examined the causal relationships among energy consumption, carbon dioxide emissions and income in India using a multivariate framework of Toda and Yamamoto for the 1971-2006 period. Their results provide evidence of the existence of bidirectional (feedback) Granger causality between energy consumption and CO2 emissions in the long-run but neither CO2 emissions nor energy consumption causes movements in real income. In addition, there is no long-run causality relationship between income and CO2 emissions but in the short-run causality exists in India.

In addition, researchers have looked not only at output/income or economic development variables but also extended their analysis to include other aspects such as financial development or trade openness or trade intensity of a country. The branch of literature which emphasizes the relationship between carbon emission and foreign trade considers the fact that the developed economies would specialize in human or physical capital intensive activities which are less emission intensive than those activities pursued in developing countries. Trade therefore may result in increased pollution in developing countries due to the increased production of these emission intensive goods in these countries. The study of Grossman and Krueger (1991) is pioneering in this regard while similar research question has also been addressed by Lucas et al. (1992), Wyckoff and Roop (1994), Suri and Chapman (1998), Anderson et al. (2010), etc. The results of these studies in terms of the relationship between trade and environmental quality is however inconclusive.

3 DATA AND METHODOLOGY

This study utilizes annual data on CO2 emissions (C) (metric tons per capita) per capita, energy use (E) (kg of oil equivalent) per capita, real GDP (Y) (both in constant 2000 US$) per capita and openness ratio (T) which is used as a proxy for Foreign trade for India. We collect the data on India's CO2 emissions (C) per capita, energy use (E) per capita, real GDP (Y) per capita from the World Development Indicators (WDI) published by the World Bank. Although the output and CO2 emissions series commences in 1960, the energy use series begins in1971 in the WDI. Thus, the year of 1971 is defined as the starting point. The analysis is confined to the period 1971-2007 due to data availability. Thus, we get 36 observations on each series ranging from 1971 to 2007 – the longest possible joint dataset on India's CO2 emission, energy and GDP. All the data used in the study are in logarithmic form. This transformation can reduce the problem of heteroskedasticity as log transformation compresses the scale in which the variables are measured (Gujrati, 1995).

The relationship between carbon emission, energy consumption, national income, square of per capita real income and trade openness of a nation can be expressed in the following basic multivariate model:

$$C_t = \alpha + \beta_1 E_t + \beta_2 Y_t + \beta_3 Y^2{}_t + \beta_4 T_t + \varepsilon_t \tag{1}$$

where, $\varepsilon_t$is white noise. Logarithmic transformation of the above equation and inclusion of a trend variable would leave the basic equation as follows:

$$LC_t = \alpha_0 + \alpha_t + \beta_1 LE_t + \beta_2 LY_t + \beta_3 LY^2{}_t + \beta_4 LT_t + \varepsilon_t \tag{2}$$

where, t is the trend variable, LC: Log of Carbon Emission; LE: Log of Energy Consumption; LY: Log of Real GDP per capita; LY^2 is square of per capita real income, and LT: Log of Trade Openness ratio as proxy for foreign trade.

Generally, it is expected that the higher level of energy consumption should result in greater economic activity and stimulate CO2 emissions; therefore, it is expected that β_1 is greater than metricconverterProductID0 in0 in Eq. (2). Under the EKC hypothesis, the sign of β_2 is expected to be positive where as a negative sign is expected forβ_3. The expected sign of β_4 is mixed depending on stage of economic development of a country. This may be negative in the case of developed countries, as it may reduce the production of pollution intensive goods and instead import these from other countries with less restrictive environmental protection laws. On the other hand, the sign of β_4 may be positive in the case of developing countries as they tend to have dirty industries with heavy share of pollutants (Grossman and Krueger,1995).

The main significance of this paper from the research work conduct by Stern (2004) and Perman and Stern (2003). Stern (2004) points out that the empirical evidence in support of the stocktickerEKC is weak. In addition, our work suggests that several of the studies (see, interalia, Perman and Stern, 2003; Canas et al., 2003; Dinda et al., 2000; Galeotti et al., 2006) that model emissions as a function of income augmented by income-squared and income-cubed and trade openness type variables suffer from an additional problem—that of multicollinearity. We confirm this by undertaking a test for collinearity between income and income-squared and income-and Trade openness for our time series dataset from 1971-metricconverterProductID2007 in2007 in India. In this paper, we found that income-squared and trade openness variables suffer from multicollinearity problem that is why this study does not consider these two variables in the model for India. Therefore, the paper is constructed on carbon emission, energy consumption and growth in India.

$$C_t = \alpha + \beta_1 E_t + \beta_2 Y_t + \varepsilon_t \tag{3}$$

where, $\varepsilon_t$is white noise. Logarithmic transformation of the above equation and inclusion of a trend variable would leave the basic equation as follows

$$LC_t = \alpha_0 + \alpha_t + \beta_1 LE_t + \beta_2 LY_t + \varepsilon_t \tag{4}$$

where, t is the trend variable, LC: Log of Carbon Emission; LE: Log of Energy Consumption; LY: Log of Real GDP per capita.

The estimation process would begin with studying the time series properties of the variables and testing the order of integration. In order to establish the line of causality among variables, the famous Granger causality tests would be carried out. The proposed research would estimate the impact of energy consumption, and income on emission using cointegration approach so as to ensure long run relationship between them. In this study, we also estimate model with the system based reduced rank cointegration approach by Johansen and Juselius (1990). While there are several ways to examine interaction between variables, the influential work of Sims (1980) made VAR model and innovation accounting useful in time-series studies. Other works in this line include Blanchard and Quah (1989), Evans (1989), King et al. (1991), Pesaran and Shin (1998). As

Hamilton (1994:291) asserts, impulse response functions and variance decompositions are used to summarize the dynamic relations between variables in a VAR.

The objectives of our empirical estimation are to examine how the variables are related in the long-run and to assess the dynamic causal carbon emission, energy consumption and growth in India. Hence, our methodological approach in this paper includes three steps:

1) We need to check for a unit root in CO2 emissions (C) per capita, energy use (E) per capita, real GDP (Y) per capita in levels. We are using three different types of unit root tests: the augmented Dickey–Fuller (ADF) test (Dickey and Fuller, 1979; 1981), the Phillips– Perron (PP) test (Phillips and Perron, 1988) and the Kwiatkowiski–Phillips–Schmidt–Shin (KPSS) test (Kwiatkowski et al., 1992).

2) If the variables are I(1) then they have a long run relationship. VAR will be inappropriate. Hence, we need to test them for cointegration. If the variables are cointegrated, i.e. C (1, 1), a vector error correction (VEC) model will be used to discover the long run relationship. So, the third step is to test for causality by employing the appropriate types of causality tests.

3) If the cointegration relations between the variables are absent, we can run them in a VAR and there by get variance decompositions and impulse responses.

Figure 1 shows the series in log. A clear upward trend is evident in LC stand for the Log of Carbon Emission; LE stands for the Log of Energy Consumption; LY stand for the Log of Real GDP per capita series. Figure 1 shows the movement of the variables (in logarithmic form) over time

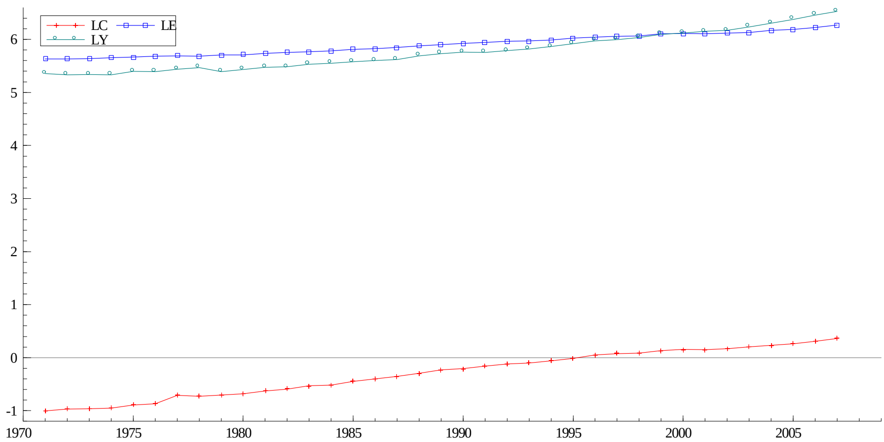

FIGURE 1 - Graphical representation of the data for India

Source: Authors calculation

In order to obtain a better understanding of the behavior of CO2 emissions (C) (kt) per capita, energy use (E) (kt of oil equivalent) per capita and real GDP (Y) (both in constant 2000 US$) per capita for India, a preliminary analysis of the data is first carried out. Table 1 presents summary of the logarithms of the CO2 emissions (LC) per capita, energy use (LE) per capita, real GDP (LY) per capita for India.

TABLE 1- Descriptive statistics

India	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Observations
LC_{IN}	-0.313	-0.263	0.307	-1.002	0.419	-0.174	1.674	36
LE_{IN}	5.892	5.890	6.225	5.630	0.187	0.120	1.645	36
LY_{IN}	5.748	5.711	6.456	5.330	0.334	0.479	2.040	36

Source: Authors calculation

Note: LC: Log of Carbon Emission; LE: Log of Energy Consumption; and

LY: Log of Real GDP per capita, IN=India; and Data Range: India: 1971-2007.

Source: World Development Indicators (WDI-World Bank, 2010)

4 EMPIRICAL RESULTS

4.1 Unit Roots Tests

Table 2 presents the results of the unit root tests based on the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP) and Kwiatkowiski–Phillips–Schmidt–Shin (KPSS) statistics on the natural logarithms of the levels and the first differences of the variables. All tests are providing us with a consistent set of results on unit root tests. For example, while the carbon emission, energy consumption, and output series have unit roots regardless of the tests, the first differences of these series, Δ emission, Δ energy and Δ output respectively, are clearly stationary under both the ADF and PP tests. For KPSS, the null hypothesis is the series is stationary. Thus, KPSS test issued to complement ADF and PP tests in order to have robust results. Hence, the results of unit root tests reveal that carbon emission, energy consumption and output are integrated of order one, I(1), in India. All the I(1) variables can only be regressed on each other if they are cointegrated. Thus, we proceed to testing the variables using the Johansen cointegration approach.

TABLE 2 - Unit root test results

Variables	Augmented Dicky-Fuller (ADF) Tests		Phillips-Perron (PP) Tests		Process	Kwiatkowiski–Phillips–Schmidt–Shin(KPSS)	Process
	Statistics	*P*-values	Statistics	*P*-values		Statistics	
LC_{IN}	-1.754(0)	0.705	-1.754(0)	0.705	I(1)	0.173** (4)	I(0)
LE_{IN}	-2.122(0)	0.5164	-2.122(0)	0.516	I(1)	0.137* (4)	I(0)
LY_{IN}	-0.796(0)	0.956	-0.657(1)	0.968	I(1)	0.719*** (5)	I(0)
ΔLC_{IN}	-7.265*** (0)	0.000	-7.632*** (0)	0.000	I(0)	0.121(8)	I(1)
ΔLE_{IN}	-5.573*** (0)	0.000	-5.569*** (0)	0.000	I(0)	0.085(0)	I(1)
ΔLY_{IN}	-7.181*** (0)	0.000	-7.342*** (3)	0.000	I(0)	0.742(3)	I(1)

Source: Authors calculation

Note: The variables LC stand for the Log of Carbon Emission; LE stand for the Log of Energy consumption; LY stand for the Log of Real GDP per capita; IN stands for the India and Δ *denotes the first difference of the variable. The null hypothesis states that the variable has a unit root.*

, ** and * denotes rejection of the null at 10%, 5% and 1% level of significance.*

Figures in Parentheses ( ) indicate Lag Length.

The critical values and details of the tests are presented in Dicky and Fuller (1979, 1981) and Phillips and Perron (1988). The AIC determines the lag length (P) in the ADF tests (see Stock and Watson, 2007:561 for details), MacKinnon (1996) one-sided p-values in the ADF Tests.

PP test with automatic lag selection based on Newey–West, lags=3.

Critical values for the KPSS test are from Kwiatkowski et al., (1992)

4.2 Cointegration Test

Table 3 presents Johansen cointegration tests with C02, Energy and GDP. The λ_{trace} and λ_{max} statistics are calculated as per Johansen (1995). We have three variables and null hypotheses are thus two in number under each test. The null hypothesis for the trace test is that there are, at most, r cointegrating vectors, while the alternative is that there are more. The test is performed sequentially, beginning with the null hypothesis that there are at most zero cointegrating vectors, and if this null hypothesis is rejected, continuing with the null hypothesis that there is at most one cointegrating vector. For the maximum eigenvalue test, the null hypothesis is that there are exactly r cointegrating vectors, while the alternative is that there are exactly r+1. Again, the test is carried out sequentially, beginning with the null hypothesis that there are no cointegrating vectors. Since the Johansen approach (1995) is sensitive to the lag length used, the optimal lag length of the VAR model was examined by the Akaike Information Criterion (AIC) or the Schwartz Bayesian Criterion (SBC). In this study we use the SBC as a lag selection criterion. Empirically, SBC never selects lag values that are larger than AIC, while AIC selects relatively higher lag values. AIC and SBC are used to determine the appropriate lag length. The order of the distributed lag on the dependent variable and the regressors can be selected using either the AIC or SBC. However, depending on Monte Carlo evidence, Pesaran and Smith (1998) found that SBC is preferable to AIC, as it is a parsimonious model that selects the smallest possible lag length, while AIC selects the maximum relevant lag length

TABLE 3 - Johansen cointegration tests

Cointegration Rank Tests:			λ Statistics	Critical Values	P-values	Cointegrating Equations
λ_{trace} Tests						
	H_0: r =0	H_A: r >0	37.36743*	29.79707	0.0055	1
	H_0: r =1	H_A: r >1	8.148322	15.49471	0.4497	0
	H_0: r =2	H_A: r >2	0.052604	3.841466	0.8186	0
λ_{max} Tests						
	H_0: r =0	H_A: r =1	29.21911*	21.13162	0.0029	1
	H_0: r =1	H_A: r =2	8.095717	14.2646	0.3691	0
	H_0: r =2	H_A: r =3	0.052604	3.841466	0.8186	0

Source: Authors calculation

Note: The trace and max are calculated as per Johansen (1995) Critical Values are calculated for the 5 percent significance level. indicates Trace and states Maximum Eigen value unrestricted co-integration rank Test, P-values are calculated as per Mackinnon et al. (1999). One asterisk (*) denotes significance at 5% level. denotes the number of co-integrating vectors. The trace and max test statstics are computed by allowing for linear deterministic trends in the data. The lag length is determined by the SBC (see Enders 2004:363).

R stands for the rank of the matrix, which denotes the number of the cointegrating equations between the variables.

The corresponding λ-statistics and their critical values are shown in the column. As long as each λ-statistic is below its critical value, we will fail to reject the corresponding null hypothesis of no cointegration. The p-values reported here follow the MacKinnon et al., (1999) procedure. The p-values from the Osterwald-Lenum (1992) procedure are not statistically different from those of the previous procedure, and thereby not reported here to save space. If we fail to reject the first hypothesis of no cointegrating relation, the second null hypothesis automatically becomes redundant. The last column against each null hypothesis in the table gives the number of cointegrating equations. The results of the cointegration tests in Table 3 are consistent, suggesting at least one cointegrating relationships among the variables in the series at 5% level of significance for India.

4.3 Granger Causality

The multivariate Granger proposed by Granger (1969) and popularized by Sims (1972) methodology will be applied to identify direction of causality among the variables of interest, i.e. carbon emission, energy consumption and GDP. The causality test assumes that the time series at hand are mean reverting process. However, it is highly likely that variables of this study are nonstationary. Formal tests will be carried out to find the time series properties of the variables. Engle and Granger (1987) assert that if the series X and Y (for example) are individually I(1) and cointegrated then there would be a causal relationship at least in one direction. However, the direction of causality can be detected through the Vector Error Correction model (VECM) of long-run cointegrating vectors. Granger-causality test is a convenient approach for detecting causal relationship between two or more variables. A time series (X) is said to Granger-cause another time series (Y) if the prediction error of current Y declines by using past values of X in addition to past values of Y. Thus, then augmented with an error correction term (ECT) as shown below:

$$\Delta LC = \delta_0 + \sum_{t=1}^{q} \delta_{1i} \Delta LC_{t-1} + \sum_{t=1}^{q} \delta_{2,i} \Delta LE_{t-1} + \sum_{t=1}^{q} \delta_{3,t} \Delta LY_{t-1} + \delta_4 Z_{t-1} + \upsilon_t \tag{5}$$

$$\Delta LE = \varphi_0 + \sum_{t=1}^{n} \varphi_{1i} \Delta LE_{t-1} + \sum_{t=1}^{n} \varphi_{2i} \Delta LC_{t-1} + \sum_{t=1}^{n} \varphi_{3t} \Delta LE_{t-1} + \varphi_4 Z_{t-1} + \varepsilon_t \tag{6}$$

$$\Delta LY = \beta_0 + \sum_{t=1}^{m} \beta_{1i} \Delta LY_{t-1} + \sum_{t=1}^{m} \beta_{2i} \Delta LC_{t-1} + \sum_{t=1}^{m} \beta_{3t} \Delta LE_{t-1} + \beta_4 Z_{t-1} + \mu_t \tag{7}$$

where Z_{t--1} is the ECT obtained from the long run cointegrating relationship between carbon emission, energy consumption and GDP per capita. The above error correction model (ECM) implies that for each of the model possible sources of causality are two: lagged dynamic regressors and lagged error correction term.

There is casual flow running from energy consumption to carbon emission in India. Since the majority of India's commercial energy comes from coal, the coal has the highest CO2 emission coefficient. There is a feedback causal relationship between energy consumption and economic growth in India which implies that the level of economic activity and energy consumption mutually influence each other; a high level of economic growth leads to a high level of energy consumption and vice versa. Next we estimate the ECM along with the short-run parameters. The sign of the error correction (EC) coefficient must be negative and significant to ensure convergence of the dynamics to the long-run equilibrium. The value of the EC coefficient, which signifies the speed of convergence to the equilibrium process, the most important term in Table 4 is the sign and value of the coefficient on the EC term. The negative sign on the EC term confirms the expected convergence process in the long-run for carbon emissions and growth.

Table 4 - Results of Granger causality tests

India	DLC	DLE	DLY	ECT_{t-1} (t-statistic)
DLC		4.88**	0.007	0.053 [1.518]
DLE	1.742		8.529**	0.009 [0.689]
DLY	0.198	5.114**		-0.125** [-3.964]

Source: Authors calculation

Note: (**) rejects the null at 5% level of significance

5 CONCLUSION AND POLICY IMPLICATIONS

The relationship between carbon emission, energy consumption and economic growth for India, using the Johansen–Juselius maximum likelihood procedure in a multivariate framework during the period of 1971-2007, is investigated. The empirical results give support for unique and robust long term Granger causality between carbon emissions and economic growth for India in the form of an increasing linear relationship between per capita stocktickerGDP and per capita emission. This can be explained as follows. Although India is rich in coal and abundantly endowed with renewable energy resources in the form of solar, wind, hydro and bio-energy, around 53% of India's total energy needs has been met by coal followed by oil (31%) and natural gas (8%), and only 6% from hydro electric power, 1% from nuclear and 1% from renewable energy sources. The majority of India's commercial energy comes from coal (IEP, 2008). Thus, coal has the highest CO2 emission coefficient. There is causal relationship from energy consumption to carbon emission in the case of India. In addition, there is feedback causal relationship between energy consumption and economic growth in India which indicates the level of economic activity and energy consumption mutually influence each other in that a high level of economic growth leads to a high level of energy consumption and vice versa.

To change this unidirectional causal relationship, India must focus attention on the use of clean coal technologies and also try to shift the use of energy from coal to alternative cleaner sources like natural gas, nuclear, renewable and hydrogen energy. Such measures will help to allow India to maintain its future growth aspirations as well as implementing its National Action Plan on Climate Change (NAPCC, 2008). At present, Indian government wants to achieve an 8–10% economic growth rate to eradicate poverty and meet its human development goals. The NAPCC also states categorically that India's per capita greenhouse gas emissions will "at no point exceed that of developed countries".

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6 REFERENCES

Acaravci, A., and Ozturk, I. 2010. On the Relationship between Energy Consumption, CO2 Emissions and Economic Growth in Europe. Energy 35(12): 5412-5420.

Akbostanci, E., Turut-Asik, S., Tunc, G.I. 2009. The relationship between income and environment in Turkey: is there an environmental Kuznets curve? Energy Policy 37(3): 861–867.

Alam, M.J., Begum, I.A., Buysse, J., Rahman, S. and Huylenbroeck, G.V. 2011. Dynamic modeling of causal relationship between energy consumption, CO2 emissions and economic growth in India. Renewable and Sustainable Energy Reviews 15(6): 3243-3251.

Andersen, O., Gossling, S., Simonsen, M., Walnum, H.J., Peeters, P. and Neiberger, C. 2010. CO2 emissions from the transport of China's exported goods. Energy Policy 38(10): 5790-5798.

Ang, J. 2007. CO2 emissions, energy consumption, and output in France. Energy Policy 35: 4772–4778.

Apergis, N., and Payne, J.E. 2009. Energy consumption and economic growth in Central America: evidence from a panel cointegration and error correction model. Energy Economics 31: 211–216.

Apergis, N., and Payne, J.E. 2010. The emissions, energy consumption, and economic growth nexus: Evidence from the commonwealth of independent states. Energy Policy 38(1): 650-655.

Balachandra, P., Ravindranath, D., and Ravindranath, N.H. 2010. Energy efficiency in India: Assessing the policy regimes and their impacts. Energy Policy 38: 6428–6438.

Blanchard, O.J., and Quah, D. 1989. The Dynamic Effects of Aggregate Demand and Supply Disturbances. American Economic Review 79(4): 655-673.
Canas, A., Ferrao, P. And Conceicao, P. metricconverterProductID2003. A2003. A new environmental Kuznets curve? Relationship between direct material input and income per capita: evidence from industrialized countries. Ecological Economics 46: 217–229.
Dickey, D., and Fuller, W.A. 1979. Distribution of the Estimates for Autoregressive Time Series with a Unit Root. Journal of the American Statistical Association 74: 427-431.
Dickey, D., and Fuller, W.A. 1981. Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root. Econometrica 49: 1057-72.
Dinda, S., Coondoo, D. and Pal, M. 2000. Air quality and economic growth: an empirical study. Ecological Economics 34: 409–423.
Dinda, S., and Coondoo, D. 2006. Income and emission: a panel data-based cointegration analysis. Ecological Economics 57: 167–181.
Enders, W. 2004. Applied Econometric Time Series. 2e, New Jersey: Willey.
Engle, R.F., and Granger, C.W.J. 1987. Co-integration and error-correction: representation, estimation and testing. Econometrica 55(2): 251–276.
Evans, G.W. 1989. Output and Unemployment Dynamics in the United States: 1950-1985. Journal of Applied Econometrics 4: 213-37.
Friedl, B., and Getzner, M. 2003. Determinants of CO2 emissions in a small open economy. Ecological Economics 45(1): 133–148.
Galeotti, M., Lanza, A. and Pauli, F. 2006. Reassessing the environmental Kuznets curve for CO2 emissions: a robustness exercise. Ecological Economics 57: 152–163.
Granger, C.W.J. 1969. Investigating causal relations by econometric models and cross-spectral methods. Econometrica 34(3): 424-438.
Grossman, G.M. and Krueger, A.B. 1991. Environmental Impacts of a North American free trade agreement. NBER Working Paper, 3914. NBER, Cambridge.
Grossman, G., and Krueger, A. 1995. Economic environment and the economic growth. Quarterly Journal of Economics 110: 353–377.

Gujarati, D.N. 1995. Basic Econometric, New York: The McGraw-Hill companies Inc.

Hamilton, J.D. 1994) Time Series Analysis, Princeton, NJ: Princeton University Press.

Heil, M.T., and Selden, T.M. 1999. Panel stationarity with structural breaks: carbon emissions and GDP. Applied Economic Letters 6: 223–225.

Integrated Energy Policy (IEP), 2008. Published by Planning Commission, Government of India (GoI), Government of India.

Jalil, A., and Mahmud, S.F. 2009. Environment Kuznets curve for CO2 emissions: a cointegration analysis for China. Energy Policy 37(12): 5167-72.

Johansen, S., and Juselius, K. 1990. Maximum likelihood estimation and inference on cointegration with application to money demand. CityOxford Bulletin of Economics and Statistics 52: 169–210.

Johansen, S. 1995), Likelihood-Based Inference in Cointegrated Vector Autoregressive Models Oxford University Press, Oxford.

King, R.G., Plosser, C. and Stock, J.H. 1991. Stochastic Trends and Economic Fluctuations. American Economic Review 81(4): 819-40.

Kraft, J. and Kraft, A. 1978. On the relationship between energy and GNP. Journal of Energy Development 3: 401–403.

Kuznet, S. 1955. Economic growth and income in equality. American Economic Review 45(1): 1–28.

Kwiatkowski, D., Phillips, P. C. B., Schmidt, P. and Shin, Y. 1992. Testing the Null of Stationarity Against the Alternative of a Unit Root: How Sure Are We That Economic Time Series Have a Unit Root? Journal of Econometrics 54: 159–78.

Lau, E., Chye, Xiao-Hui., Choong, Chee-Keong. 2011. *Energy-Growth Causality: Asian Countries Revisited*. International Journal of Energy Economics and Policy 1(4): 140-149.

Lucas, R., Wheeler, D. and Hettige, H. 1992. Economic development, environmental regulation, and international migration of toxic industrial pollution. In: Low, P. (Ed.) International Trade and Environment. Discussion Papers, No.159, World Bank, Washington, StateDC.

MacKinnon, J.G. 1996. Numerical Distribution Functions for Unit Root and Cointegration Tests. Journal of Applied Econometrics 11: 601-618.

MacKinnon, J.G., Haug, A.A. and Michelis, L. 1999. Numerical Distribution Functions of Likelihood Ratio Tests for Cointegration. Journal of Applied Econometrics 14: 563-577.

Mallah, S., and Bansal, N.K. 2010. Renewable energy for sustainable electrical energy system in India. Energy Policy 38: 3933–3942.

Masih, A.M.M., and Masih, R. 1996. Energy consumption, real income and temporal causality; results from a multi-country study based on cointegration and error correction modeling techniques. Energy Economics, 18:165–183.

Narayan, P.K., and Singh, B. 2007. The electricity consumption and GDP nexus for the Fiji Islands. Energy Economics 29: 1141–1150.

Narayan, P.K., Narayan, S. and Prasad, A. metricconverterProductID2008. A2008. A structural VAR analysis of electricity Consumption and real GDP: evidence from the G7 countries. Energy Policy 36(7): 2765-2769.

National Action Plan on Climate Change (NAPCC), 2008. Ministry of Environment and Forests Government of India.

Osterwald-Lenum, M. metricconverterProductID1992. A1992. A Note with Quantiles of the Asymptotic Distribution of the Maximum Likelihood Cointegration Rank Test Statistics. Oxford Bulletin of Economics and Statistics 54: 461-472.

Ozturk. I. metricconverterProductID2010. A2010. A literature survey on energy–growth nexus. Energy Policy, 38(1):340-349.

Ozturk, I. and Acaravci, A. 2010. CO2 Emissions, Energy Consumption and Economic Growth in Turkey. Renewable and Sustainable Energy Reviews 14(9): 3220-3225.

Ozturk, I., Aslan, A. and Kalyoncu, H. 2010. Energy Consumption and Economic Growth Relationship: Evidence from Panel Data for Low and Middle Income Countries. Energy Policy 38(8): 4422-4428.

Pao, H.T., and Tsai, C.M. 2011. CO2 emissions, energy consumption and economic growth in BRIC countries. Energy Policy 38: 7850-7860.

Parikh, J., Panda, M., Ganesh-Kumar, A. and Singh, V. 2009. CO2 emissions structure of Indian economy. Energy Policy, 34:1024–1031.

Perman, R., and Stern, D.I. 2003. Evidence from panel unit root and cointegration tests that the environmental Kuznets curve does not exist. The Australian Journal of Agricultural and Resource Economics 47: 325–347.

Pesaran, H.M., and Smith, R.J. 1998. Structural Analysis of Co-integration VARS. Journal of Economic Surveys 12(5): 471–505.

Phillips, P.C., and Perron, P. 1988. Testing for a Unit Root in Time Series Regression. Biometrika 75(2): 335-46.

Shafik, N. 1994. Economic development and environmental quality: an econometric analysis. Oxford Economic Papers 46: 757–773.

Sims, C. 1972. Money, income, and causality. American Economic Review 62(4) 540-552.

Sims, C.A. 1980. Macroeconomics and Reality. Econometrica 48 1-48.

Soytas, U., Sari, R. and Ewing, T. 2007. Energy consumption, income, and carbon emissions in the United States. Ecological Economics 62: 482–489.

Soytas, U., and Sari, R. 2009. Energy consumption, economic growth, and carbon emissions: challenges faced by an EU candidate member. Ecological Economics 68: 1667–1675.

Stern, D.I. 2004. The rise and fall of the environmental Kuznets curve. World Development 32: 1419–1439.

Stock, **J.H., and** *Watson,* M.W. ***2007***. Introduction to Econometrics. 2nd Edition, Addison-Wesley, Amsterdam.

Suri, V., and Chapman, D. 1998. Economic growth, trade and energy: implications for the environmental Kuznets curve. Ecological Economics 25: 195–208.

Wolde-Rufael, Y. 2006. Electricity consumption and economic growth: a time series experience for 17 African countries. Energy Economics 34: 1106–1114.

Wyckoff, A.M., and Roop, J.M. 1994. The embodiment of carbon in imports of manufactured products: implications for international agreements on greenhouse house gas emissions. Energy Policy 22: 187–194.

Yang, H.Y. metricconverterProductID2000. A2000. A note on the causal relationship between energy and GDP in Taiwan. Energy Economics 22: 309–

317.
Zhang, X.P., and Cheng, X.M. 2009. Energy consumption, carbon emissions, and economic growth in China. Ecological Economics 68(10): 2706–2712.

KAUZALNOST IZMEĐU EMISIJE UGLJIKA, POTROŠNJE ENERGIJE I RASTA U INDIJI

Sažetak

Ovaj rad istražuje dugoročnu Grangerovu kauzalnost između potrošnje energije, emisije ugljikovog dioksida i ekonomskog rasta u Indiji u periodu od 1971. do 2007. Za testiranje Grangerove kauzalnosti u kointegracijskim modelima koji uračunavaju stohastička svojstva varijabli korišteni su prošireni Dickey-Fuller test (ADF), Phillips-Perron test (PP) i KPSS test. Najvažniji rezultat je da je utvrđena povratna kauzalna veza između potrošnje energije i ekonomskog rasta, što ukazuje na međusoban utjecaj razine ekonomske aktivnosti i potrošnje energije; veliki ekonomski rast dovodi do visokog stupnja potrošnje energije i obrnuto. Vrijednost korekcije greške potvrđuje dugoročno očekivani proces konvergencije za emisiju ugljika i rast u Indiji što upućuje na zaključak da će politika smanjenja emisije ugljika oštetiti ekonomski rast Indije ukoliko ne bude zamjenskih politika koje će pokušati modificirati kauzalnu vezu.

Ključne riječi: emisije ugljika, potrošnja energije, rast, Indija