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Relationship between energy consumption, CO_2 emissions, economic growth and trade in India

Srinivasan Palamalai [a*], Inder Siddanth Ravindra [b], Karthigai Prakasam [b]

[a] Xavier Institute of Management & Entrepreneurship, Karnataka, India.
[b] Department of Economics, Christ University, Karnataka, India.
[*]Corresponding author's email address: srinivasaneco@gmail.com

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ABSTRACT

The purpose of the study is to examine the causal nexus between various sources of energy consumption, viz. Coal, Crude Oil, Electricity and Natural Gas, CO_2 emissions, economic growth and trade in India using the Perron unit root test, Gregory and Hansen cointegration test and Vector Error Correction Model. The study exhibits a long-run relationship between various sources of energy consumption, economic growth, CO_2 emissions and trade in India. By and large, the empirical results confirm that economic growth fuels rate of various sources of energy consumption i.e. coal, crude petroleum, electricity and natural gas. The findings reveal that increase in CO_2 emissions leads to achieve high level of economic activity in India. In addition, the study finds that foreign trade influences the various sources of non-renewable energy consumption in the long-term. However, the energy consumption do not significantly contributes towards promoting foreign trade, except crude petroleum, in the short-run.

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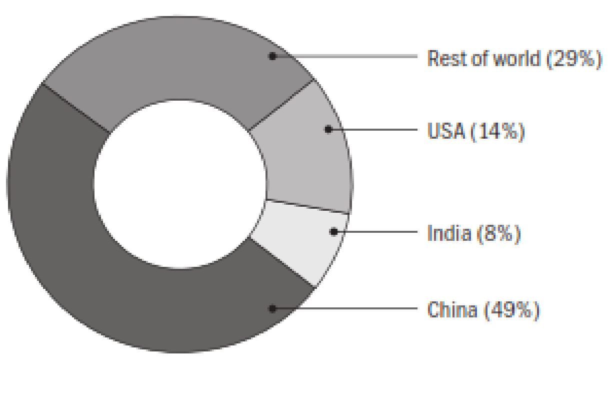
1.0 Introduction

Energy plays a crucial role in the socio-economic development and human welfare of a country. It has become a strategic commodity and any uncertainty about its supply can threaten the working of the economy, especially in the developing economies. Energy security, as a strategic perspective, is of importance to India's economic growth and achieving human development objectives such as the alleviation of poverty and unemployment. India is the seventh largest energy producer and the fifth largest energy consumer in the world. However, among the other countries, India has one of the lowest per capita energy consumption levels at 30 percentage of the world average. Also, energy supply in India falls short of the growing demand within the country. Even when energy is apparently available, it is unreliable and irregular. Over the last two decades, the Indian economy has grown at a constructive rate and the sustained economic growth in the country is placing an enormous demand on its energy resources. But, due to the existence of imbalance between demand and supply for all the sources of energy, the Government of India has been tasked to boost energy supplies before the country faces potentially severe energy supply constraints. Besides, the Indian government has realised the importance of reducing its greenhouse gas emissions as its contribution to a worldwide attempt to limit global warming. By 2020, India's mission is to reduce its greenhouse gas emissions per unit of economic output by 20-25 percentage when compared to the levels in year 2005, in keeping with the Copenhagen Accord.

Given India's growing demand for energy, high dependence on fossil fuels and limited reserves of fuels, India uses the main sources of energy such as coal and lignite, crude oil, petroleum products and natural gas, etc. The Indian economy is highly dependent on coal energy. Coal contributed to about 52.87 percentage of the total primary energy consumption in the country during 2010-11.

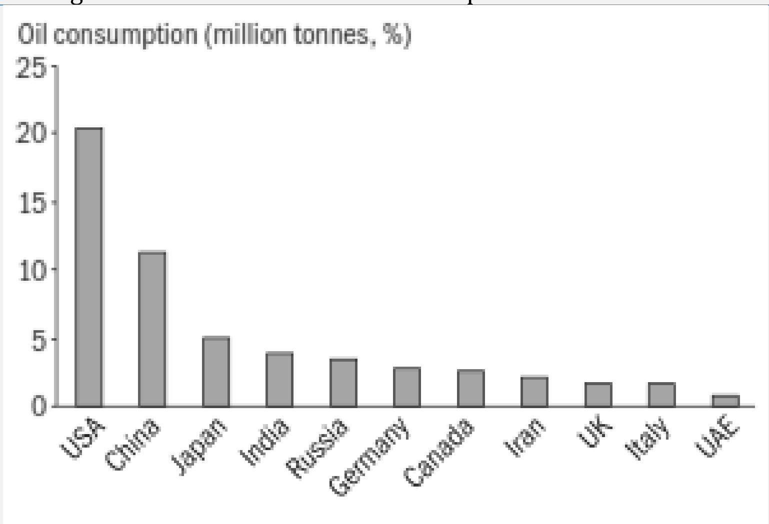
Figure 01: Distribution of coal consumption across the world



Source: Compiled from BP statistics, 2012

Figure 01 show that Indian economy accounts for 8 percentage of the world coal consumption and is the third largest consumer of coal in the world after China and USA. Besides, the crude oil is the next most important fuel in India and it account for 39.3 percentage of the primary commercial energy supply (TERI Energy Data Directory and Yearbook, 2012).

Figure 02: Distribution of oil consumption across the world



Source: Compiled from British Petroleum statistics, 2012

Figure 02 indicate that Indian economy was the fourth largest consumer of oil in the world after USA, China, and Japan and accounted for 4 percentage of the world oil consumption during the year 2011-12. In terms of consumption of petroleum products, the transport sector is the largest and the fastest-growing consumer in India, accounting for 39 percentage of petroleum products consumed, followed by residential and commercial and industry sectors (TERI Energy Data Directory and Yearbook, 2012). Moreover, the other important energy resources of India are natural gas and electricity. Natural gas accounts for 10 percentage of primary energy consumption in India (British Petroleum, 2012). According to British Petroleum Statistics 2012, India has eleventh position among natural gas consumers of the world. In the case of electricity, the country has made significant progress towards the augmentation of its power infrastructure. Though, the growth in electricity consumption over the past decade has been slower than the GDP's growth, this increase could be due to high growth of the service sector and efficient use of electricity. However, it is a matter of concern that per capita consumption of electricity is among the lowest in the world. Moreover, poor quality of power supply and frequent power cuts and shortages impose a heavy burden on India's fast-growing trade and industry.

Over the years, there has been increasing concerns about shortage in energy supply, rise in energy use and climate change. With increasing pressure of population and increasing use of energy in different sectors of the economy, India's greenhouse gas (GHG) emissions have also been increasing. India is now the fourth largest emitter of GHGs in the world, after the USA, China, and Russia. With regard to longer term action on global warming, India has - along with all other parties to the United Nations Framework Convention on Climate Change (UNFCCC) - pledged its support for the Durban Platform on enhanced cooperation, whose aim is a global agreement on climate change, to be effective from 2020, and most likely with long term binding targets for a range of developed and emerging economies alike. In order to be prepared for the challenges of limiting emissions growth over the coming decades, attention in India's energy community is now beginning to focus on how the economy could lower their carbon intensity over the long term. Several other initiatives have also been undertaken and are planned to tackle climate change and reduce energy consumption without compromising economic activity in India. Our study attempts to empirically investigate the relationship between energy consumption, environmental degradation or pollution emissions and economic growth in India.

Due to the increasing threat of global warming and climate change, several authors attempt to examine the relationship between energy consumption, environmental degradation and economic growth. The main focus of this line of research has been on the Environmental Kuznets Curve (EKC) or what is called as Carbon Kuznets Curve (CKC) hypothesis. The supposition of the hypothesis is such that initially as per capita income rises environmental degradation exaggerates, but after achievement of a critical level of economic growth it tends to fell down. Therefore, as Rothman and De Bruyn (1998) argues that economic growth may become a solution rather than a source of the problem. This may be either due to increase in the demand for environmental quality as economies grow (Lantz and Feng, 2006) or the possible energy saving because of the increasing awareness among the people regarding the harmful impact of environmental pollution.

The conservation of energy could ensure energy security and lower the emission of greenhouse gases. The implementation of energy conservation policies requires careful investigation. Hence, an increased interest has been placed on the nature of the relationship between energy consumption and economic development because understanding the path of causality will aid in shaping environmental and energy policies. From the supply-side point of view, if energy consumption causes economic development, this implies that the economy is dependent on energy and a low or falling supply of energy would adversely affect income. This is referred to as the growth hypothesis. Energy conservation policies would lead to a fall in output. From the demand point of view, if economic development causes energy consumption this implies that the economy is less dependent on energy. This is referred to as the conservation hypothesis. Energy conservation policies such as the phasing out of energy subsidies can be implemented with little or no adverse effects on income. If no causal relationship exists between energy consumption and economic development, energy conservation policies can be implemented without having an unfavourable effect on output. This is referred to as the neutrality hypothesis. If bidirectional causality is discovered between energy consumption and economic development this implies that economic development and energy consumption are complementary. This is referred to as the feedback hypothesis. Energy policies should focus on improving energy consumption efficiency to avoid adverse effects on income. The long-run relationship between energy consumption and economic development and the direction of causality can differ from country to country because of country-specific conditions and methodological differences. Variations may also be due to omitted variable bias or the absence of input substitution possibilities.

It has also been postulated that trade plays a significant role in the economic growth of a country as exports are injections into the economy. Exports have a spill-over effect on the production process of the economy which contributes to greater total productivity. Additionally, through greater specialisation, a country can benefit from economies of scale and comparative advantage. An adequate infrastructure, such as the provision of energy is increasingly recognized as a key factor in providing a suitable environment for industrial and economic development and exports. Production for export from the industrial sector depends on the level of energy consumption by the sector. The equipment and machinery employed in the production process are dependent on energy for their functioning. Additionally, transporting goods for export requires energy too.

From the theoretical arguments, it is clear that the economic growth, energy consumption and CO_2 emissions and trade are interdependent. The direction of causality between economic growth, energy consumption and CO_2 emissions is important for the implementation of related policies. If, for example, energy consumption causes economic growth, the country would have to implement expansive energy policies. If energy use causes CO_2 emissions, then the country would rather have to invest in increasing energy efficiency in order to decrease emissions without negatively impacting economic growth. On the other hand, if economic growth causes energy consumption, then conservative energy policies can be implemented without any adverse effect on economic growth. If there is no causality between these variables, then the country will have to implement separate policies to affect the levels of the individual variables as a change in the levels of one of the variables will have no impact on the other variable. Finally, if there is bidirectional causality between any of these variables, then they are mutually affected and policies need to take into consideration that any change in one will impact the other.

2.0 Review of literature

The linkage between economic growth, energy consumption and CO_2 emission has been categorized into three research strands in empirical literature. 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. The EKC hypothesizes an inverted U-shaped relationship between (per capita) income and pollution levels, i.e. environmental quality first deteriorates and then improves with per capita income. 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 strand 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. In their pioneering work, Kraft and Kraft (1978) used annual U.S. data from 1947 to 1974 to study the relationship between gross national product (GNP) and gross energy inputs. They discovered that increased GNP leads to increased energy consumption. Murray and Nan (1992) found that increased economic activity results in increased energy consumption. Cheng and Lai (1997) demonstrated unidirectional relationship from real GDP to energy consumption in Taiwan. Moreover, studies such as Ghosh (2002), Ghosh (2009) and Pradhan (2010) for India, Gelo (2009) for Croatia, Mucuk and Yilmaz (2010) for Turkey, Binh (2011) for Vietnam, Eddrief-Cherfi and Kourbali (2012) for Algeria, Onuonga (2012) for Kenya, Shahbaz and Feridun (2012) for Pakistan, Kwakwa (2012) for Ghana and Ishida (2013) for Japan detected unidirectional causality running from growth to energy use.

On the other side, Lee (2005) found unidirectional causality from increased energy consumption to real GDP growth for the developing countries. Mehrara (2007) for the oil-exporting countries, Narayan and Smyth (2008) for the G7 nations, Sarker et al. (2010) for Bangladesh, Odhiambo (2011) for South Africa, Li and Li (2011), Tiwari (2011) and Vidyarthi (2013) for India, Talebi et al. (2012) for Iran and Acaravci and Ozturk (2012) for Turkey inferred that the energy consumption Granger caused real economic activity. Moreover, several authors detected a reciprocal relationship between energy consumption and economic growth (Glasure and Lee, 1998; Francis et al., 2007 and Chen et al., 2007). Paul et al. (2004) and Ozturk and Uddin (2012) for India, Apergis and Payne (2011) for the developed and developing nations, Apergis and Danuletiu (2012) for Romania, Sultan (2012) for Mauritius, Yazdan and Hossein (2012) for Nigeria, Salahuddin and Khan (2013) for Australia and Nnaji, et al. (2013) for Iran revealed bidirectional causality between energy consumption and economic growth. Moreover, the studies revealed independent relationship between economic activity and energy consumption (e.g. Akarca and Long, 1980; Erol and Yu, 1987; Yu and Jin, 1992 and Cheng, 1996). Recently, Ocal et al. (2013) detected no causal relationship between coal consumption and gross domestic product in Turkey.

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 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), Alam et al. (2011), Jafari et al. (2012) and Farhani (2013).

In addition, the authors included the foreign trade variable in their empirical analysis based on the argument 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), Wycko and Roop (1994), Suri and Chapman (1998) and Anderson et al. (2010). The results of these studies in terms of the relationship between trade and environmental quality is however inconclusive.

From the existing strands of literature, it can be clear that the direction of causality have been inconclusive in the context of emerging economies like India. Notably, the previous studies with reference to India have addressed the issue of causality using the aggregated energy consumption data, without considering the disaggregated data on various forms of energy consumption. Since the Indian economy depends on the various forms of energy resources such as coal, electricity, natural gas and oil for its economic activity, it is necessary to consider the individual sources of energy consumption in relation with real growth rate of the economy and CO_2 emissions. Therefore, the study undertakes an empirical analysis towards verifying this nexus of energy consumption, CO_2 emission and economic growth with reference to Indian economy using data on various types of energy consumption for suggesting different policy strategies for different forms of energy demand to bring a balance between consumption and conservation of energy in sustaining and speeding up the growth momentum of the economy.

In this context, our study attempts to examine the causal nexus between various sources of energy consumption, viz. Coal, Crude Oil, Electricity and Natural Gas, CO_2 emissions, economic growth and trade in India. The rest of the paper is organized as follows: 'Methodology' section describes the data and methodology applied in the study. Next section provides the empirical results and discussion followed by the concluding remarks is depicted in the 'Conclusion' Section.

3.0 Data and methodology

Perron's (1989) unit root test was employed to infer the stationarity properties of the data series in the presence of a structural break. Besides, Gregory-Hansen (1996) structural break cointegration procedure was applied to investigate the long-run equilibrium relationship between various forms of energy consumption, CO_2 emissions, economic growth and trade in India. Further, employing Vector Error Correction Model (VECM), the present study investigates short-run causal nexus between energy consumption, CO_2 emissions and economic growth in India. Finally, the study used variance decomposition analysis to show the percentage of forecast error variance for each of the variable selected that may attribute to its own shocks and to fluctuations in other variables.

3.01 Perron (1989) unit root test with structural breaks

Dickey and Fuller (1979, 1981) introduced the idea of a unit root and proposed a standard unit root testing procedure which is popularly known as ADF (Augmented Dickey-Fuller) test of unit root. Until the work of Nelson and Plosser (1982), the general view was that macroeconomic data series were stationary around a deterministic trend. However, by using the unit root tests of Dickey and Fuller (1979, 1981), Nelson and Plosser (1982) found that all historical time series have a unit root except for the unemployment rate. An important implication of their findings is that, under the unit root hypothesis, random shocks have permanent effects on the long-run effects of macroeconomics. In other words, fluctuations are not transitory. However, this finding was challenged by Perron (1989), who argued that in the presence of a structural break, the standard ADF (augmented Dicky Fuller) tests are biased towards non-rejection of the null hypothesis. Perron's unit root test allows for a break under the null and alternative hypotheses, and he showed that if an exogenous break is present, then most of the macroeconomic time series used by Nelson and Plosser (1982) are not characterized by the presence of a unit root. In addition, he also showed that persistence arises only from large and infrequent shocks, and that after frequent shocks, the economy returns to a deterministic trend.

Perron's (1989) procedure is characterized by a single exogenous (known) break in accordance with the underlying asymptotic distribution theory. Perron uses a modified Dickey-Fuller (DF) unit root tests that includes dummy variables to account for one known, or exogenous structural break. The break point of the trend function is fixed (exogenous) and chosen independently of the data. Perron's (1989) unit root tests allows for a break under both the null and alternative hypothesis. These tests have less power than the standard DF type test when there is no break. However, Perron (2005) points out that they have a correct size asymptotically and is consistent whether there is a break or not. Moreover, they are invariant to the break parameters and thus their performance does not depend on the magnitude of the break.

The equations of the Perron unit root test take into account the existence of three kinds of structural breaks and are as follows:

$$X_t = \alpha_0 + \alpha_1 DU_t + d(DTB)_t + \beta_t + \rho X_{t-1} + \sum_{i=1}^{p} \phi i \, \Delta X_{t-1} + e_t \qquad (01)$$

Equation (01) represents a model which allows for a break in the intercept of a series.

$$X_t = \alpha_0 + \gamma DT_t^* + \beta t + \rho X_{t-1} + \sum_{i=1}^{p} \phi i \, \Delta X_{t-1} + e_t \qquad (02)$$

Equation (02) represents a model which allows for a break in the trend of a series.

$$X_t = \alpha_0 + \alpha_1 DU_t + d(DTB)_t + \gamma DT_t + \beta t + \rho X_{t-1} + \sum_{i=1}^{p} \phi i \, \Delta X_{t-1} + e_t \qquad (03)$$

Equation (3) represents a model which allows for a break in both the intercept and trend of a series.

In equations (01), (02) and (03), the intercept dummy DU_trepresents a change in the level; $DU = 1$ if ($t > TB$) and zero otherwise. The slope dummy DT_t(alsoDT_t*)represents a change in the slope of the trend function; $DT^* = t - TB$ (or $DT^* = t$ if $t > TB$) and zero otherwise; the crash dummy $(DTB) = 1$ if $t = TB + 1$ and zero otherwise; TB is the break date.

3.02 Gregory and Hansen cointegration for long run relationships with structural breaks

The Gregory and Hansen (1996) cointegration test is employed to test for cointegration with the inclusion of a structural break in the cointegrating relationship. The test has the advantage of being able to test cointegration along with the issue of a structural break which can be determined endogenously. Gregory and Hansen (1996) suggest three alternative models accommodating changes in parameters of the cointegration vector under the alternative. The first one (equation 04) is the so-called level shift model (or C model) that allows for the change in the intercept only. The second model (equation 05) accommodating a trend in data also restricts a shift only to the change in level with a trend (C/T model). The last model (equation 06) allows for changes both in the intercept and slope of the cointegration vector (or R/S model).

Equation (04) denotes the first type of structural change where there is a level shift in the cointegrating relationship. This can be modelled as a change in the intercept μ, keeping the slope coefficient α constant.

$$Y_{1t} = \mu_1 + \mu_2 \phi_{t\tau} + \alpha^T Y_{2t} + e_t \quad (04)$$

Equation (05) denotes the second type of structural change where there is a level shift with time trend in the cointegrating relationship.

$$Y_{1t} = \mu_1 + \mu_2 \phi_{t\tau} + \beta t + \alpha^T Y_{2t} + e_t \quad (05)$$

In equations (04) and (05), μ_1 represents the intercept before the shift; μ_2 represents the change in the intercept at the time of the shift.

Equation (06) denotes the third type of structural change where there is a shift in the slope vector as well in the cointegrating relationship.

$$Y_{1t} = \mu_1 + \mu_2 \phi_{t\tau} + \alpha_1^T Y_{2t} + \alpha_2^T Y_{2t} \phi_{t\tau} + e_t \quad (06)$$

In the equation (6), μ_1 represents the intercept before the shift; μ_2 represents the change in the intercept at the time of the shift; α_1 represents cointegrating slope coefficients before the regime shift; α_2 represents the change in the slope coefficients. The null hypothesis of no cointegration with structural breaks is tested against the alternative of cointegration by the Gregory and Hansen approach. The single break date in these models is endogenously determined.

The dummy variable which captures the structural change is represented as:

$$\varphi_{t\tau} = \begin{cases} 0, \text{ if } t \le n\tau \\ 1, \text{ if } t > n\tau \end{cases} \quad (07)$$

Where$\tau \in (1, 0)$ is a relative timing of the change point. Equations (04), (05), and (06) are estimated sequentially with the break point changing.

3.03 Vector error correction model

The Vector Error Correction Model (VECM) was employed to investigate the temporal causality between various forms of energy consumption, CO_2 emissions, economic growth and trade in India. The Granger Representation Theorem (Engle and Granger, 1987) states that if a set of variables is cointegrated, then there exists a valid error correction representation of the data, in which the short-term dynamics of the variables in this system are influenced by the deviation from long-term equilibrium. In a VECM, short-term causal effects are indicated by changes in other differenced explanatory variables and the long-term relationship is implied by the level of disequilibrium in the cointegration relationship, i.e., the lagged error correction term (ECT). Hence, the Vector Error Correction model is useful for detecting short- and long-term Granger causality tests (Granger, 1969). The causal nexus between selected time-series variables was investigated by estimating the following Vector Error Correction Model (VECM) (Johansen, 1988 and Johansen and Juselius, 1990):

$$\Delta Y_{1t} = \mu_1 + \gamma_1 z_{t-1} + \sum_{i=1}^{p-1} \theta_{1i}\Delta Y_{1t-i} + \sum_{i=1}^{p-1} \mho_{1i}\Delta Y_{2t-i} + \sum_{i=1}^{p-1} \lambda_{1i}\Delta Y_{3t-i} + \sum_{i=1}^{p-1} \lambda_{1i}\Delta Y_{4t-i} + \varepsilon_{1t} \quad (08)$$

$$\Delta Y_{2t} = \mu_2 + \gamma_2 z_{t-1} + \sum_{i=1}^{p-1} \theta_{2i}\Delta Y_{2t-i} + \sum_{i=1}^{p-1} \mho_{2i}\Delta Y_{1t-i} + \sum_{i=1}^{p-1} \lambda_{2i}\Delta Y_{3t-i} + \sum_{i=1}^{p-1} \xi_{2i}\Delta Y_{4t-i} + \varepsilon_{1t} \quad (09)$$

$$\Delta Y_{3t} = \mu_3 + \gamma_3 z_{t-1} + \sum_{i=1}^{p-1} \theta_{3i}\Delta Y_{3t-i} + \sum_{i=1}^{p-1} \mho_{3i}\Delta Y_{2t-i} + \sum_{i=1}^{p-1} \lambda_{3i}\Delta Y_{1t-i} + \sum_{i=1}^{p-1} \xi_{3i}\Delta Y_{4t-i} + \varepsilon_{1t} \quad (10)$$

$$\Delta Y_{4t} = \mu_4 + \gamma_4 z_{t-1} + \sum_{i=1}^{p-1} \xi_{4i}\Delta Y_{4t-i} + \sum_{i=1}^{p-1} \mho_{4i}\Delta Y_{2t-i} + \sum_{i=1}^{p-1} \lambda_{4i}\Delta Y_{3t-i} + \sum_{i=1}^{p-1} \theta_{4i}\Delta Y_{1t-i} + \varepsilon_{1t} \quad (11)$$

where, Y_1, Y_2,Y_3 and Y_4 represents the various sources of energy consumption, CO_2 emissions, Gross Domestic Product (GDP) and foreign trade, respectively. $\gamma'_s z_{t-1}$ is the error correction term derived from the cointegrating vector. θ, λ, ξ and ℧ are the short-run parameters to be estimated, p is the lag length, and ε_t are assumed to be stationary random processes with a mean of zero and constant variance.

For each equation in the VEC Model, we employed short-term Granger causality to test whether endogenous variables can be treated as exogenous by the joint significance of the coefficients of each of the other lagged endogenous variables in that equation. The short-term significance of sum of the each lagged explanatory variables (θ, λ, ξ and ℧'s) can be exposed either through joint F or Wald χ^2 test. Besides, the long-term causality is implied by the significance of the t-tests of the lagged error correction term (z_{t-1}(ECT_{t-1})). However, the non-significance of both the t-statistics and joint F or Wald χ^2 tests in the Vector Error Correction Model indicates econometric exogenity of the dependent variable.

3.04 Variance decomposition analysis

Finally, the study applied variance decomposition analysis to show the percentageage of forecast error variance for each of the variable selected that may attribute to its own shocks and to fluctuations in other variables. Information from this analysis should provide some further evidence on the patterns of linkages amongst variables under consideration, as well as contribute to enhancing insights upon how these variables react to system-wide shocks and see how these responses propagate over time. This forecast error can be accounted for by its own innovations and the innovations of other variables in the system. In a statistical sense, if a variable explains most of its own shock, then it does not allow variances of other variables to contribute to it being explained and is therefore said to be relatively exogenous.

In the present study, we have taken annual data over the period from 1970 to 2012. The study comprises of time-series data on CO_2 emissions (metric tons per capita) per capita, real GDP (constant 2000 US$) per capita and openness ratio, a proxy for foreign trade, of the Indian economy. The various forms of energy consumption such as coal, natural gas, crude petroleum and electricity are considered for the study and are expressed as a ratio to GDP in order to measure them as per unit of output. All the necessary information was collected from the various issues of World Development Indicators (WDI) published by the World Bank.

4.0 Empirical results and discussion

The conventional Augmented Dickey Fuller (ADF) test was popularly used to check whether the variables contain a unit root or not. However, the conventional ADF method fails to allow for existing breaks in the data series and provides biased and misleading inference towards the non-rejection of the null hypothesis. Hence, the present study employed Perron's (1989) structural unit root test to examine the stationarity property of the data series with a structural break which allows for (i) a break in the level (or intercept) of a series, (ii) a break in the slope (or rate of growth) of a series (or trend) and (iii) a break in the one-time change in both the level and the slope of the series (or intercept and trend). Table 01 report the results of Perron's structural unit root test for the data series on various sources of energy consumption (viz. coal, natural gas, electricity and crude petroleum), CO_2 emissions, economic growth and trade. The findings reveal that unit root null for all the series in the presence of structural break are rejected under intercept, trend and intercept and trend function, respectively, and found to be stationary at first differences, i.e. they are integrated in the order of I(1).

Table 01: Perron unit root test results

Variables	Intercept				Intercept & Trend				Trend			
	Level	Break Point	First Difference	Break Point	Level	Break Point	First Difference	Break Point	Level	Break Point	First Difference	Break Point
COAL	-0.895	2006	-11.594*	1978	-1.998	1999	-11.413*	1978	-2.491	1999	-10.225*	1992
CRUDE	-2.636	2006	-8.309*	2000	-3.516	1998	-8.276*	1998	-2.814	2006	-7.542*	2002
ELECTRICITY	-1.887	1998	-8.437*	1995	-4.497	1995	-8.589*	1995	-4.231	1994	-7.405*	2001
GAS	-2.784	1980	-9.526*	1980	-3.523	1985	-9.227*	1980	-3.481	1994	-8.223*	1984
CO_2	-4.020	2000	-5.033***	1986	-3.993	2000	-5.291**	1986	-3.191	1994	-4.935**	1983
GDP	-3.272	2006	-7.372*	2002	-3.551	1999	-8.006*	2006	-3.417	2002	-7.296*	2001
TRADE	-2.902	1990	-5.071***	1986	-2.859	1990	-5.279***	1986	-2.412	2004	-5.004**	1983

Notes: * indicates significance at one percentage level.

Once structural breaks were detected by the Perron's unit root test, the Gregory and Hansen (1996) cointegration test was employed to examine the long-run relationship between the variables in the presence of structural breaks and its result are presented in Table 02. The table result confirms the existence of long run relationship with possible structural breaks among the various forms of individual energy consumption, CO_2 emissions, economic activity and trade in India. The study suggests that the energy consumption such as coal, crude petroleum, electricity and natural gas tend to have long-term relation with economic growth, CO_2 emissions and trade in India.

Having established the long-run relationship, the next step is to estimate a Granger causality test based on vector error correction model (VECM) and the results are presented in Table 03. The table results of Vector Error Correction Model for coal consumption reveal that the error correction coefficients of coal, GDP and CO_2 are found to be statistically significant at one percentage levels, implying they influence each other in the long-run. In other words, there exists bidirectional relationship between coal consumption, GDP and CO_2 emissions in the long-term.

Besides, the results provide evidence of long-run causality running from trade to Coal consumption, GDP and CO_2 emissions in India. In the short-run, the VECM results show one-way causality runs from GDP to coal consumption in India. Further, the findings indicate the causation running from CO_2 to GDP, and trade to GDP and CO_2 emissions in the short-run.

Table 02: Gregory and Hansen cointegration test results

SPECIFICATION	MODEL	ADF	Break Point	Z_a	Break Point	Z_t	Break Point
COAL = f (GDP, CO_2& TRADE)	Level Shift	-4.021*	1983	-24.987*	1983	-4.085*	1983
	Level Shift with Trend	-4.480*	1984	-23.349*	1984	-3.932*	1977
	Regime Shift	-6.170*	1985	-42.829*	1985	-6.245*	1985
GDP = f (COAL, CO_2& TRADE)	Level Shift	-4.229*	1982	-24.272*	1975	-4.179*	2001
	Level Shift with Trend	-4.700*	1974	-23.470*	1975	-4.023*	1977
	Regime Shift	-5.846*	1984	-40.462*	1987	-6.061*	1987
CO_2 = f (GDP, COAL & TRADE)	Level Shift	-4.373*	2000	-27.312*	2001	-4.391*	2001
	Level Shift with Trend	-4.666*	2001	-31.637*	2000	-4.777*	2000
	Regime Shift	-4.887*	1993	-31.578*	1993	-4.947*	1993
TRADE = f (GDP, CO_2 & COAL	Level Shift	-5.245*	1983	-26.627*	1983	-4.443*	1983
	Level Shift with Trend	-4.449	1994	-23.816*	1983	-3.948*	1983
	Regime Shift	-5.547*	1982	-28.757*	1982	-4.521*	1983
CRUDE = f (GDP, CO_2& TRADE)	Level Shift	-4.240*	1988	-24.089*	2000	-4.075*	2000
	Level Shift with Trend	-5.583*	1974	-39.358*	1991	-5.650*	1974
	Regime Shift	-4.889*	1998	-31.521*	1998	-4.949*	1998
GDP = f (CRUDE, CO_2 & TRADE)	Level Shift	-3.457*	2000	-22.566*	2000	-3.527*	2000
	Level Shift with Trend	-4.823*	2005	-30.404*	2005	-4.792*	2005
	Regime Shift	-4.471*	1993	-30.364*	1994	-4.644*	1994
CO_2 = f (GDP, CRUDE & TRADE)	Level Shift	-4.154*	1982	-28.103*	2000	-4.265*	2000
	Level Shift with Trend	-4.707*	2001	-33.288*	2001	-4.764*	2001
	Regime Shift	-5.357*	1994	-34.051*	1994	-5.076*	1994
TRADE = f (GDP, CO_2& CRUDE	Level Shift	-5.075*	1981	-21.866*	1983	-3.734*	1983
	Level Shift with Trend	-4.806*	1974	-32.190*	1974	-4.864*	1974
	Regime Shift	-5.155*	1985	-21.619*	1983	-3.959*	1993
ELECTRICITY = f (GDP, CO_2& TRADE)	Level Shift	-6.192*	1996	-41.749*	1996	-6.267*	1996
	Level Shift with Trend	-5.829*	1997	-38.979*	1997	-5.899*	1997
	Regime Shift	-7.030*	1996	-46.811*	1996	-7.115*	1996
GDP = f (ELECTRICITY, CO_2& TRADE)	Level Shift	-5.584*	1996	-38.213*	1996	-5.651*	1996
	Level Shift with Trend	-4.900*	1997	-31.999*	1997	-4.959*	1997
	Regime Shift	-5.642*	2003	-36.864*	2003	-5.707*	2003
CO_2 = f (GDP, ELECTRICITY, TRADE)	Level Shift	-5.501*	1998	-42.100*	1996	-6.233*	1996
	Level Shift with Trend	-6.371*	1994	-40.893*	1995	-6.066*	1995
	Regime Shift	-6.335*	1995	-43.771*	1995	-6.412*	1995
TRADE = f (GDP, CO_2, ELECTRICITY)	Level Shift	-4.223*	1982	-17.273*	1983	-3.184*	1983
	Level Shift with Trend	-4.266*	1980	-25.592*	1982	-4.099*	1982
	Regime Shift	-3.797*	1992	-23.561*	1992	-3.911*	1992
NATURAL GAS = f (GDP, CO_2& TRADE)	Level Shift	-4.855*	1984	-31.773*	1984	-4.914*	1984
	Level Shift with Trend	-4.796*	1985	-30.891*	1984	-4.795*	1984
	Regime Shift	-5.720*	1986	-36.574*	1986	-5.578*	1986
GDP = f (NATURAL GAS, CO_2& TRADE)	Level Shift	-4.167*	1977	-26.606*	2000	-4.155*	1977
	Level Shift with Trend	-3.777*	1986	-30.284*	1977	-4.592*	1977
	Regime Shift	-4.765*	1998	-29.534*	1994	-4.800*	1999
CO_2 = f (GDP, NATURAL GAS &TRADE)	Level Shift	-5.014*	2002	-31.820*	2000	-4.714	1977
	Level Shift with Trend	-5.158*	1977	-35.356*	1977	-5.2211	1977
	Regime Shift	-6.002*	2002	-36.207*	1999	-5.407*	1999
TRADE = f (GDP, CO_2& NATURAL GAS)	Level Shift	-4.869*	1982	-21.625*	1983	-3.743*	1983
	Level Shift with Trend	-4.753*	1981	-19.252*	1981	-3.343*	1989
	Regime Shift	-5.265*	1985	-21.343*	1983	-3.902*	1995

Notes: * indicates the significance at one percentage level.

Table 03: Result of vector error correction model

Dependent Variable	Short-Run Effect				Long-Run Effect
	Wald χ^2 statistics				t-statistics
Model 1: COAL, GDP, CO_2& TRADE	COAL	GDP	CO_2	TRADE	ECT(s)
COAL	-	4.334**	17.83*	1.189	-1.131*
GDP	0.018	-	13.30*	13.35*	0.653*
CO_2	0.994	0.058	-	4.833**	0.919*
TRADE	1.283	2.574	2.460	-	-0.474
Model 2: CRUDE, GDP, CO_2&& TRADE	CRUDE	GDP	CO_2	TRADE	ECT(s)
CRUDE	-	25.79*	0.464	2.522	-1.128*
GDP	5.795**	-	13.24*	1.544	0.047
CO_2	0.004	0.137	-	0.977	-0.152
TRADE	5.193**	0.263	1.824	-	-0.849**
Model 3: ELECTRICITY, GDP, CO_2& TRADE	ELECTRICITY	GDP	CO_2	TRADE	ECT(s)
ELECTRICITY	-	25.17*	16.14*	2.552	-0.882*
GDP	1.959	-	8.794*	2.967**	0.342**
CO_2	4.445**	2.613	-	0.651	0.808*
TRADE	1.809	2.404	3.983**	-	0.063
Model 4: NATURAL GAS, GDP, CO_2& TRADE	NATURAL GAS	GDP	CO_2	TRADE	ECT(s)
NATURAL GAS	-	19.83*	0.022	0.117	-0.410**
GDP	0.754	-	5.674**	2.774***	-0.044
CO_2	0.255	0.141	-	0.067	0.063
TRADE	2.528	0.497	9.587*	-	-0.407**

Notes: *, ** and *** indicate the significance at one, five & ten percentage level, respectively. Optimal lag length is determined by the Schwarz Information Criterion (SIC).

With respect to VECM results for crude consumption in India, the findings show that error correction coefficients of crude and trade are found to be statistically significant, implying they influence each other in the long-run. In other words, there exists bidirectional relationship between crude consumption and trade in the long-term. Besides, the results confirm a long-run causality running from GDP to crude consumption and trade in India. In the short-run, bidirectional causality exists between crude consumption and GDP and unidirectional causality runs from CO_2 emissions to GDP in India. Besides, the empirical results show crude consumption Granger cause trade in the short run.

With regards to electricity consumption, the error correction coefficients of electricity, GDP and CO_2 are found to be statistically significant, implying they influence each other in the long-run. In other words, there exists bidirectional relationship between electricity consumption, GDP and CO_2 emissions in the long-term. Besides, the results provide evidence of long-run causality running from trade to electricity consumption, GDP and CO_2 emissions in India. In the short run, unidirectional causality runs from GDP to electricity consumption in India. Besides, the short-run unidirectional causality runs from carbon dioxide emissions to economic activity and trade in India.

In the case of natural gas consumption in India, the VECM results show that error correction coefficients of natural gas and trade are found to be statistically significant, implying they influence each other in the long-run. In other words, there exists bidirectional relationship between gas consumption and trade in the long-term. Moreover, the results confirm a long-run causality running from GDP to natural gas consumption and trade in India. In the short-term, unidirectional causality running from gross domestic product to natural gas consumption and carbon dioxide emissions to gross domestic product and trade in India.

Table 04: Variance decomposition analysis

Variance Decomposition Analysis of Coal, GDP, CO_2& Trade				
Variance Decomposition of COAL				
Period	COAL	GDP	CO_2	TRADE
1	100.0000	0.000000	0.000000	0.000000
5	70.08109	5.117804	23.79644	1.004663
10	63.05149	8.328643	27.65131	0.968552
15	59.26603	9.683675	30.10009	0.950206
20	57.04810	10.53694	31.47491	0.940043
Variance Decomposition of GDP				
1	63.63431	36.36569	0.000000	0.000000
5	19.26341	54.89102	17.37998	8.465598
10	12.66932	61.36451	16.71650	9.249669
15	10.21676	63.38909	16.81756	9.576591
20	8.927959	64.50427	16.81679	9.750986
Variance Decomposition of CO2				
1	0.024123	25.62414	74.35174	0.000000
5	20.48326	50.89352	25.65842	2.964807
10	23.08963	58.30361	14.99465	3.612107
15	24.15417	61.08975	10.89380	3.862280
20	24.71655	62.56189	8.725955	3.995602
Variance Decomposition of TRADE				
1	0.959165	2.765994	8.379184	87.89566
5	6.543896	25.76967	5.051834	62.63460
10	7.441742	29.17591	3.505893	59.87646
15	7.790045	30.53142	2.920045	58.75849
20	7.973228	31.24746	2.611471	58.16784
Variance Decomposition Analysis of Crude, GDP, CO_2& Trade				
Variance Decomposition of CRUDE				
Period	CRUDE	GDP	CO_2	TRADE
1	100.0000	0.000000	0.000000	0.000000
5	64.28882	2.060338	9.308970	24.34188
10	61.94011	1.590501	5.962082	30.50731
15	61.47400	1.167124	4.379831	32.97905
20	61.17982	0.925259	3.473471	34.42145
Variance Decomposition of GDP				
1	11.73817	88.26183	0.000000	0.000000
5	19.27322	68.42815	9.216323	3.082307
10	19.90937	70.12028	6.658617	3.311727
15	20.45046	70.58629	5.549562	3.413692
20	20.74119	70.83497	4.953062	3.470778
Variance Decomposition of CO2				
1	1.378175	31.43432	67.03840	0.149108
5	1.065214	30.12236	68.67482	0.137601
10	0.936846	29.58763	69.34449	0.131025
15	0.869548	29.30073	69.70210	0.127627
20	0.317943	38.46897	61.21309	0.000000
Variance Decomposition of TRADE				
1	14.06644	9.665888	13.01371	63.25397
5	19.37388	25.87946	21.48293	33.26372
10	21.14794	27.97616	21.40248	29.47342
15	21.60292	28.65730	21.54288	28.19690

20	21.84401	29.01893	21.61484	27.52222
Variance Decomposition Analysis of Electricity, GDP, CO_2& Trade				
Variance Decomposition of ELECTRICITY				
Period	ELECTRICITY	GDP	CO_2	TRADE
1	100.0000	0.000000	0.000000	0.000000
5	55.10227	6.055591	36.77362	2.068516
10	50.84824	4.138257	43.12999	1.883520
15	48.44819	3.090455	46.64592	1.815431
20	46.98790	3.567980	45.98354	1.736780
Variance Decomposition of GDP				
1	23.41704	76.58296	0.000000	0.000000
5	13.36480	77.22090	8.045406	1.368893
10	10.64358	82.08788	6.353546	0.915001
15	9.737761	83.75860	5.804830	0.698810
20	9.245643	84.70539	5.461656	0.587314
Variance Decomposition of CO2				
1	9.877681	17.24129	72.88103	0.000000
5	8.144078	48.92592	41.74247	1.187531
10	5.915281	60.22235	32.55802	1.304357
15	4.952612	64.62378	29.10536	1.318253
20	4.420124	67.07229	27.17866	1.328917
Variance Decomposition of TRADE				
1	0.714265	5.388243	23.18306	70.71443
5	0.330084	20.05771	28.67658	50.93563
10	0.200573	21.40468	28.80022	49.59452
15	0.157875	21.93923	28.73968	49.16321
20	0.135238	22.21026	28.73400	48.92051
Variance Decomposition Analysis of Gas, GDP, CO_2& Trade				
Variance Decomposition of GAS				
Period	GAS	GDP	CO_2	TRADE
1	100.0000	0.000000	0.000000	0.000000
5	70.37112	14.90793	8.681430	6.039522
10	72.21473	11.71133	8.371585	7.702358
15	72.89495	10.40838	8.330057	8.366611
20	73.29054	9.689094	8.284211	8.736159
Variance Decomposition of GDP				
1	17.12006	82.87994	0.000000	0.000000
5	23.82996	68.02384	7.114714	1.031483
10	26.06495	67.40032	5.833545	0.701188
15	27.28989	67.12599	5.009375	0.574745
20	27.93868	66.98367	4.571935	0.505718
Variance Decomposition of CO2				
1	0.222507	43.36761	56.40989	0.000000
5	0.499581	47.41045	50.57266	1.517308
10	0.505637	48.68123	49.13841	1.674724
15	0.512758	49.10780	48.64554	1.733900
20	0.516257	49.33642	48.38183	1.765495
Variance Decomposition of TRADE				
1	11.50192	19.07904	1.694481	67.72456
5	15.01933	52.38691	2.258329	30.33543
10	15.91441	58.06024	1.800791	24.22455
15	16.23536	60.03128	1.652719	22.08064
20	16.39864	61.03101	1.575885	20.99447

The results of Variance Decomposition Analysis (VDA) for the individual sources of energy consumption, gross domestic product, carbon dioxide emissions and trade over a 20-period horizon are presented in Table 04. With regards to coal energy, the table results show that the carbon dioxide emissions account for 23.7 percentage of the variations in coal consumption at 5-year horizon and then it increases to 31.4 percentage at 20-year horizon. Following this, the GDP and trade explain only about 10.5 and 0.9 percentage of the shock in the coal consumption variable on the 20th year, respectively. Besides, the coal consumption account for 63.6 percentage of the variations in GDP variable initially and then it reduces to 8.9 percentage on the 20th year. Consistently, around 16.5 and 9.5 percentage of the shock in the coal consumption is explained by CO_2 emissions and trade, respectively, throughout the 20-year period.

Furthermore, the GDP, coal energy, and trade variable accounts for 62.5 percentage, 24.7 percentage and 3.9 percentage of the shock explained by CO_2 emissions on the 20th year, respectively. The GDP and coal energy variable explains about 31.2 and 7.9 percentage of the shock in the trade during the 20th year, respectively.

With regard to VDA of crude consumption, the table results show that trade explains about 34.4 percentages of the variations in crude consumption at 20th year. Following this, the CO_2 and GDP variable explains 3.4 and 0.9 percentage of the shocks in crude consumption, respectively. Besides, the crude consumption, CO_2 emissions and trade accounts for 20.7 percentages, 4.9 percentage and 3.4 percentage of the variations in GDP variable on the 20th year, respectively. The GDP variable account for 38.4 percentage of the shock explained by CO_2 emissions and influence of shock in the crude consumption is tend to be petite during the 20th year. Consistently, around 21.5 percentages of the shocks in the trade are explained by crude and CO_2 emissions throughout the 20-year period.

The VDA of electricity consumption reveals that CO_2 emission and GDP accounts for 45.9 and 3.5 percentage of the shock explained by electricity consumption during the 20th year, respectively. Besides, the electricity consumption, CO_2 emission and trade variables explain about 9.2 percentages, 5.4 percentage and 0.5 percentage of the shock in GDP, respectively. The GDP variable account for 67.0 percentage of the shock explained by CO_2 emissions and following this, the influence of electricity consumption and trade to variations in the CO_2 emission records to only about 4.4 percentage and 1.3 percentage, respectively, during the 20th period. The response of electricity consumption and CO_2 emissions to the shocks in trade records 0.13 and 28.7 percentage on the 20th period, respectively.

Finally, the results of VDA for the natural gas indicate that the carbon dioxide emissions, GDP and trade accounts for around 8.3 percentage, 10.0 percentage and 7.7 percentage of the variations in gas consumption, respectively, throughout 5-year horizon. Following this, the gas consumption, CO_2 and trade explains about 27.9 percentage, 4.5 percentage and 0.5 percentage of the shock in the GDP variable on the 20th year, respectively. Besides, the economic activity account for 49.3 percentage of the variations in CO_2 emission and the percentage of the shocks explained by gas consumption and trade on GDP is seem to be meagre. The gas consumption and CO2 emission variable explains about 16.3 and 1.5 percentage of the shock in the trade during the 20th year, respectively. By and large, the VDA for the individual sources of energy consumption in relation with economic activity, CO_2 emissions and trade appear to be consistent with the results obtained from the VECM discussed above.

5.0 Conclusion

The present study attempts to examine the causal nexus between various sources of energy consumption, viz. Coal, Crude Oil, Electricity and Natural Gas, CO_2 emissions, economic growth and trade in India using the Perron's (1989) unit root test, Gregory and Hansen (1996) cointegration test and Vector Error Correction Model. The study exhibit the long-run relationship between various sources of energy consumption, economic growth, CO_2 emissions and trade in India. The empirical results confirm that the high level of economic activity leads to more use of crude and natural gas energy in the long-term. And reciprocal relationship exists between economic activity and energy use of coal and electricity in the long-run, implying a high level of economic growth leads to a high level of energy consumption of coal and electricity and vice versa. Similarly, the feedback relationship exists between CO_2 emissions and consumption of electricity and coal in the long-term.

The study also confirms that foreign trade influences coal and electricity consumption in the long-term, suggesting a high level of foreign trade activity leads to a high level of energy use of coal and electricity in India. In addition, the trade and energy consumption of crude and natural gas are mutually reinforcing in the long-run.

In the short-term, the findings indicate that economic activity influences the consumption of coal, electricity and natural gas, implying a high level of economic growth leads to a high level of coal, electricity and natural gas consumption in India. The study detects short-term feedback relationship between economic activity and crude petroleum consumption. Besides, the short-run causal relationship exists from CO_2 emissions to economic activity in the case of various sources of energy consumption in India. However, the study confirms that various individual sources of energy consumption do not contribute any significant role towards foreign trade in the short-term, except crude petroleum consumption.

In view of the empirical evidence that economic growth fuels rate of various sources of energy consumption, i.e. coal, crude petroleum, electricity and natural gas in the Indian context, the present study suggests that economy needs to effectively implement energy efficiency measures and investment should be made in renewable energy resources in order to reduce the dependence on fossil fuels for sustainable growth. Although, the increasing levels of CO_2 emission positively influence high level of economic activity in India, there is an urgent need of more effective energy conservation policy to reduce the environmental pollution without affecting economic activity.

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