An empirical analysis of energy consumption and economic growth in India: are they causally related?

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Abstract: In this paper an attempt is made to present the energy scenario of India in terms of energy consumption, energy security and energy efficiency. Growth trends and the changes in growth trends of these variables have been estimated for the period 1981 to 2010. In addition, the study makes an attempt to study the causal relationship between energy consumption and GDP both at aggregate and disaggregate levels using cointegration and Vector Error Correction (VECM) methods. The empirical results reveal that India is energy insecure, in spite of an increase in energy efficiency. It seems energy consumption and GDP are bidirectionally related at the aggregate level. In view of these findings some policy suggestions have been provided.

JEL Classification: Q42; Q43; Q50; Q56

Keywords: Energy security, energy efficiency, causality, cointegration, VECM model, holistic approach, sustainable economic growth.

1. Introduction

India is one of the fastest growing economies in the world. Energy consumption is among the key inputs in attaining such growth. India's growth experience is somewhat different from the experience of developed countries as its energy requirements are growing faster leading to energy insecurity and due to the pollution impacts. Sustaining the present economic growth in India requires an increase in the energy security coupled with energy efficiency and with an effective policy of reducing CO_2 impacts. Energy security has become an important concern for the policy makers in India as it is vital to achieve the targeted economic growth of 9-10 percent in the coming years. India's energy consumption has grown at a trend growth rate of 4.5 per cent and the production by 3.72 per cent during 1981 to 2010. India accounts for 2.4 per cent of the world's total annual energy production, but consumes about 3.3 per cent of the world's total annual energy. With a targeted growth rate of 10% to 9 per cent and an estimated energy elasticity of 0.56 (for the period 2001 to 2010), the energy requirement in the country is expected to grow at 5.6 per cent in coming 5-6 years. Though primary energy consumption has increased significantly in absolute terms, India's per capita consumption of energy continues to be lower than many emerging economies. The Government of India in its mid-term review of the Tenth Five Year Plan recognized the fact that under-performance of the energy sector can be a major constraint in achieving a growth rate of 8% GDP during the plan period. It has, therefore, called for acceleration of the reforms process and adoption of an integrated energy policy. However, the relationship between energy and economic growth has different implications. If energy growth influences economic growth, and not vice versa, Increase in energy consumption is important to enhance and sustain economic growth. But this has environmental implications. And the policies aiming at energy conservation may retard economic growth. Contrarily, if economic growth influences energy consumption, energy conservation policies may be attempted with little or no significant impact on economic growth. Similarly if there is bi-directional causality, a combination of these policies may be attempted. If there is no causation between growth and energy consumption, they are independent, and the policies have to be attempted in each without bothering implications for the other. Following Kraft and Kraft (1978), several researchers have attempted to study the relationship between energy consumption and GDP though; the evidence is not conclusive.

The earlier works on causality between energy consumption and economic growth have been due to several authors. The authors have used several methodological approaches, varying time period data sets for different countries. These studies have involved several countries in cross-country context, and sometimes a single country in studying the cause and effect relationship between these two variables. Most of these are aggregative studies though, some have concentrated on disaggregate energy consumption such as oil, petroleum, coal and power. The evidence presented by these studies is mixed and not conclusive. However, the studies on the causal relationship using long period data of India are limited. There are no empirical studies which attempted the changes in growth and elasticities using time series data.

In view of the importance of energy consumption in influencing economic growth and its sustainability and the resultant environmental effects, the present work attempts to study the causal links between energy consumption and GDP of India both at aggregate and disaggregate levels. The study is arranged as follows: In the next section we present the brief review of relevant empirical studies on the issue.

Section III is on data and econometric model. In section four, we present the empirical findings. The final section is on conclusions and policy implications.

2. Review of literature

In this section, we attempt a brief review of empirical literature available on the subject. Mukhopadhyay and Chakraborthy (2005) and Parikh and Chaitanya (1980) studied the energy intensity in India and claim that the energy requirements per unit value added are higher. Mitra (1992) observes that many developing countries are still using energy planning methods developed to face the challenges of advanced countries. Reddy and Balachandra (2005) looked at various parameters that influence the energy demand in India. Following Kraft and Kraft (1978), several researchers have attempted to study the relationship between energy consumption and GDP though; the evidence is not conclusive. Mallick (2009) examines whether energy use drives economic growth or vice versa in the Indian context during 1970–71 to 2004–05. Using the Granger causality test, the study suggests that it is the economic growth that fuels more demand for both crude oil and electricity consumption and it is the only growth of coal consumption that drives economic growth. When influence of different components of energy on the two major components of economic growth is investigated with the same causality test, none of the energy components found to be significantly influencing the two components of economic growth, viz. private consumption and investment (Granger, 1969 Granger, 1988). In contrast, the variance decomposition analysis of Vector Autoregression (VAR) suggests that there could be a bidirectional influence between electricity consumption and economic growth, other results remaining unchanged (Johansen,1988; Johansen,1991). Therefore, the study yields mixed and contradictory results. The evidence of bi- directional relationship is found in the works of Ghazi and El- Sakka (2004) and Jumbe (2004) which have analyzed Canada and Malawi respectively. On the opposite, the works of Rufael (2005) and Morimoto and Hope (2004) in Shangai and Sri Lanka show the presence of unidirectional causality running from energy consumption to economic growth. The results of Soyatas and Sary (2006) are once more mixed. Oh and Lee (2004) find evidence of a long-run bi-directional causal relationship and a short-run unidirectional causality running from energy to GDP in Korea.

Besides, Yoo and Jung (2005) find support for unidirectional causality from nuclear energy consumption to economic growth for Korea. In an examination of the causal relationship between nuclear energy consumption and economic growth for a sample of six countries (Yoo and Jung, 2005). Yoo and Ku (2009) provide evidence of unidirectional causality from nuclear energy consumption to economic growth for Korea; unidirectional causality from economic growth to nuclear energy consumption for France and Pakistan; bidirectional causality between nuclear energy consumption and economic growth for Switzerland; and the absence of a causal relationship between nuclear energy consumption and economic growth for

Argentina and Germany. However, these two studies examined the causal relationship between nuclear energy consumption and economic growth within a bivariate framework (Yoo and Ku, 2009).
As Apergis and Payne (2010) in their study examines the relationship between nuclear energy consumption and economic growth for sixteen countries within a multivariate panel framework over the period 1980–2005. As cited by Apergis and Payne that Pedroni's (1999, 2004) heterogeneous panel cointegration test reveals there is a long-run equilibrium relationship between real GDP, nuclear energy consumption, real gross fixed capital formation, and the labor force with the respective coefficients positive and statistically significant. The results of the panel vector error correction model finds bidirectional causality between nuclear energy consumption and economic growth in the short-run while unidirectional causality from nuclear energy consumption to economic growth in the long-run. Thus, the results provide support for the feedback hypothesis associated with the relationship between nuclear energy consumption and economic growth (Apergis and Payne, 2010).

According Apergis and Payne (2010) there are four hypotheses have been associated with the causal relationship between energy consumption and economic growth. First, the growth hypothesis postulates that energy consumption can directly impact economic growth and indirectly as a complement to labor and capital in the production process. The presence of unidirectional causality from energy consumption to economic growth confirms the growth hypothesis. Second, the conservation hypothesis suggests that energy conservation policies which reduce energy consumption and waste will not have an adverse impact economic growth. Apergis and Payne concluded that the conservation hypothesis is supported if there is unidirectional causality from economic growth to energy consumption. Third, the feedback hypothesis asserts that energy consumption and economic growth are interrelated and may very well serve as complements to each other. The feedback hypothesis suggests there is a bidirectional causal relationship between energy consumption and economic growth. Fourth, the neutrality hypothesis considers energy consumption to be a relatively small component of overall output and thus will have little or no impact on economic growth. As in case of the conservation hypothesis, energy conservation policies would not adversely impact economic growth. The absence of a causal relationship between energy consumption and economic growth lends support for the neutrality hypothesis (Apergis and Payne, 2010).

Fatai, et al., (2004) collected data for the selected countries from the International Energy Agency (IEA) energy database which comprises annual data 1960–1999, for coal, oil, gas, electricity and total final energy consumption. All data were transformed to natural logarithms. Fatai, et al., (2004) attempted to study the close relationship between energy consumption and real GDP growth and found that energy conservation policies are likely to affect real GDP growth. They examined the possible impact of energy conservation policies on the New Zealand economy and compared with Australia and several Asian economies. They confirmed that there is causality between energy consumption and GDP in New Zealand further investigated as is the causal relationship between GDP and various disaggregate energy data (coal, natural gas, electricity and oil). In this study, they also found that energy conservation policies may not have significant impacts on real GDP growth in industrialized countries such as New Zealand and Australia compared to some Asian economies (Fatai, Oxley and Scrimgeour,2004).

Fatai, et al., (2004) found evidence of a unidirectional link from real GDP to aggregate final energy consumption and unidirectional link from real GDP to industrial and commercial energy consumption in New Zealand and Australia. They further revealed that in the case of the four Asian economies: India, Indonesia, Thailand and The Philippines, a unidirectional link from energy to income was established for India and Indonesia and a bidirectional link for Thailand and The Philippines (Fatai, Oxley and Scrimgeour,2004). Our study has taken different years 1981-2010 and we mainly focused on Indian energy consumption.

In another study Akilo (2008) examines the causal relationship between energy consumption and economic growth for eleven countries in sub-Saharan Africa. Using the auto-regressive distributed lag (ARDL) bounds test, the study finds mixed results. With the exclusion of the obvious differences among countries in terms of structural and economic policy characteristics, the multiplicity of results obtained depend upon the variables adopted and, above all, from the methodological approach followed to test causality. Initially using the standard Granger test and the Sims' methodology the causal relationships are tested. These two approaches assume that data series are stationary. As pointed out by Granger (1988) these tests do not permit to find any long-run information between the variables, being able to capture only the short-run relationships. For this reason, the empirical findings of causal linkages based on these tests are often inconsistent. Later, researchers have begun to employ a cointegration approach which is now considered as the most appropriate to investigate for causality since it overcomes the problem depicted before. Kraft and Kraft (1978), Akarca and Long (1980), Yu and Wang (1984), Erol and Yu (1987), Hwang and Gum (1991), Stern (1993), Masih and Masih (1997), Glasure and Lee(1997), Asafu-Adjaye (2000), Yang (2000), Soytas, Sari and Ozdemir (2001), (Guttormsen,2004), and Rufael (2005) are studies which have made important contributions to the literature.

There are also studies which examine energy by separating it into its sub-components such as electricity and petroleum. Ghosh (2002) examined economic growth and electricity consumption of India and found a uni-directional causality relationship from economic growth to electricity consumption. Jumbe (2004) found the relationship between electricity consumption and GDP for Malawi for the period between 1970 and 1999 and found a bi-directional causality relationship. However, when he examined the relationship between non-agriculture GDP and electricity consumption, he found a unidirectional causality relationship from GDP to energy consumption. Rufael (2006) examined the relationship between electricity consumption ad GDP for 17 African countries for the period between 1971 and 2001 and found mixed results. Nachane, Nadkarni and Karnik's research (1988) using the Engle-Granger cointegration approach found long-run relationship between energy consumption and economic growth for 11 developing countries and five developed countries. Similar methodologies were also used in other studies. However, these results were ambiguous.

3. Data and the econometric model

The basic source for the data collection is the Planning Commission, India. The study period considered for the empirical analysis was 1981 to 2010. The data on variables such as energy consumption, production, and imports at the aggregated level and for various sub-components such as coal, petroleum, electricity, natural gas, and nuclear power have been collected for this period. The data on real GDP has been collected from the Economic Survey of India. More precisely the dataset comprise annual measures of GDP in constant prices and of various energy components. All the series have been transformed into natural logarithms for the required computations. An empirical analysis involving growth rates, elasticities and causality has been attempted for the study period.

To study the trends in energy consumption, production and imports for the total energy and its various components a semi-log functional form has been estimated and the growth rates have been computed as g=b*100. A double-log functional form has been estimated in computing the energy elasticity (which is measured as the ratio of growth rate of GDP to the growth rate of energy), captures both the structure of the economy as well as the efficiency. Similarly, the changes in trends in growth and elasticities of various components of energy have been computed. For this purpose, the study period has been divided into three sub-periods, viz; 1981 to 1990, 1991 to 2000 and 2001 to 2010. A linear trend growth model with the intercept and slope dummies has been employed to verify changes in the trends. Two measures of energy security indicators have been employed in this study: i) Energy Security Indicator in terms of Imports, which is defined as a ratio of energy imports to total energy consumption (ESIM) and ii) Energy Security Indicator in terms of production, which is defined as a ratio of energy production to total energy consumption (ESIP). Energy security requires a decline in ESIM and also an increase in ESIP. In order to verify the causality, we examine the relationship between energy consumption and GDP of India using a two-step procedure as follows:

The first step investigates the existence of a unit root in the variables. Since many macroeconomic series are non-stationary, unit root tests are useful to determine the order of integration of the variables and, therefore, to provide the time-series properties of data, the Philips – Perron test (1988) has been employed.
The second step explores the causal relationship between the series. If the series are stationary, then the standard Granger's causality test should be employed. But, if the series are non-stationary and the linear combination of them is stationary, the ECM approach should be adopted. For this reason, testing for cointegration is a necessary pre-requisite to implement the causality test. We have used Johansen's method for verifying the cointegration between natural logs of energy consumption and GDP.

The present study utilizes Johansen maximum likelihood procedure for co integration test using maximum Eigen-value and Trace statistics. However, in the first step, Phillips – Perron (1988) unit root test is used to verify the degree of integration. The test (PP) proposes an alternative non-parametric method for serial co-relation when testing for a unit root among the variables. The PP method estimates the non-augmented Dicky-Fuller test (1979) equation and modifies the t ratio of the coefficient so that serial correlation does not affect the distribution of the test statistic. If the presence of co integration is confirmed by Johansen test, the vector error correction (VEC) model can be used to show the direction of causality relationship.

4. Empirical Findings

The trends in growth and elasticities at the aggregate level and for various sources of energy consumption have been computed dividing the study period (1981 to 2010) into three sub-periods, viz; 1981 to 1990, 1991 to 2000 and 2001 to 2010. The sub-periods have been chosen on the basis of an economic reasoning that the first sub period represents passive liberalization and the later periods, economic reforms and active liberalization in India. The linear trend growth equation of the following type has been used to see the changes in the trends in variables:

$$L_n\ Y = \alpha + \beta_t + (\alpha_1 - \alpha)D_1 + (\alpha_2 - \alpha_1)D_2 + (\beta_1 - \beta)D_{1t} + (\beta_2 - \beta_1)D_{2t}$$

Where D_1 = 0 for the period 1981 to 1990 and D_1 = 1 for the remaining period , D_2 = 0 for the period 1991 to 2000 and D_2 = 1 for the remaining period, α and β are intercept and slope parameters for the period 1981 to 1990 and a_1 and b_1 are those for the period 1991to 2000. Similarly a_2 and b_2 are those for the period 2001 to 2010.

L_n Y= Natural logarithm of Y, say energy consumption

$(\alpha_1 - \alpha)$ = differential intercept for the second sub-period

$(\alpha_2 - \alpha_1)$ = differential intercept for the third sub-period

(β_1 – b) = differential slope coefficient (growth rate) for the second sub-period
(b_2 – β_1) = differential slope coefficient (growth rate) for the third sub-period
α = intercept for period one
β = Slope coefficient (growth rate) for the period one.

4.1 Trends in energy security

The increase in ESIP and the decline in ESIM indicate a decline in energy dependence and therefore, an increase in energy security. These ratios have been computed and a linear trend equation with intercept and slope dummies has been used to verify the changes in energy security over the study period. The results presented in table 1 reveal that energy insecurity is on increase in India. The model used is as follows:

$$Y_t = \alpha + \beta + (\alpha_1 - \alpha)D_1 + (\alpha_2 - \alpha_1)D_2 + (\beta_1 - \beta)D_{1t} + (\beta_2 - \beta_1)D_{2t}$$

Where, Y_t is a measure of energy security, D_1 =0 for 1981 to 1990 and =1 for the rest of the period, D_2 =0 for 1991to 2000 and =1 for the remaining period. And t=time.

Table 1 Energy Security Trends in India

Variable	1981 to 1990	1991to 2000	2001 to 2010
ESIM	-1.0	0.0	1.0
ESIP	2.0	-1.0	-2.0

Source: Computed by the authors.

4.2 Trends in Energy Consumption

Energy consumption and energy insecurity move together. As energy consumption increases energy insecurity also increases. To trace this, we have studied the trends in energy consumption in India using the same model. For this purpose, both total energy and various sources of energy have been used. We have estimated the trends in growth and elasticity for coal and lignite separately. Coal is the most important energy source in India as it constitutes 50 per cent of the total energy. It is an important source of generating power in India. Therefore, we have studied the trends in coal energy consumption to start with. The directional growth rates have been computed using the following model

$$L_n Y_t = \alpha + \beta_t + (\alpha_1 - \alpha)D_1 + (\alpha_2 - \alpha_1)D_2 + (\beta_1 - \beta)D_{1t} + (\beta_2 - \beta_1)D_{2t}$$

Where, $L_n Y_t$ is the natural log of coal and t is time. Other coefficients have the same meaning as explained above. Below we present the growth rates of energy consumption for various sources including coal:

Table 2 Growth Rates of Energy Consumption in India

Energy source	1981 to 1990	1991 to 2000	2001-2010
Coal	3.33	3.01	6.03

Lignite	17.87	5.18	3.06
Oil	9.88	7.02	3.45
Petroleum	7.69	1.71	0.67
Natural Gas	20.76	7.13	5.99
Hydro Power	-4.68	1.00	9.00
Nuclear Power	19.15	12.57	2.59
Wind Power	-5.30	14.28	19.58
Com. Energy	4.06	5.08	5.86
Total Energy	3.90	8.14	4.50

Source: Computed by the authors

The results indicate that coal consumption is growing at an average rate of 3.33 per cent during the first sub period, 3.01 per cent in the second sub period and 6.03 per cent in the third sub-period. Coal and lignite combined are the largest source of energy in India meeting about 55 per cent of commercial energy requirement. The lignite consumption is not sizeable, and the growth shows a decline continuously. However, the growth of coal has been stable in the second sub-period and has grown at 5.18 per cent in the third sub-period. The lignite has increased by 17.87% during first sub-period. It has declined in the second sub-period and further to 3.06 per cent during the third sub-period. Therefore, the growth trends in the lignite sector have continuously declined. The trends in growth rates of these sources of energy are as expected as their efficiency is at a lower level and due to substitution of other energy sources.

The decade of the 1970's has witnessed major oil supply disruptions. During the 1970s, the OPEC has cut down its oil production causing severe oil supply distortion to the developing as well as developed countries. From 1975 onwards the oil prices remained high and only during recent period, they came down and started rising again. During 1980, due to rising oil prices the second oil shock had taken place. And during October, 1990, Iraq invaded Kuwait leading to a phenomenal rise in oil prices. However, during the 90s the oil price shock has been absorbed and the impact was not as serious as it was during the 1980's. Due to these turn of events, energy consumption of oil has been impacted and the growth rate of the oil consumption reveals this picture. When we locate the table mentioned below, it is clear that oil energy consumption in India has grown by 9.88 per cent during the first sub-period, i.e. 1980-81 to 1990-91, and this has slowed down slightly during the second sub-period to 7.02 per cent. Similarly, in the third sub-period, the oil consumption has fallen further by 3.45 per cent. The decline in the growth rates of energy consumption of oil reflects the price volatility on the oil front. Analogously, the petroleum consumption has increased by 7.69 per cent during the first sub-period and declined to 1.71 per cent during the second period. The growth in consumption of petroleum has further dwindled to 0.67 per cent during the third sub-period. Both oil and petroleum energy consumption growth had similar trends reflecting the situation in international oil price rise and volatility.

The consumption of natural gas in India has grown by 20.76 per cent during the first sub-period and came down to 7.13 per cent during second sub-period. This growth has further fallen to 5.99 per cent during the third sub-period. Though, the growth rate in the consumption of natural gas has been showing a decline over the three sub-periods, it is still one of the fastest growing energy consumption components in India.

India is one of the largest producers of electricity power in the world. It is ranked sixth in the annual electricity consumption, accounting for about 3.5 per cent of the world's total annual energy consumption. India's need for power has increased at a phenomenal rate as it is one of the strategic components of sustaining economic growth. When we locate the growth trends in energy consumption of power, the following results emerge. The growth trends of three sources, viz. hydro power, nuclear power, and wind power have been presented in the same table. It has been perceived that hydro power was growing at a negative growth rate of 4.68 per cent during the first sub-period and this trend has been reversed during the second sub-period as the hydro power energy consumption has increased by 1 per cent. This has further increased to 9 per cent during the third sub-period. Thus, the energy consumption of hydro power has increased astoundingly during 2000-01 to 2009-10. When we look at the growth trends of energy consumption of nuclear power, a somewhat different picture emerges. It has grown by 19.15 per cent during the first sub period and fell to 12.51 per cent during the second sub-period and further declined to 2.59 per cent. Similarly, wind power was growing at a negative growth rate of 5.3 per cent during first sub-period, has started rising at 14.28 per cent and it has further increased to 19.58 per cent which clearly shows that an increasing interest in consuming wind energy as a source of power. The growth trends in the power energy reveal the importance of hydro power and wind power. Thus the growth trends of various components of energy have presented mixed trends during these sub periods. Similar mixed trends are noticed at the aggregate level also.

Total Energy Consumption

Total energy consumption in India is growing at 3.9 per cent during the first sub-period and it has risen to 8.14 per cent during the second sub-period. However, it has declined to 4.5 per cent during the third sub-period. Incongruous to this, commercial energy has grown at 4.06 per cent in the first sub- period, and continued to grow at 5.08 per cent and 5.09 per cent in the succeeding sub-periods.

Total Energy Production

We now present the trends in the growth of energy production in India. The total energy production in India has grown by 4.82 per cent during the first sub-period and has risen to 7.51 per cent. However, it came down to 3.72 per cent during the third sub-period. Therefore, in the recent period, energy consumption is growing by 4.5 per cent and the production is growing by 3.72 per cent leading to a widening gap between production and consumption. This has led to an increase in the imports of energy during this period.

Energy Imports

As the gap between energy production and consumption is widening, the imports of energy started rising in India. This is apparent from the below mentioned table. The imports of energy in India, though they expanded at a negative growth rate during the first sub-period, have started rising at 11.84 per cent during the second sub-period, and correspondingly in the third sub-period, they have risen by 7.19 per cent.

Table 3 Trends in Energy consumption, Production and Imports

	1981 to1990	**1991 to 2000**	**2001 to 2010**
Energy Consumption	3.9	8.14	4.5
Energy production	4.82	7.51	3.72
Energy Imports	-12.73	11.84	7.19

Source: Computed by authors

4.2 Energy Elasticity and Efficiency in India Total Energy

Below we present the trends in the elasticities for the sub-periods as mentioned above. These elasticities are energy elasticities which measure percentage change of GDP produced for a given one percentage change in energy consumption. Obviously an increase in this ratio indicates an increase in the energy productivity, i.e. energy efficiency. Thus energy elasticity is used to measure energy efficiency. The linear trend model with intercept and slope dummies has been used as follows:

$$L_n Y_t = \alpha + \beta L_n EC_t + (\alpha_1 - \alpha)D_1 + (\alpha_2 - \alpha_1)D_2 + (\beta_1 - \beta)D_1 L_n EC_t + (\beta_2 - \beta_1)D_2 L_n EC_t$$

Where, $L_n Y_t$ is the natural log of GDP, $L_n EC$ is the natural log of energy component. The remaining coefficients have the same meaning (in terms of elasticities) as explained earlier.

Table 4 Energy elasticity and Efficiency in India

Energy source	**1981 to 1990**	**1991 to 2000**	**2001 to 2010**
Coal	1.04	1.61	1.38
Lignite	-0.57	0.93	1.76
Oil	-0.49	3.66	4.26

Petroleum	-0.55	1.18	2.28
Natural Gas	0.26	0.79	0.84
Hydro Power	1.31	1.12	0.79
Nuclear Power	1.02	0.43	-0.21
Wind Power	---	0.39	0.30
Com. Energy	0.26	1.11	1.47
Non Com. Energy	1.16	5.17	3.96
Total Energy	-1.31	0.45	1.78

Source: Computed by the authors.

Note: For wind power, the data are not available for the first sub-period.

The above table indicates that the energy efficiency has increased in India during the study period. Though it was negative during the first sub-period, it has increased to 0.68 during the second sub-period and further to 1.79 during the third sub-period, which clearly indicates an increase in energy efficiency in India. The energy elasticities are also computed for the different sources of energy and are presented in the following tables:

The elasticity of commercial energy was 1.0 in the first sub-period. It has increased to 1.15 during the second sub-period and it further increased to 1.47 during the third sub-period. Thus, the commercial energy in India has been efficient in all sub-periods during the study period.

The elasticity of non-commercial energy was 1.16 in the first sub-period. It has increased to 5.17 during the second sub-period and it has fallen to 3.96 during the third sub-period. Thus, the non-commercial energy in India shows a heightening in efficiency for the first two sub-periods though there was a decline during the third sub-period.

The Energy Efficiency of different sources of Energy

In this section, we present the energy elasticities for various sources of energy to verify whether it has been is rising for the above mentioned sub-periods.

The elasticity of coal was 1.04 during the first sub-period. It has increased to 1.61 during the second sub-period and dwindled slightly to 1.39 during the third sub-period. It is evident that coal has been efficient during the study period though the efficiency has declined during the third sub-period. The elasticity of lignite was negative during the first sub-period. It has increased to 0.93 during the second sub-period and has slightly increased to 1.76 per cent during the third sub-period. It is evident that lignite has been efficient during all the sub-periods and the efficiency has increased constantly.

The elasticity of natural gas was 0.20 during the first sub-period. It has increased to 0.93 during the second sub-period and further increased to 1.76 during the third sub-period. The natural gas has been efficient during the study period and the efficiency has increased in all the sub-periods.

The elasticity of oil was -0.49 in the first sub-period. It has increased to 3.66 during the second sub-period and has further increased to 4.34 during the third sub-period. Thus, the oil energy in India shows a rise in elasticity during the second and third sub-periods. The elasticity of petroleum was -0.55 in the first sub-period. It has increased to 1.18 during the second sub-period and further to 2.28 during the third sub-period. Thus, the petroleum energy in India shows an increase in efficiency during the second and third sub-periods. The elasticity of hydropower was 1.32 in the first sub-period and has fallen both in the second and sub-periods by 1.12 and 0.79, respectively implying a decline in efficiency during the second and third sub-periods. Similarly, the elasticity of nuclear power was 1.02 in the first sub-period and has declined both in the second and sub-periods by 0.43 and -0.21, respectively.

The elasticity of wind power during the first sub-period has not been computed owing to non-availability of the data. Therefore, the model has been adjusted to compute the elasticities for the remaining two sub-periods. The elasticity of wind power in India was 0.04 during the second sub-period and it has increased to 0.30 during the third sub-period indicating an increase in the efficiency. From the above discussion, it is clear that energy efficiency in India is rising except a few energy sources such as coal and nuclear power.

4.3 Energy Elasticity, Energy Growth and Economic Growth

We have made an endeavour in this section to project the required energy consumption growth for sustaining a 10 per cent economic growth for the coming years in India. The projection is centred on the energy data collected from the Planning Commission of India. The energy data are in MTOE and the GDP data are in constant prices. The projection is based on the assumption that the energy elasticities remain stable and the projected economic growth would be around 10 per cent in coming years. India has experienced a decline in the growth rate in the recent years due to global slowdown. However a recovery has started by now. A constant elasticity functional form (double-log functional form) has been used taking energy consumption as the dependent variable and the GDP as the independent variable. Energy growth projection is made using the product of energy elasticity (ratio of % change in energy consumption to the % change in GDP) and economic growth. The following table presents these results:

Table 5: Energy Elasticity, Economic Growth and Energy Growth in India

Energy Component	**1981 to 1990**	**1991 to 2000**	**2001 to 2010**	**GDP Growth**	**Energy Consumption Growth**	**Projected Energy Demand (MTOE)***
Total Energy Consumption	0.09	1.47	0.56	10%	0.56*10%=5.6%	685.45
Commercial Energy	0.87	0.87	0.68	10%	0.68*10%=6.8%	520.29
Non-Commercial Energy	0.86	0.19	0.25	10%	0.25*10%=2.5	165.98
Coal	0.96	0.62	0.72	10%	0.72*10%=7.2	234.77
Lignite	-	1.07	0.57	10%	0.57*10%=5.7	9.59
Natural Gas	5.0	1.26	1.19	10%	1.19*10%=11.9%	55.42
Oil	-	0.27	0.23	10%	0.23*10%=2.3%	153.45
Petroleum	-	0.85	0.44	10%	0.44*10%=4.4%	354.83
Hydro Power	0.76	0.89	1.26	10%	1.26*10%=12.6%	4.72
Nuclear Power	0.98	2.32	-	10%	2.32*10%=23.2%	10.04
Wind Power	-	25.64	3.33	10%	3.33*10%=33.3%	1.16

Note: Energy demand is projected based on 10 per cent GDP growth and the energy consumption growth for the period, 2001 to 2010.

The above table indicates two things: 1) An increasing efficiency in India's energy sector that may be due to several factors, some of them being demographic shifts from rural to urban areas, structural economic changes towards lesser energy intensive industry, impressive growth of services, improvement in efficiency of energy use, and inter-fuel substitution and 2) A required energy growth of 5.6 per cent to sustain 10 per cent rate of India's growth in the coming years.

4.4 Causality between Energy Consumption and GDP

Energy growth is one of the important arguments for economic growth. The sustainability of economic growth obviously depends on achieving energy security. The growth in energy consumption sets a limit for achieving sustainable economic growth. Studying the causal relationship between energy consumption and economic growth is important particularly for a country like India, as it is growing around 6 per cent and expected to grow around 10 per cent in coming years. In order to acquire and sustain such high levels of growth, achieving energy security is very important. This also should result in pollution free economic growth.

The results of the Philips-Perron unit root test for levels and first difference of the variables are presented in the following tables. As the table shows, all variables are non-stationary in levels (except petroleum) and stationary in first difference. Thus, they are integrated with order 1 (I (1).

Table 6: Results of Phillips-Perron Unit Root Test

Variables	**Levels**	**First Difference**
LGDP	-0.30	-5.02*
LTOTAL ENERGY	-5.39	-13.17*
LCOM ENERGY	-3.05	-7.59*
LCOAL	-2.12	-4.58*
LNGAS	-2.67	-4.73*
LHP	-1.54	-4.42*
LNP	-2.88	-6.718*
LOIL	-2.09	-2.87***
LPET	-3.14	-5.27*

*Source: Authors' Calculations. *= Significant at 1 per cent; **= Significant at 5 per cent; ***= significant at 10 per cent.*

Table 7: Johansen Cointegration Test results: Trace Test and Max Eigen-value Test

Series	**λ Trace Statistic**	**λ Max Eigen-Value**
LGDP,LTOTAL ENERGY	27.00	18.39
LGDP,LCOMENERGY	23.79	20.28
LGDP,LCOAL	18.33	19.29
LGDP,LNGAS	29.81	20.58
LGDP,LHP	30.94	28.59
LGDP,LNP	25.46	23.47
LGDP,LOIL	24.58	19.51
LGDP,LPET	39.79	30.61

Note: The Trace and Max Eigen value statistics are significant at 0.05 probability level rejecting the null hypothesis of no cointegration (r=0). Thus there is at least one cointegrating equation

The above Table shows the co integration test results. According to Johansen's cointegration test the value of the calculated Maximum Eigen-value and Trace test statistics are greater than their critical values which denote the rejection of the hypothesis of non-cointegration as well as long-run neutrality hypothesis. This clearly shows that, all the energy components and the GDP are in long run equilibrium. There exists a long run equilibrium relationship between these variables.

The results of the VECM model estimation have been shown in the following tables for the causality relationship between real GDP and energy and for components of energy consumption separately. For the brevity, only the coefficients of lagged variables with their t values in the brackets are presented.

Tab le 8: Vector Error Correction Estimates: LGDP, LTOTALENERGY

	D(LGDP)	**D(LTOTAL ENERGY)**
Cointegration equation 1	0.029416 (1.57)	-0.542901(-2.61)*
D(LGDP(-1)	0.009197(0.04)	5.10114(2.15)*
D(LGDP(-2)	0.125670(0.20)	6.535582(2.23)*
D(LTOTAL ENERGY(-1)	-0.037771(-2.18)*	-0.645204(-3.37)*
D(LTOTAL ENERGY(-2)	-0.018637(0.01)	-0.090215(0.12)
Constant	0.056347(3.07)*	-0.535115(0.20)

*Note: * indicates the significance at 0.05 probability level. Figures in the parentheses are corresponding t values and LGDP is log of GDP, LTOTAL ENERGY is log of total energy Consumption respectively.*

As most of the lagged variables of GDP and the total energy consumption (-1) are statistically significant, it may be concluded that energy consumption and GDP of India are mutually causally connected. This is understandable because energy consumption is one of the variables influencing GDP from the demand side and sustenance of economic growth requiring certain amounts of energy consumption growth.

Table 9: Vector Error Correction Estimates: LGDP, LCOMENERGY

Error Correction	**D(LGDP)**	**D(LCOM ENERGY)**
Cointegration equation 1	0.011889 (1.37)	-0.103298(-2.63)*
D(LGDP(-1)	-0.028120(-0.14)	1.487645(1.62)
D(LGDP(-2)	0.133310(0.64)	2.107389(2.23)*
D(LCOMENERGY(-1)	-0.087849(-2.03)*	-0.142001(-0.72)
D(LCOM ENERGY(-2)	-0.032228(-1.07)	0.073755(0.54)
Constant	0.062325(3.52)*	-0.131233(-1.64)

*Note: * indicates the significance at 0.05 probability level. Figures in the parentheses are corresponding t values and LGDP is log of GDP, LCOM ENERGY is log of Commercial energy Consumption respectively.*

The results indicate that some of the lagged variables of commercial energy consumption and GDP are statistically significant indicating bidirectional causality between commercial energy and GDP of India. We have studied the causality between energy consumption and GDP using other energy components. As most of the lagged variables for these variables are statistically insignificant at 0.05

probability level, we conclude that they are independent of each other. Below we present the results for the other components of energy:

Table 10: Vector Error Correction Estimates: LGDP, LCOAL

Error Correction	**D(LGDP)**	**D(LCOAL)**
CointEq1	0.024018 (0.01594)	0.200763 (0.08043)
D(LGDP(-1))	-0.086676 (0.21058)	-0.014881 (1.06234)
D(LGDP(-2))	0.032614 (0.19592)	1.424858 (0.98839)
D(LCOAL(-1))	-0.092091 (0.05473)	0.036308 (0.27612)
D(LCOAL(-2))	-0.097977 (0.05868)	0.139788 (0.29602)
C	0.081831 (0.02100)	0.004813 (0.10594)

Note: Figures in the parentheses are t values and LGDP is log of GDP, LCOAL is log of Coal Consumption respectively.

Table 11: Vector Error Correction Estimates: LGDP, LOIL

Error Correction	**D(LGDP)**	**D(LOIL)**
CointEq1	-0.000313 (0.00027)	0.001352 (0.00067)
D(LGDP(-1))	-0.234999 (0.30642)	-0.134462 (0.75184)
D(LGDP(-2))	-0.051911 (0.29534)	-0.456719 (0.72465)
D(LOIL(-1))	0.027927 (0.07953)	0.399554 (0.19515)
D(LOIL(-2))	0.033970 (0.06681)	-0.217527 (0.16392)
C	0.071514 (0.02683)	0.043282 (0.06584)

Note: Figures in the parentheses are t values and LGDP is log of GDP, LOIL is log of oil Consumption respectively.

Table 12: Vector Error Correction Estimates: LGDP, LPET

Error Correction:	**D(LGDP)**	**D(LPET)**
CointEq1	-0.000313[-1.14380]	0.001352[2.01132]
D(LGDP(-1))	-0.234999[-0.76693]	-0.134462[-0.17884]
D(LGDP(-2))	-0.051911[-0.17577]	-0.456719[-0.63026]
D(LPET(-1))	0.027927[0.35114]	0.399554[2.04743]*
D(LPET(-2))	0.033970[0.50849]	-0.217527[-1.32704]
C	0.071514 (0.02683)	0.043282 (0.06584)

*Note: * indicates the significance at 0.05 probability level. Figures in the parentheses are t values and LGDP is log of GDP, LPET is log of petrol consumption respectively.*

Table 13: Vector Error Correction Estimates: LGDP, LNGAS

	D(LGDP)	**D(LNGAS)**

CointEq1	0.024018[1.50649]	0.200763[2.49616]*
D(LGDP(-1))	-0.086676[-0.41160]	-0.014881[-0.01401]
D(LGDP(-2))	0.032614[0.16646]	0.033482[1.44159]
D(LNGAS(-1))	-0.092091[-1.68249]	0.036308[0.13149]
D(LNGAS(-2))	-0.097977[-1.66969]	0.139788[0.47222
C	0.081831[3.89668]*	0.004813[0.04543]

*Note: * indicates the significance at 0.05 probability level. Figures in the parentheses are t values and LGDP is log of GDP, LNGAS is log of natural gas consumption respectively.*

Table 14: Vector Error Correction Estimates: LGDP, LHP

Error Correction	**D(LGDP)**	**D(LHP)**
CointEq1	-0.012600[-0.73489]	0.200155[2.27206]*
D(LGDP(-1))	0.165110[0.76433]	1.322794[1.19178]
D(LGDP(-2))	0.082775[0.39132]	-0.045408[-0.04178]
D(LHP(-1))	0.073524[1.67475]	0.220451[0.97730]
D(LHP(-2))	-0.042364[-0.85841]	0.192345[0.75854]
C	0.044820 (0.01773)	-0.055976 (0.09108)

*Note: * indicates the significance at 0.05 probability level. Figures in the parentheses are t values and LGDP is log of GDP, LHP is log of Hydro power Consumption respectively.*

5. Conclusions and policy implications

1. Econometric estimation for the energy sector in India reveals that all the variables such as production, consumption, and imports have been growing for all the subsectors. However, the gap between energy consumption and production has widened leading to net imports. There is an evidence of increasing energy import dependence in India leading to energy insecurity. The energy insecurity has increased in the second sub-period and remained more or less the same during the third period.

2. The growth trends of energy at the sub group level have shown mixed trends with a faster trend during the decade immediately after the advent of economic reforms in India. Total energy consumption in India has grown at 3.9 per cent during the first sub-period and further by 8.14 per cent during the second sub-period. However, it came down to 4.5 per cent during the third sub-period. While, the commercial energy has grown at 4.06 per cent in the first sub period, and continued to grow at 5.08 per cent in the subsequent period. Energy production in India has grown at 4.82 per cent

during first sub-period and has risen to 7.51 per cent and at 3.72 per cent during the subsequent periods.

3. The gap in the growth rates of energy consumption and production led to an increase the growth of energy imports in India. The growth of energy imports rose to 24.57 per cent during the second sub-period and similarly in the later period, they rose by 20 per cent. From the empirical results, it can be concluded that energy consumption, production in India have been growing, but the gap between these two has widened.

4. The energy efficiency has been increasing in India during the study period. The elasticity, though it was insignificant during the first sub-period, has increased to 0.45 during the second sub-period and further to 1.78 during the third sub-period, which clearly indicates an increase in energy efficiency in India after economic reforms have been introduced. The commercial energy in India has been efficient in all sub-periods during the study period. The non- commercial energy in India has shown an increase in efficiency for the first two sub-periods though there was an evidence of decline during the third sub-period.

5. Johansen's cointegration test denotes the rejection of the null hypothesis of non-cointegration between the variables and thus supports the long-run neutrality hypothesis. Thus GDP and energy consumption including the disaggregated components of energy are cointegrated. Considering the lagged explanatory variables T-statistics and their significance levels, it can be seen that in the short-run, there is bidirectional Granger causality running from energy consumption to real GDP at the aggregate level.

6. There is an evidence of bidirectional causality between energy consumption and GDP of India. Due to the significance of error correction coefficients in energy consumption equations, a deviation in energy consumption will be adjusted to equilibrium value in the long-run. In view of these empirical findings the following policy measures may be suggested:

Policy implications

1. Achieving energy security and its sustainability need a holistic approach in which development needs and environmental implications have to be integrated. The linkages between energy, environment and economic development are important in framing the policies of achieving and sustaining energy security. India should evolve strategies of sustaining energy security leading to inclusive economic growth with least environmental hazards.

2. Increase in the efficiency of energy consumption is important in attaining energy security. India should aggressively pursue cost-effective opportunities to improve energy efficiency and reduce energy intensity. A competitive market without any entry barriers is the most efficient way of attaining energy security.

3. The bidirectional causation between energy consumption and GDP has several implications. India should attain energy security to sustain its economic growth. At the same time, proper energy conservation policies are also needed which do not hamper the attained economic growth. In the process, it should reduce carbon related problems with proper energy mix and by reducing its dependence on fossil fuels.

4. Appropriate investment climate is an important element of energy security. A continuous flow of investment and technology to discover, develop and exploit new resources; and technology transfer from industrialized countries is necessary. There is an urgent need for increased technological research.

5. The strategies to attain the energy security are constrained by the country’s energy resources. India needs to diversify energy supplies in order to insulate the economy from any future shock on the energy front. Fossil fuels provide dependability and grid stability right through the year and will form the backbone of the energy supply chain.

6. In the medium-term, India should achieve higher efficiencies of energy utilization, reduction of distribution losses, up gradation of grid stability for absorbing increased quantum of renewables and promotion of renewables. The country should also engage itself in the development of emerging fuels such as hydrogen, storage devices, and nano- technologies.

7. In the long-term, India should start cutting back on the fossil fuels and improve the production in favor of clean renewables such as, solar, wind, tidal, hydro, plug in vehicles, bi-fuel engines (hydrogen plus diesel, hydrogen plus natural gas), nuclear, etc. Thus, India’s strategy should move towards expanding the energy baskets, neutralizing the flip side aspects of fossil fuels and other energy forms, priority to clean and energy sources and finally a total shift to clean and renewable energy by making it affordable.

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