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Modeling Energy Efficiency and Economic Growth: Evidences from India

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ABSTRACT: India's fossil fuel based energy-led economic growth has changed its pattern over a time and it is mainly driven by energy efficiency. In this paper, we have considered reduction in energy waste as a proxy of energy efficiency and analyzed its interplay with economic growth for 1971-2010. We have used Vector Error Correction model, and it has been seen that unidirectional causality exists from economic growth to energy waste, and this causal association is both short run and long run in nature. Moreover, energy waste is following a negatively elastic relationship with the economic growth along the energy efficiency frontier.

Keywords: Economic Growth; Energy Waste; India, Vector error correction
JEL Classifications: O44; Q42; Q43

1. Introduction

Indian growth history has been fairly a grown up subject matter of interest for researchers across the world. Since 1971, India is experiencing an elevated decadal average growth rate. Beginning with a decadal average of 3.08 per cent in 1971-80, the gross domestic product (GDP) has ascended to 5.57 per cent in 1980-2000 and 7.47 per cent in 2001-10. Enabler of this significant growth is the energy consumption, which was evident in the form of electrical power consumption (Ghosh, 2002). During 1971-2010, fossil fuel energy consumption of India has gone up to more than two and half times. It can be said that this intensification in electrical power consumption has heightened the economic growth. Indian economic growth and energy consumption follow a causal relationship, which says that energy consumption is the reason behind economic growth of India (Cheng, 1999). Within the boundary of this established causal association, we will consider only the one segment of energy consumption, i.e. the fossil fuel energy consumption.

However, certainly there is shadow beneath the lamp. Elevated fossil fuel based energy consumption has also heightened the level of emission in the environment. Majority of the power utilized in economic development is power generated from fossil fuels. During 1971-2010, amount of fossil fuel consumption as a fraction of total power consumption has almost doubled. This has resulted in huge level of Carbon Dioxide (CO_2) emission in the atmosphere. During 1971-2010, CO_2 emission has gone up from 205,869.05 kilo tons in 1971 to 1,979,424.60 kilo tons in 2010, i.e. nearly an increase of 9.61 times. Consequently, the amplified utilization of fossil fuel, which is facilitating the economic growth of India, is as well worsening the atmosphere. Nevertheless, this phenomenon is quite understandable for the case of India, as for a developing nation, attracting more investment and employment of the same is endowed with more importance than the environmental protection (Acharyya, 2009). This underestimation of environmental damage can in turn bring harm to the economic growth. Nevertheless, the amount of combustible energy waste has been reducing, which signifies the enhanced energy efficiency in India, which has been catalyzed by public-private partnership (Sinha-Khetriwal *et al.*, 2005). On one hand, when gradually rising fossil fuel energy consumption is affecting the environment, then on the other hand, rising ecological awareness is lowering the amount of energy waste. They sound to be contradictory, but for India, it is a fact. Besides the rise in greenhouse gas emissions, during 1971-2010 percentage of combustible waste as a percentage of total energy consumption has been reduced to 24.89 per cent from 61.22 per cent.

Looking at the present economic growth scenario in India, researchers have stated that demand for commercial energy in India is going to encounter a rise within next decade (Asif and Muneer, 2007). After economic liberalization in 1991, economic growth was set in pace, and in order to sustain that growth, combustible fossil fuel generated energy was required. However, in order to keep their carbon footprints intact, most of the developed nations try to dump their polluting technologies to developing and underdeveloped nations, and this phenomenon was not different for India, as well (Marton, 1986; Siddharthan and Lal, 2004). Due to this scenario, the ambient air, water, and soil pollution started to rise in the post-liberalization period, and in order to combat this situation, efficient energy management technologies were required by the industrial houses of India. Economic growth of India demanded higher consumption of energy, and the pattern was in turn degrading the environment. Therefore, there was a need to bring forth changes in the growth pattern in terms of introducing alternate sources of energy, thereby, reducing energy waste and enhancing energy efficiency.

If we look at the literature on energy economics, then we can see that analysis of energy efficiency has been carried out in several contexts, which were started after the pioneering works in this field is by Khazzoom (1980), Brookes (1990), and Saunders (1992). Howarth (1997) has analyzed energy efficiency in terms of cost of energy and expenditure on energy services, Smulders and De Nooij (2003) have analyzed it in terms of energy conservation, Pérez-Lombard *et al.* (2008) have analyzed it through emergence of energy efficient buildings. Bozkurt and Akan (2014) have carried out this study for Turkey, Hu and Wang (2006) have done it for China, Stern (1993) has done it for USA, Mahadevan and Asafu-Adjaye (2007) have done it for developing and developed nations, Shahateet (2014) has done it for Arab countries, Wolde-Rufael (2006) has done it for African nations, Hondroyiannis *et al.* (2002) have done it for Greece and etc. However, this is quite surprising to notice that there is not a single study in Indian context, which we have encountered, and considering the oil-importing nations across the world, India holds a significant position, and, therefore, a study on Indian context can prove out to be significant from policymaking perspective. There lies a gap in the existing literature, and this is the focus of our paper.

In this study, we intend to analyze the effect of economic growth on the energy efficiency in a trivariate framework consisting of economic growth, energy efficiency, and energy consumption. For this study, we have chosen energy waste as the proxy for energy efficiency, as reducing energy spillover is an indicator of energy efficiency, which is predominant in Indian context. The rest of the paper is divided in three sections. In the second section details of the econometric methodology has been discussed, in the third section the results has been analyzed, and in the fourth and last section the concluding remarks of the study has been summarized.

2. Econometric Methodology

In this section, we will discuss about the econometric methodologies applied to look into the association between economic growth, energy consumption, and energy waste. To start with, we should check the integration characteristics of the data. For this purpose, unit root tests have been applied. If variables in the dataset are I(1) in nature, then cointegration test is used to look into the long run equilibrium association among them. Based on the findings of aforementioned test, order of integration will be found, and that will ensure the applicability of error correction model (ECM), based on which directions of causality among the variables are found. In the subsequent sections, we will discuss these methodologies one by one.

2.1 Investigation for Integration

In most of the cases, time series economic data exhibits non-stationary nature, as their central tendencies are found to be upwards over a long period. However, in order to investigate the considerable long run association among the variables, carrying out non-stationarity test becomes essential. This test primarily focuses on order of integration, at which point considered variables become stationary in nature. The test is carried out on the level data, and subsequently on differentiated forms of the variables. For this purpose, we will apply augmented Dickey-Fuller test (Dickey and Fuller, 1981), Phillips-Perron test (Phillips and Perron, 1988), and Kwiatkowski-Phillips-Schmidt-Shin test (Kwiatkowski *et al.*, 1992). These three tests will be conducted for checking the serial correlation, heteroscedasticity, and deterministic trend present in variables under consideration. Following are the test statistics considered for each of the cases:

Augmented Dickey-Fuller (ADF) test: $\left(\frac{\sigma^2}{\lambda^2}\right)^{1/2} .t_{\pi=0} - \frac{1}{2}\left(\frac{\lambda^2-\sigma^2}{\lambda^2}\right)\left(\frac{T.SE(\pi)}{\sigma^2}\right)$ (1)

Phillips-Perron (PP) test: $T\pi - \frac{1}{2}\left(\lambda^2-\sigma^2\right)\left(\frac{T^2.SE(\pi)}{\sigma^2}\right)$ (2)

Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test: $\left(T^{-2}\sum_{t=1}^{T} S_t^2\right) / \lambda^2$ (3)

Where, $\sigma^2 = \lim_{T\to\infty} T^{-1}\sum_{t=1}^{T} E\left[u_t^2\right]$ (4)

$$\lambda^2 = \lim_{T\to\infty}\sum_{t=1}^{T} E\left[T^{-1}S_t^2\right] \quad (5)$$

$$S_t = \sum_{t=1}^{T} u_t \quad (6)$$

2.2 Investigation for Cointegration

Cointegration is an econometric methodology to investigate the subsistence of long run equilibrium association among variables. This is imperative from an algebraic perspective, as progression of the variables over a long timeframe adjusts the inconsistencies being appeared along the shorter durations. In accordance with Dickey *et al.* (1991), if the cointegrated association among variables is not present or weak in nature, then probability of existence of variability in their long-term movement is very high. In view of the existence of this cointegrated association among variables, conducting a regression analysis becomes significant. However, for any number of non-stationary time series variables to be cointegrated, it is imperative for their linear combination to be stationary in nature (Engle and Granger, 1987). However, it is seemingly not appropriate to stick to a methodology, which is capable of analyzing the cointegrated association between only two variables. That is the reason behind our preference of the cointegration testing methodology by Johansen and Juselius (1990) over the one that of by Engle and Granger (1987), as scope of our analysis is not confined by bivariate nature of analysis. Trace and maximum eigenvalue statistics are the two major components of this cointegration analysis (Johansen, 1988, 1991). We will discuss both of these two statistics.

Consider Y_t as an (n X 1) vector of I(1) integrated variables and ε_t as an (n X 1) vector of error terms. Then the vector autoregressive model (VAR) of order N can be expressed as per the following:

$$\Delta Y_t = \mu + \Pi \Delta Y_{t-1} + \sum_{i=1}^{N} \Gamma_i \Delta Y_{t-i} + \varepsilon_t \quad (7)$$

Where, $\Pi = \sum_{i=1}^{N} A_i - \mathrm{I}$ (8)

$$\Gamma_i = -\sum_{j=i+1}^{N} A_j \quad (9)$$

Precisely, $\prod$ contains the information about coefficients, which determine the nature of long run association among variables under consideration. Rank of this matrix, which determines number of cointegrating vectors among variables, is calculated through two statistics, namely trace and maximum eigenvalue. The trace test embarks upon the null hypothesis of having cointegrating vectors equal to the rank of the matrix (say r) aligned with the alternate hypothesis of having cointegrating vectors of number n (< r). In case of the maximum eigenvalue test, it embarks upon null hypothesis of having cointegrating vectors equal to the rank of the matrix (= r) against the alternative hypothesis of having cointegrating vectors exactly one more than the rank of the matrix (= r + 1). The test statistics are as per the following:

Trace statistics (JJ_T) $= -T\sum_{i=r+1}^{n} \ln(1-\eta)$ (10)

Maximum eigenvalue statistics (JJ_{ME}) = $-T\ln(1-\eta_{r+1})$ (11)

Where, η = i^{th} principal canonical correlation

2.3 Investigation for Causality Association

In this section, we will make use of Granger causality test (Granger, 1969) to investigate the causal association encompassing parameters, namely economic growth, energy consumption, and energy waste for India. The Granger causality test based on error correction model (Toda and Phillips, 1993) can be formulated in the following manner:

$$\begin{aligned}\Delta\ln EG_t = a_0 + a_1\Delta\ln EG_{t-1} + a_2\Delta\ln EG_{t-2} + \ldots + a_n\Delta\ln EG_{t-n} + \\ b_1\Delta\ln EW_{t-1} + b_2\Delta\ln EW_{t-2} + \ldots + b_n\Delta\ln EW_{t-n} + \\ c_1\Delta\ln EC_{t-1} + c_2\Delta\ln EC_{t-2} + \ldots + c_n\Delta\ln EC_{t-n} + ECT_{t-1}\end{aligned} \tag{12}$$

$$\begin{aligned}\Delta\ln EC_t = a_0 + a_1\Delta\ln EC_{t-1} + a_2\Delta\ln EC_{t-2} + \ldots + a_n\Delta\ln EC_{t-n} + \\ b_1\Delta\ln EW_{t-1} + b_2\Delta\ln EW_{t-2} + \ldots + b_n\Delta\ln EW_{t-n} + \\ c_1\Delta\ln EG_{t-1} + c_2\Delta\ln EG_{t-2} + \ldots + c_n\Delta\ln EG_{t-n} + ECT_{t-1}\end{aligned} \tag{13}$$

$$\begin{aligned}\Delta\ln EW_t = a_0 + a_1\Delta\ln EW_{t-1} + a_2\Delta\ln EW_{t-2} + \ldots + a_n\Delta\ln EW_{t-n} + \\ b_1\Delta\ln EG_{t-1} + b_2\Delta\ln EG_{t-2} + \ldots + b_n\Delta\ln EG_{t-n} + \\ c_1\Delta\ln EC_{t-1} + c_2\Delta\ln EC_{t-2} + \ldots + c_n\Delta\ln EC_{t-n} + ECT_{t-1}\end{aligned} \tag{14}$$

Where, EG stands for economic growth, EW stands for energy waste, EC stands for energy consumption, and ECT_{t-1} is the lagged error correction term.

GDP is used as a proxy measure for economic growth (EG), combustible waste as a percentage of total energy is used as a proxy measure for energy waste (EW), and energy usage of oil equivalent is used as a proxy measure for energy consumption (EC). The annual data from 1971 to 2010 has been taken from the World Bank database. No major structural breaks are found for any of the three variables under consideration.

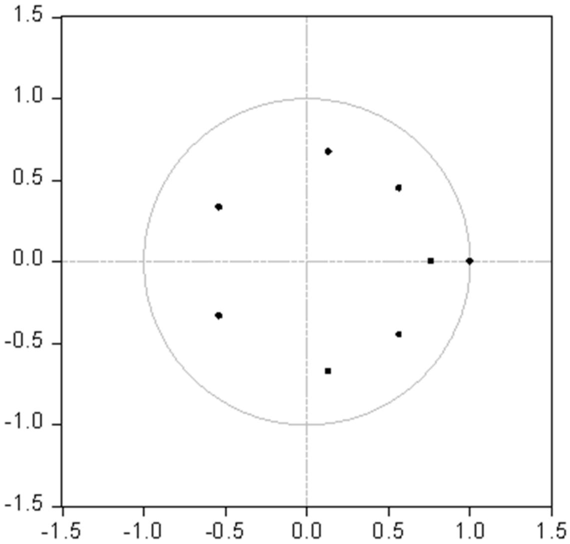
3. Analysis

Analysis of collected data starts with checking the stationarity nature of variables under consideration, for which unit root tests have been conducted. The results of unit root test are recorded in Table 1. It can be visualized that the level data does not show any indications of stationarity, which confirms existence of unit roots in all the four variables under consideration. Subsequently, we moved towards differencing them and conducting unit root tests on the differentiated variables. It is evident from the results that all the four variables are showing stationary nature after first differentiation. This result also confirms that the variables are I(1) in nature (Figure 1).

Table 1. Unit root test results

		ADF	*PP*	*KPSS*
Level				
Intercept	EG	0.501026	0.383000	0.769768
	EW	2.078668	1.983462	0.773819
	EC	1.424505	1.492853	0.781439
Intercept and Trend	EG	-0.822281	-1.177163	0.109605
	EW	-2.744440	-2.744440	0.129813
	EC	-2.106200	-2.236296	0.073878
First Difference				
Intercept	EG	-5.492174[a]	-5.583894[a]	0.201027
	EW	-5.320134[a]	-5.314678[a]	0.411684
	EC	-6.112145[a]	-6.116148[a]	0.235131
Intercept and Trend	EG	-5.468922[a]	-5.505470[a]	0.173178
	EW	-5.759701[a]	-5.754942[a]	0.130744
	EC	-6.296549[a]	-6.296575[a]	0.087963
a value at 1% significance level b value at 5% significance level				

Figure 1. Unit circle consisting of unit roots



Once it has been established that the variables are integrated of order one, it is needed to test the cointegration association between them. The cointegration testing methodology by Johansen and Juselius (1990) have been applied on the variables. The results are presented in Table 2. The results show that a brawny long run association subsists among the variables. Null hypotheses of having no cointegrating vectors have been rejected by both the statistics, and they show that one cointegrating vector is present between the variables. Based on these results, we can proceed for further analysis.

Table 2. Cointegration test results

Trace test				*Maximum Eigenvalue test*			
Null	*Alternate*	JJ_T	*Critical Value*	*Null*	*Alternate*	JJ_{ME}	*Critical Value*
$r \leq 0$	$r > 0$	27.68362[a]	24.27596	$r \leq 0$	$r = 1$	18.56885[a]	17.79730
$r \leq 1$	$r > 1$	9.114769	12.32090	$r \leq 1$	$r = 2$	6.274065	11.22480
≤ 2	$r > 2$	2.840704	4.129906	$r \leq 2$	$r = 3$	2.840704	4.129906
a value at 1% significance level "r" symbolizes the number of cointegrating vectors							

As we have seen the being of cointegration vectors among variables under consideration, we can proceed to formulate the ECM. The results of causality test are recorded in Table 3. Lag length selection criterion are provided in Table 4. Sequential modified LR test statistic (each test at 5% level), final prediction error, Akaike information criterion, Schwarz information criterion and Hannan-Quinn information criterion have been used for this purpose. We can see that unidirectional causality exists from economic growth to reduction in energy waste. Between energy waste and economic growth, the nature of causality is both long run and short run in nature, which is demonstrated by the error correction term of Eq. 14. However, error correction terms for Eq. 12 and Eq. 13 are not significant, and, therefore, the possibility of long run associations in those cases can be ruled out. A short run causal association subsists from economic growth to energy consumption, which has already been established by Paul and Bhattacharya (2004). However, we are not interested in this causal association, as this is already a well-established area in the literature of energy economics, and Ozturk (2010) has given a detailed literature survey on this aspect.

Table 3. Causality test results

	Independent Variable			*Error Correction Term*
Dependent Variable	ΔEG	ΔEW	ΔEC	
ΔEG	-	3.997988[c]	2.499220	0.028486
ΔEW	6.747354[b]	-	4.028595	-0.261548[c]
ΔEC	6.728901[b]	1.975873	-	0.359923
a value at 1% significance level b value at 5% significance level c value at 10% significance level		Deductions:	ΔEW <= ΔEG	

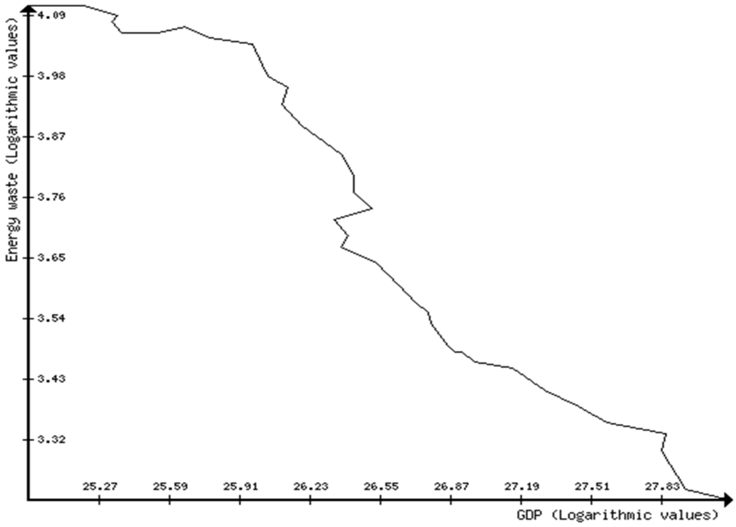
Table 4. Lag length selection results

Lag	*LogL*	*LR*	*FPE*	*AIC*	*SC*	*HQ*
0	106.5230	NA	6.38e-07	-5.751275	-5.619315	-5.705218
1	289.8563	325.9260*	3.98e-11*	-15.43646*	-14.90862*	-15.25223*
2	295.9775	9.861916	4.73e-11	-15.27653	-14.35281	-14.95413
3	307.3600	16.44142	4.27e-11	-15.40889	-14.08929	-14.94832
4	313.5701	7.935037	5.28e-11	-15.25389	-13.53841	-14.65514
LR: sequential modified LR test statistic (each test at 5% level) FPE: Final prediction error AIC: Akaike information criterion SC: Schwarz information criterion HQ: Hannan-Quinn information criterion						

By far, fossil fuel based energy consumption amounts to nearly 73 percent of the total energy consumption in India. Hence, for India, fossil fuel consumption is the primary reason for greenhouse blanket formation. From this perspective, it can be said that, whenever energy conservation practices are considered, it majorly poses impacts on the driver of economic growth and the externalities caused by growth. In this case, the externality is negative in nature, and is having the form of CO_2 emission. Therefore, to have a control over this negative externality, it is required to have energy efficiency, which can be indicated by lowering of combustible energy waste, the intervention used in this case. Considering India, formation of Petroleum Conservation Research Association (PCRA) in 1977, and Bureau of Energy Efficiency in 2001 are two major steps in bringing forth energy efficiency in Indian industrial scenario. Due to this, we can see that 10.86 percent growth rate of CO_2 emission per unit of fossil fuel consumption during first half of the study had come down to 0.84 percent during second half of the study period, indicating a nearing zero fossil fuel consumption elasticity of emission. Moreover, it also can be seen that the 2.16 percent average growth rate of fossil fuel consumption during first half of the study period has come down to 1.37 percent during second half of the study period. Indicating energy efficiency, the diminishing growth of fossil fuel consumption can have a possible causal effect on economic growth, due to which it became imperative to fuel economic growth via alternative and nuclear renewable resources, as fossil fuel consumption per unit of GDP has come down to 2.99 percent in 2010 from 8.49 percent in 1971.

By looking at the economic efficiency frontier in Figure 2, it can be said that the energy waste follows a negatively elastic relationship with the economic growth, which means that economic growth and energy efficiency are following a positive association, and this association is signified by the economic growth elasticity of energy waste i.e. -12.42 per cent. This entire scenario points towards achievement of a sustainable energy-led economic growth, which is characterized by going for alternate and renewable sources of energy, like nuclear power, solar power, wind energy, etc. The pattern of economic growth in India is itself calling for efficient energy management initiatives, in which the wastage and spillover of commercial energy can be reduced to the minimum extent possible. In addition, this demand, associated with the negative elasticity is characterized by the unidirectional causal association from economic growth to reduction in energy waste.

Figure 2. Energy efficiency frontier



Graphical reconfirmation of the aforementioned results has been provided as generalized impulse responses (Figure 3). Results of impulse response functions endow us with additional impending towards established causal associations among the variables. To set off this study, it is imperative to look into the long-run stability of the associations among the variables. For this purpose, we have carried out a series of diagnostic tests to check serial correlation (LM test), heteroscedasticity (White test) and stability test (Ramsey RESET test). The results those are recorded in Table 5, confirm the constancy of the model analyzing the associations among economic growth, energy consumption, and energy waste.

Figure 3. Generalized Impulse Responses

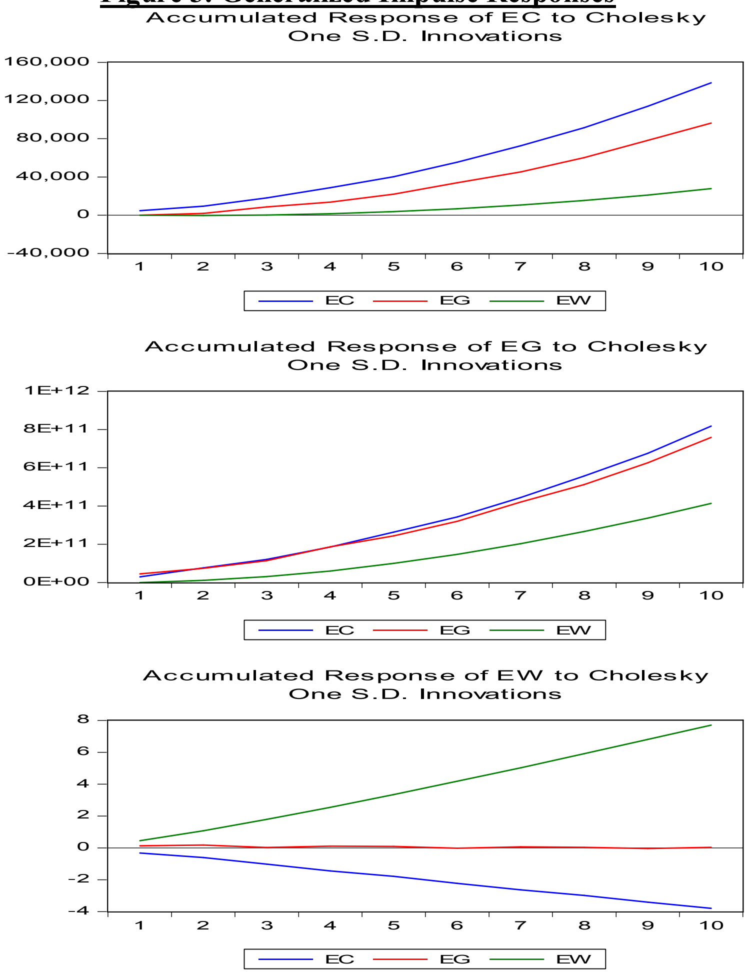


Table 5. Diagnostic test results

Variables	R^2	*Adj.* R^2	*LM*	*White*	*Ramsey RESET*
EG	0.991558	0.990855	15.97802[a]	3.936801[a]	119.1980[a]
EW	0.979841	0.978161	52.36818[a]	13.39543[a]	945.3439[a]
EC	0.996203	0.995887	10.18507[a]	4.438088[a]	20.69747[a]

4. Conclusion

The study investigates about the long-run causal associations among economic growth, energy waste, and energy consumption, considering the statistics for India during 1971-2010. The econometric analysis of the data substantiates the following findings:

First, the considered variables are showing stationarity after first differentiation, and they are first order integrated. Second, long run equilibrium associations among the variables are ensured by the presence of one cointegrating vector. Third, the econometric model shows unidirectional causal association from economic growth to reduction in energy waste, and this causal association is both short run and long run in nature.

This study by far concludes that devoid of an efficient energy management initiative, a sustainable economic growth objective can never be attained, as it acts as a mediating feature between energy consumption and energy waste. While focusing on policy decisions regarding economic growth, leaving apart the environmental aspects always poses a serious threat towards the sustainable growth objective, which is not desirable for a developing nation like India. This issue has been addressed by the established unidirectional causal association from economic growth to reduction in energy waste.

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