International Journal of Humanities and Social Science Research
www.socialsciencejournal.in
ISSN: 2455-2070
Received: 17-02-2024, Accepted: 12-03-2024, Published: 03-04-2024
Volume 10, Issue 2, 2024, Page No. 43-47

# An empirical investigation of the Energy-Led growth hypothesis in India

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**Abstract**
The present research paper seeks to examine the energy-led growth hypothesis in India by analyzing the time series data from 1990 to 2021. The classification of energy sources as renewable (RE) and nonrenewable (NRE) is determined through the composite index. The production of solar energy and hydropower is quantified in terawatt-hours. It is classified as renewable energy, whereas coal, oil, and gases are given as percentages to indicate non-renewable energy sources. The results from the dynamic ordinary least squares analysis indicate a positive and significant association between the independent variables (RE and NRE) and the dependent variable (EG). On the other hand Granger causality analysis reveals only a bidirectional causal connection between EG and RE. Additionally, the outcomes of the robustness results (FMOLS and CCR) confirm the findings obtained from the DOLS technique. Overall, the study provides evidence in support of the energy-led growth concept.

**Keywords:** Renewable energy, non-renewable energy, economic growth, DOLS model

## Introduction

Attaining sustainable economic growth (EG) while, preserving environmental quality is a fundamental objective of global development (Guang *et al*., 2023) [16]. The environment is deteriorating due to several reasons that determine its growth. Energy consumption (EC) is widely recognized as one of the primary causes of environmental degradation among various human activities (Dagar *et al*., 2022) [9]. On the other hand, EC contributes to perform a variety of economic functions and has been considered as a significant component of economic growth in all economies (Ahmad *et al*. 2023 [3]; Chiou-Wei, 2008) [8]. In recent decades, the complex relationship between EC and EG has gathered significant attention in India. As one of the fastest-growing economies, India faces the dual challenge of meeting its burgeoning energy demands while ensuring sustainable and inclusive economic development (Thambi *et al*., 2018) [44]. The concept of "energy-led growth" has emerged as a pivotal framework for understanding the interplay between energy dynamics and economic expansion (Behera, 2015) [7]. India's journey towards economic development has been marked by a substantial increase in EC across various sectors, ranging from industry and transportation to residential and commercial use (Shahbaz *et al*., 2016) [39]. This upswing in energy demand is intricately linked to the country's ambitious goals for industrialization, urbanization, and improving the standard of living for its vast population. Renewable (RE) and Non-renewable energy (NRE) sources play distinctive roles in India's energy condition. The country has been actively exploring the potential of renewable resources, such as solar and hydro-power, to address both energy security concerns and environmental sustainability Simultaneously, the reliance on non-renewable sources, including coal, oil, and natural gas, remains significant due to their immediate contribution to meeting the growing energy needs. Against this backdrop, researchers and policymakers are increasingly drawn to investigating the nexus between energy patterns and economic growth. This exploration involves examine the impact of renewable and non-renewable energy sources on the overall economic performance of the country. The temporal aspect is crucial, considering the dynamic nature of both energy technologies and economic systems. Through comprehensive analysis and empirical evidence, the research seeks to shed light on the pivotal role of energy in steering India's path toward sustainable and inclusive growth.

## Review of literature

Researchers have extensively examined the connection between GDP and EC across various countries. Various studies, including those by Munir *et al*. (2020) [29], Khan *et al*. (2020), Gozgor *et al*. (2018) [15], and Haseeb *et al*. (2017) [18], have revealed a positive correlation between EG and EC. However, these investigations differ in terms of time periods, methodologies, and study areas. Hasan *et al*. (2023) have found a distinctive perspective in their research and identified an inverted U-shaped effect of EC on EG, specifically in Spain. This finding contrasts with the general trend observed in prior studies. Additionally, many researchers tried to investigate the causal link between EG and EC. Kahia *et al*. (2016) [25] noted a one-way causation from EG to RE in the short-run but in the long run, the findings indicate the presence of bidirectional causality for the entire group of MENA (Middle East and North Africa). Furthermore, one-way causality was reported by Lee and Chang (2005) [27], Narayan and Smyth (2005) [31], Paul and Bhattacharya (2004) [33], Shiu and Lam (2004) [40], and Wolde-Rufael (2004) [45]. In contrast to these unidirectional results, several researchers, including Ali *et al*. (2023) [4], Pegkas (2020) [34], Adams *et al*. (2018) [1], Sinha *et al*. (2014) [42], Erdal *et al*. (2008) [11], Yoo SH (2005) [46], Jumbe (2004) [24], Hondroyiannis *et al*. (2002) [21], and

Ghosh (2002), have identified a bidirectional causal connection between EG and EC. Furthermore, Altinay and Karagol (2004) [5], Ghali and El-Sakka (2004) [13], and Halicioglu (2009) found no evidence of causality between EC and EG. In addition to exploring the overall impact of EC on EG, certain studies have investigated the distinct effects of RE and NRE consumption. For instance, research conducted by Ivanovski *et al.* (2021) [22] observed that RE and NRE consumption was identified as contributors to EG in non-OECD countries. This implies that developing nations may play a pivotal role in the transition to renewables, even amid challenges in technological advancements. Conversely, findings from Polat (2021) [36] indicated a positive correlation between NRE consumption and EG in developing countries. However, in developed countries, neither NRE nor RE consumption was observed to significantly impact EG. This suggests variations in the relationship between EC types and EG across different economic contexts.

By reviewing the existing literature, diverse outcomes have emerged. Some studies identified a unidirectional relationship, while others observed a bidirectional connection, and there were instances where no causal relationship was found. Additionally, there are a limited number of empirical studies specifically focused on India. Furthermore, the evolving or varying natures of EG and EC compel us to examine the relationship between these two variables in the India, especially in the aftermath of the introduction of the New Economic Reform in 1991.

**Methodology**

This study aims to assess the impact of RE and NRE consumption (independent variables), on the EG (dependent variable) in the context of India. NRE is characterized by three key variables: coal, oil, and gases. RE is represented by solar energy generation and hydropower generation, measured in terawatt-hours. Gross Domestic Product (GDP) taken to represents economic growth (EG). The data for these variables are obtained from the World Development Indicators published by the World Bank. The statistical results are based on the information collected for all these variables for a period of 32 years from 1990 to 2021. For both the factors (RE and NRE) affecting EG composite indices are prepared. The composite indices are computed using a simple weighted index method, preserving the distinctiveness of multiple units (Alam *et al.*, 2023) [3]. The results of these indices rely on the measurement of sub-indicators that lack a common and meaningful unit of measurement (Saisana and Tarantola, 2002) [38]. The computation of these indices involves four crucial steps: variable selection, data normalization, data weighting, and result summarization (Jones and Andrey, 2007) [23]. In this study, a standardization method was employed to summarize and assign weights to the indicators (Gbetibouo *et al.*, 2010) with the help of following expression.

$$Z_j = \sum_{i=1}^{n} W_i(x_{ij} - \bar{x}_i)/S_i \quad (1)$$

(Where, Z = index, W = weight, X = indicator value, $\bar{x}$ = mean, S = standard deviation, i the indicator, and j the specific region)

After categorizing the selected RE and NRE into two broader categories, a subsequent analysis will be conducted through regression analysis. For this, the unit root test will be applied using the Augmented Dickey-Fuller (ADF) Test (Dickey and Fuller, 1979) [6] using following equation:

$$\Delta Y_t = \beta_1 + \beta_2 Y_{t-1} + \sum_{i=1}^{k} \theta \Delta Y_{t-1} + u_t \quad (2)$$

Based on the ADF results, the study proceeds to analyze cointegration among variables using the Johansen cointegration technique. After obtaining the cointegration results, the study moved towards the dynamic ordinary least squares model (Stock and Watson, 1993) [43] rather than the vector autoregressive model or vector error correction model which, commonly used in multivariate time series analysis (Helmut, 2005) [20]. The DOLS model, on the other hand uses a single equation and the generalized least squares (GLS) method to account for errors that are linked in a series (Aigheyisi, 2020) [2]. Consequently, the study employs the DOLS methodology to capture the dynamic nature of the country's growth, with RE and NRE serving as independent variables and EG as the dependent variable with the help of the following equation

$$EG_t = \beta_o + \beta_1 RE_t + \beta_2 NRE_t + \sum_{j=0}^{K} \Delta\beta_1 RE_{t+k} + \sum_{j=0}^{m} \Delta\beta_2 NRE_{t+m} + u_t \quad (3)$$

(Where EG = Economic Growth, RE =Renewable Energy, NER= Non-renewable Energy β0= drift component, β1 to β2 are the coefficients, Δ=first difference operators and ut=Stochastic Error terms).

Additionally, to assess the direction of causality, the study employs the Granger causality test (Engle and Granger, 1987) [10]. FMOLS (Phillips and Hansen, 1990) [35] and CCR (Park, 1992) [32] are used as the last step to make sure the results are reliable. This is because FMOLS and CCR can deal with problems like endogeneity, small sample bias, and serial correlation (Musa *et al*., 2019) [30]. Given the strengths of these estimators, their outcomes are utilized as benchmarks to evaluate the robustness of the DOLS results (Qasim *et al*., 2023) [37].

**Results and discussion**

**Table 1:** Summary Statistics for Equation 2

| | Level | | First Differences | | |
|---|---|---|---|---|---|
| **Variable** | **t-Statistics** | **P-Value** | **t-Statistics** | **P-Value** | **Order of Integration** |
| EG | 0.621878 | 0.9881 | -5.154702 | 0.0002 | I(1) |
| RE | -1.131037 | 0.2289 | -7.781943 | 0.0000 | I(1) |
| NRE | -1.934670 | 0.3126 | -5.096644 | 0.0003 | I(1) |

**Source:** Author Calculation

The statistical details of equation 2 reveal that the series in the models are non-stationary at level 1, but they achieve stationarity after taking their first differences, indicating integration at order one at a 5 percent level of significance. Consequently, the study investigates the potential presence of cointegration among the variables.

**Table 2:** Lag Selection Criteria

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | 40.18504 | NA | 1.41e-05 | -2.656074 | -2.513338 | -2.612439 |
| 1 | 162.5621 | 209.7892* | 4.31e-09* | -10.75443* | -10.18349* | -10.57989* |
| 2 | 170.6007 | 12.05795 | 4.74e-09 | -10.68576 | -9.686611 | -10.38031 |

**Source:** Author Calculation, *indicates lag order selected by the criterion

**(LR:** sequential modified LR test statistic**, FPE:** Final prediction error**, AIC:** Akaike information criterion**, SC:** Schwarz information criterion and **HQ:** Hannan-Quinn information criterion**)**

The determination of lag length has been performed using the VAR Lag Order Selection Criteria. The results indicate that all criteria recommend a maximum lag of 1, as reported in Table 2. Consequently, subsequent econometric analysis will be conducted based on lag 1.

**Table 3:** Johansen Cointegration Results

| Hypothesized No. | Trace Statistics | P-value | Hypothesized No. | Max-Eigen Statistics | P-value |
|---|---|---|---|---|---|
| None* | 46.10744 | 0.0023 | None | 2067729 | 0.0828 |
| At most 1* | 25.43015 | 0.0088 | At most 1* | 19.60234 | 0.0124 |
| At most 2 | 5.827808 | 0.2045 | At most 2 | 5.827808 | 0.2045 |

**Source:** Author Calculation

Table 3 presents the findings of the Cointegration analysis based on the Johansen method. The trace statistic probability value shows the presence of two Cointegrating equations, while the Max-Eigen statistic probability value suggests the presence of a single cointegration equation. However, the Johansen cointegration findings confirm the existence of a long-run relationship between the variables.

**Table 4:** Summary Statistics for Equation 3

| Variable | Coefficient | t-Statistics | P-Value |
|---|---|---|---|
| RE | 1.874366 | 2.711153 | 0.0143 |
| NRE | 6.886060 | 2.446416 | 0.0249 |
| Constant | -13.54455 | -2.416075 | 0.0265 |
| R-Squared | | | 0.63 |

**Source:** Author Calculation

Table 4 exhibits the results obtained from employing the DOLS methodology, clearly depicting a positive and statistically significant relationship between independent variables and the dependent variable. Furthermore, the model showcases good explanatory power, as evidenced by the R-squared value (63 percent). A notable observation is that the contribution of non-renewable energy to economic growth surpasses that of renewable energy, with a percentage increase in NRE and RE corresponding to EG of 6.89 and 1.87 percent and respectively. Although NRE has a more influencing power than the RE on EG, the important of RE should not be understated. Importantly, this positive sign of the RE indicates well for the country's progress toward achieving sustainable development goals by 2030. Furthermore, after examining the probability values for both independent variables, it is evident that RE has a higher level of statistical significance in comparison to NRE. In summary, the findings provide overall support for the energy-led growth hypothesis.

**Table 5:** Granger Causality Results

| Hypothesis | Observation | F- Statistic | P-Value | Decision |
|---|---|---|---|---|
| RE does not Granger Causes EG | 31 | 3.22450 | 0.0833 | Causaliy |
| EG does not Granger Causes RE | | 5.80733 | 0.0228 | Causaliy |
| NRE does not Granger Causes EG | 31 | 1.34940 | 0.2559 | No Causaliy |
| EG does not Granger Causes NRE | | 2.04707 | 0.1644 | No Causaliy |

**Source:** Author Calculation

The findings of the Pairwise Granger causality test, as shown in Table 5, indicate a bidirectional causal relationship between EG and RE. Notably, no causal relationship is identified between EG and NRE.

### 1. Robustness results

**Table 6:** Robustness Results for Equation 3

| | FMOLS | | CCR | |
|---|---|---|---|---|
| Variable | Coefficient | P-value | Coefficient | P-value |
| RE | 1.157172 | 0.0032 | 1.578613 | 0.0072 |
| NRE | 6.091420 | 0.0638 | 5.560300 | 0.0515 |
| Constant | -11.59270 | 0.0s662 | -10.86124 | 0.0473 |

**Source:** Author Calculation

The results of the robustness tests, as depicted in Table 6, using the FMOLS and CCR approaches, closely align with the observations obtained from the DOLS technique. As a result, these findings validate and the conclusions derived from the DOLS method.

## Conclusion

The study examined the energy led growth hypothesis in India using dynamic ordinary least squares (DOLS) model comprising three variables, namely, economic growth (EG), renewable energy (RE) and nonrenewable energy (NRE). The empirical investigation of the Johansen cointegration confirm the existence of long-run relationships, whereas the findings of DOLS technique demonstrated that the associations of RE and NRE with EG are significant and positive. On the other hand the granger causality test shows that a bidirectional causal relationship between EG and RE. Additionally, the outcomes of the robustness results (FMOLS and CCR) confirm the findings obtained from the DOLS technique. RE seems to have a lesser impact on EG in India as compared to NRE. This is clear from coefficient values. However, the positive impact of RE on EG provides good sign for the country's progress toward achieving sustainable development goals by 2030. Finally the study provides evidence in favor of the energy-led growth concept.

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