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Energy Consumption and Economic Growth in India: Empirical Insights and Environmental Implications

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ABSTRACT

Economic growth of a nation depends upon several factors like GDP, energy consumption etc. which in turn reflects gas emissions and global warming. Thus, energy security and economic growth is an international problem. This paper represents economic model including GDP, energy inputs and other explanatory variables based on Cobb-Douglas production function. We have empirically analyzed the relation between Indian economic growth and energy consumption. The paper also reflects the relation of India's CO_2 emission to export trade. Time series data of GDP, energy consumption and CO_2 emission for the period 2001 to 2023 has been taken from financial reports of the RBI and World Bank. Augmented Dickey Fuller test has been used to check the stationary of the variables and both variables found stationary at 1% and 5% significance level respectively. The results of Granger causality test show no Granger causality exists in either direction from economic growth to energy consumption in India. The results of ordinary least squares test show positive relation between GDP and energy consumption in India. One percent increase in energy consumption will raise GDP by 1.85%. Diagnostic tests confirm that residuals are normally distributed, coefficients are stable and there is no ARCH effect.

KEYWORDS Energy Consumption, GDP, Cobb-Douglas production function, Ordinary Least Squares Method, Granger Causality

1. INTRODUCTION

Energy is a key driving force behind economic growth and development. Since energy consumption increases on economic growth, while a shortage in energy supply can hinder economic progress. Therefore, the availability, accessibility, and affordability of energy resources become critical factors for economic development. Global financial crisis with energy policies target influences linkages between energy consumption and economic growth. Planners are seeking the path of energy conservation for national energy needs. Shortage of energy due to oil crises in 1973 have affected the national economic growth and planners has to search other sources of energy to fulfil their requirement of energy consumption. The alternative sources are

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solar, photovoltaic, Biogas, Lithium-ion batteries etc. Planning for energy economics plays a crucial role in sustainable development for the nation. Several researchers are working out on above topic. John Asafu[1] in 2000 used co-integration and error-correction model technique to estimate energy consumption and income for India, Philippines, Indonesia and Thailand. He found unidirectional Granger causality from energy to income in India and Indonesia while bidirectional Granger causality in Thailand and Philippines. Similarly, Kojo Menyah and Yemane Wolde-Rufael [2] in 2010 have attempted to test the causal relationship between nuclear energy consumption and real GDP for nine developed countries from 1971 to 2005. They found a unidirectional causality running from nuclear energy consumption to economic growth in Japan, Netherlands and Switzerland; the opposite unidirectional causality running from economic growth to nuclear energy consumption in Canada and Sweden; and a bi-directional causality running between economic growth and nuclear energy consumption in France, Spain, the United Kingdom and the United States. They suggested to mitigate the adverse effects of nuclear energy consumption on economic growth. Further, Phung Thanh Binh [3] in 2011 investigated energy consumption and economic growth in Vietnam by Granger causality test and find out that energy consumption is not a limiting factor to economic growth in Vietnam. By his investigations Vietnam government started energy allocation into more productive sectors of the economy.

Table 1: India's export, import and CO_2 Emission Performance:

Year	India's percentage Share in Global Trade		
	Merchandise exports	Merchandise Imports	CO_2 emissions
2013	1.66	2.47	5.75
2014	1.69	2.43	6.19
2015	1.62	2.34	6.23
2016	1.65	2.21	6.35
2017	1.68	2.48	6.71
2018	1.67	2.57	7.10
2019	1.71	2.53	7.01
2020	1.57	2.09	6.40
2021	1.77	2.54	6.97
2022	1.8	2.8	7.43
2023	2.1	2.5	8.00

Following above discussion, we are going to find out the relationship between energy consumption and economic growth among India, China, Pakistan, USA and U.K. Time series data for the analysis has been collected from the financial reports of the RBI and World Bank for the period of 2001 to 2023. As we know that India is on third place, while China is the world's top energy consumer and CO_2 emitter. The gap between supply and demand can be reduced by saving energy in different areas of agriculture, industry and buildings. Following Monthly Bulletin on foreign trade statistics march 2024; the import –export and CO_2 emission performance of India can be represented as given Table 1.

The percentage of India’s share in global exports fluctuates slightly throughout the decade but generally trends upward. It starts at 1.66% in 2013 and rises to 2.1% by 2023. India's share in global merchandise imports shows a more varied trend. It starts at 2.47% in 2013, drops to a low of 2.09% in 2020, and then decreases again to 2.5% by 2023. This trend suggests that India's demand for imports decreased during economic downturns but rebounded as economic activity picked up post-pandemic. India's share of global CO_2 emissions shows a consistent upward trend, from 5.75% in 2013 to 8.00% in 2023. This increase indicates that India's carbon emissions have been growing at a faster rate compared to the rest of the world, which could be linked to industrial growth, increased energy consumption. India's coal-based power sector of 211 GW is largely responsible for making India the third highest CO_2 emitter in the world. In 2021, India accounted for 2.7 Giga tonnes of CO_2 emissions, representing 7.5 percent of global energy-related emissions. Following International Energy Agency’s (IEA), approximately 91% of CO_2 emissions is due to fossil fuels and industry. Thus, as the economy expands, energy consumption and CO_2 emissions may rise, contributing to environmental harm. On the other hand, economic growth can also drive innovation and investment in clean energy technologies, helping to mitigate environmental impacts. The objective of the research is to find out the relation between energy consumption and economic growth of India.

2. RELATION BETWEEN ENERGY CONSUMPTION AND ECONOMIC GROWTH

For this let us assume that H_0 represents no relation while H_1 represents positive relation between energy consumption and economic growth for a nation. Following Najid Ahmad et al[4], Cobb-Douglas Production Function is given by

$$N(G,E) = cG^{a}E^{b} \tag{1}$$

Where, N (G, E) denotes the relation between G and E of a country; G, E denotes national GDP and Energy Consumption respectively.

For the sake of convenience, let if, possible GDP of a country depends upon energy consumption of that country which may be expressed as

$$G = \alpha E^{\beta} \mu \,;\ \alpha > 0, \beta > 0 \tag{2}$$

where G is the Gross Domestic Product, α is the total factor productivity, E is the energy consumption, β is the coefficient of energy consumption and μ is the noise error term.

Now, taking log of both sides of the eq. (2), we get

$$logG = log\alpha + \beta logE + log\mu \tag{3}$$

Time series data of GDP and energy consumption has been taken from financial reports of the RBI and World Bank, represented by Table 2.

	Table 2: Time series data of GDP and energy consumption						
Years	GDP (US$)	Energy Consumption (exajoules)	CO_2 Emission (Billion tonnes)	Years	GDP (US$)	Energy Consumption (exajoules)	CO_2 Emission (Billion tonnes)
2001	485.44	13.48	.99	2013	1856.72	25.82	2.00
2002	514.94	13.92	1.02	2014	2039.13	27.56	2.15
2003	607.70	14.41	1.06	2015	2103.59	28.52	2.23
2004	709.15	15.65	1.13	2016	2294.80	29.80	2.35
2005	820.38	16.57	1.19	2017	2651.47	30.94	2.43
2006	940.26	17.46	1.29	2018	2702.93	32.69	2.59
2007	1216.74	18.95	1.39	2019	2835.61	33.52	2.61
2008	1198.90	20.05	1.49	2020	2671.60	31.76	2.42
2009	1341.89	21.55	1.61	2021	3150.31	34.51	2.67
2010	1675.62	22.48	1.68	2022	3416.65	36.44	2.83
2011	1823.05	23.71	1.76	2023	3737.00	39.00	2.90
2012	1827.64	24.99	1.93				

The Compound Annual growth rate of GDP, Energy Consumption and CO_2 Emission From 2001to 2022 are 9.5% ,4.6% and 5.4% respectively. Fig.1, represents the comparative growth in GDP and energy consumption in India from 2001 onwards.

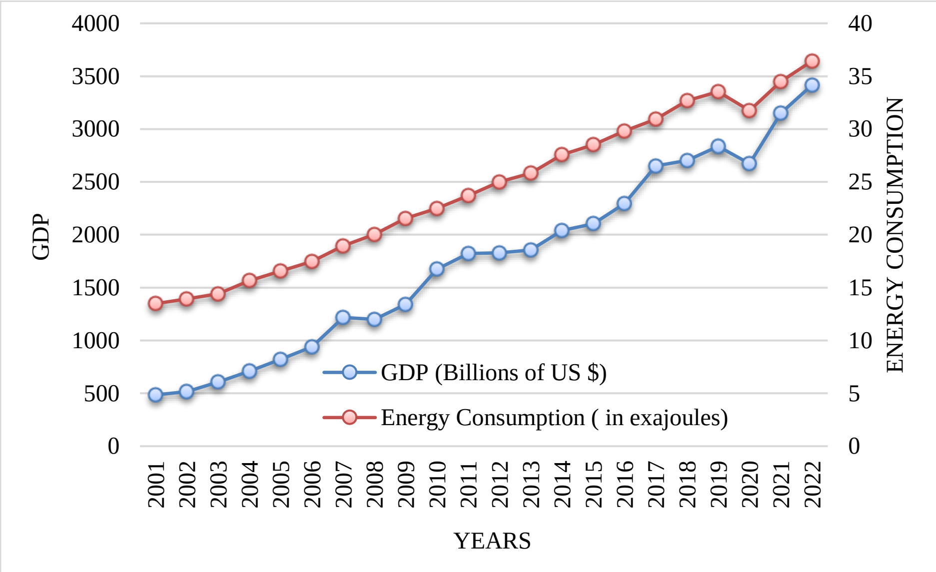

Fig. 1: Graph between GDP and Energy Consumption of India

We have used Augmented Dicky-Fuller (ADF) test to check the stationarity or to contain a unit -root of the variables (G and E) to approve the technique for the given sample. In above testing we have used E-views software which represent the trend with time. As we know that given series will be stationary only if the t-statistic value is less than the critical value. Similarly given series will be stationary only if p-value corresponding to a t-statistic is lower than the critical value. The computational results of ADF test for the difference value of log G and log E at 1% and 5 % significance level has been represented by Table 3.

Table 3: Results of Augmented Dickey-Fuller Test at Level

Variables	ADF (t critical) Value at 1% significance level	ADF (t critical) Value at 5% significance level	t-Statistic Value	Probability
D (log G)	-3.788030	-3.012363	-4.428472	0.0025
D (log E)	-3.788030	-3.012363	-4.604923	0.0017

but t static value in ADF test is less than the t critical value at both 1% and 5% significant level therefore both the series are stationary. In the same way the probability for both variables (log G and log E) are less than 0.05. Hence, H_0 hypothesis is rejected and we concluded that there is a relation between G and E. So ordinary least squares method will be appropriate technique for our computational model. But before applying Ordinary Least Squares we are applying Granger Causality test to check the direction of the variables. Following Granger causality test, we have

$$log\ G = \sum \emptyset_i logE_{t-1} + \sum \varphi_j logG_{t-1} + \mu t_1 \quad (4)$$

$$log\ E = \sum \alpha_i logE_{t-1} + \sum \gamma_j logG_{t-1} + \mu t_2 \quad (5)$$

The results of Granger Causality test are below.

Table 4: Results of Granger Causality Test

lags 2
Sample: 2001-2023

Null Hypothesis	Obs	F-Statistic	Probability
log E does not Granger Cause log G	21	0.60732	0.5569
log G does not Granger Cause log E	21	0.85692	0.4431

The results show that Energy Consumption does not Granger Cause GDP of India. The F-statistic of 0.60732 and the p-value of 0.5569 are both relatively high. This indicates that we fail to reject the null hypothesis, suggesting that past values of log E do not provide significant information in predicting current values of log G. Similarly, the F-statistic of 0.85692 and the p-value of 0.4431 indicate that we also fail to reject the null hypothesis here. This suggests that past values of log G do not significantly predict current values of log E. Therefore, changes in GDP do not Granger cause changes in energy consumption. So, no Granger causality exists in either direction from economic growth to energy consumption in India. Here The Durbin-Watson statistic is 0.679, which is significantly below 2 which is a common sign of a spurious regression. A spurious model is not acceptable. The t-statistic of 9.1841 and the associated probability (p-value) of 0.0000 indicate that this intercept is statistically significant.

Table 5: Result of Ordinary least Square Method

Dependent Variable: (log G)
Method: Least Square
Sample: 2001 2023
Included Observation: 23

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.646505	0.070394	9.184106	0.0000
Log E	1.855514	0.050923	36.43788	0.0000

R-squared	0.984430	Mean dependent var.	3.198229
Adjusted R-squared	0.983688	S.D. dependent var.	0.268647
S.E of regression	0.034311	Akaike info criterion	-3.823764
Sum squared residue	0.024722	Schwarz criterion	-3.725025
Log likelihood	45.97328	F-statistic	1327.719
Durbin-Watson stat.	0.679028	Prob (F-statistic)	0.000000

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The t-statistic for this variable is 36.4379, which is very high, with a p-value of 0.0000, indicating that energy consumption has a significant positive effect on GDP. The coefficient of energy consumption is 1.855514 that means 1 percent increase in energy consumption will raise GDP by 1.85 percent. Diagnostic tests are applied to check whether the series are free from heteroskedasticity and normality problems while stability test is used to check whether coefficients are stable or not. The results are given of diagnostic test are represented by Table 6. The normality test shows that the p-value (0.571262) is greater than 0.05, we fail to reject the null hypothesis which is a good sign for the model. The ARCH test is that there is no heteroskedasticity because the p-values for both the F-statistic (0.0086) and the Obs*R-Squared (0.0105) are less than 0.05, we reject the null hypothesis means no ARCH effect. There is no ARCH effect that is always desirable that a model should be free from ARCH effect. Ramsey RESET test is used to check the stability of the coefficients. The p-values for both the F-statistic and the t-statistic (0.0162) are less than 0.05, so we reject the null hypothesis. This suggests that the model may be miss-specified. So, there is no ARCH effect, residuals are normally distributed and coefficients are stable.

Table 6: Diagnostic tests	
Normality Test	
Jarque-Bera	1.119814 (0.571262)
Heteroskedasticity test: ARCH	
F-Statistic	8.480626 (0.0086)
Obs* R-Squared	6.550902 (0.0105)
Ramsey RESET Test (Stability test)	
F-Statistic	6.891092 (0.0162)
t-Statistic	2.625089 (0.0162)
Value in parentheses is p-value	

3. REGRESSION RESULTS

The estimated results of the equation (3) are presented in Table 5. The equation so obtained is given by

$$logG = 0.646505 + 1.855514 logE \quad (6)$$

Obviously, Energy consumption output elasticity is 1.855514. Therefore, 1% increase in energy consumption is associated with approx. 1.86% increase in GDP. This coefficient suggests a strong positive elasticity, implying that GDP is highly responsive to changes in energy consumption.

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4. COMPUTATIONAL INVESTIGATIONS ON TOTAL ENERGY CONSUMPTION AND CO_2 EMISSION IN INDIA

The computed results of total energy consumption and CO_2 emissions from 2001 to 2022 illustrates a clear correlation between them as shown in Fig.2. Both metrics show an overall upward trend, with energy consumption rising from around 400 Mtoe to over 1000 Mtoe and CO_2 emissions increasing from approximately 0.5 billion tonnes to nearly 3 billion tonnes by 2022. This strong alignment suggests that as energy demand grows, so do emissions, reflecting a significant dependence on carbon-intensive energy sources. A noticeable dip in both energy consumption and CO_2 emissions around 2019-2020 likely results from the COVID-19 pandemic, which temporarily reduced global energy demand and emissions. However, both metrics rebound sharply post-2020, with CO_2 emissions increasing slightly faster than energy consumption, indicating a possible reliance on fossil fuels during the economic recovery phase.

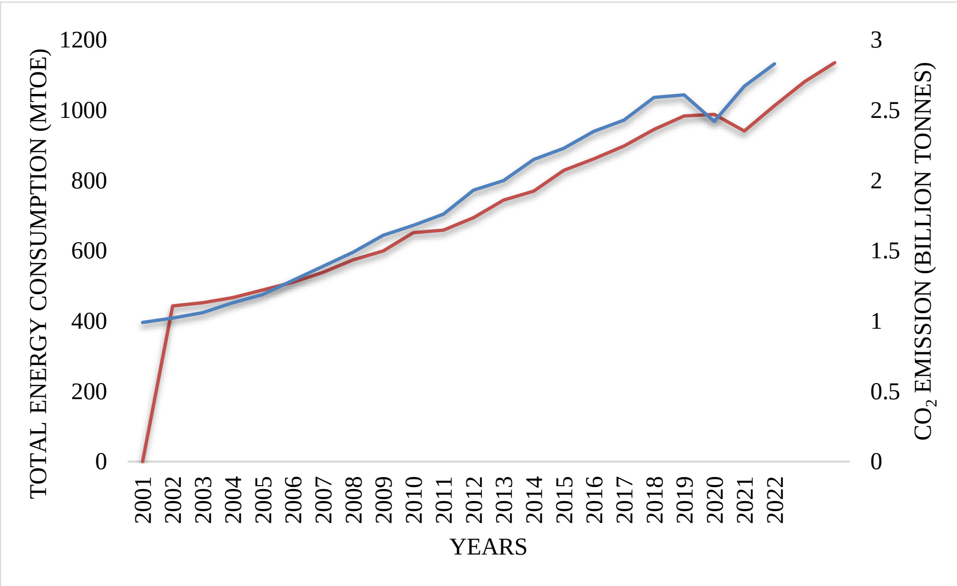

Fig. 2: Graph between Total Energy Consumption and CO_2 Emission of India

Similarly, Fig.3 represents the growth trend of GDP, total energy consumption and CO_2 emission of India. Obviously, India's rapid economic growth is one of the important reasons that lead to increase in carbon dioxide emissions in recent years. The graph from 2001 to 2022 shows that GDP has a consistent upward trend, with minor dips during the 2008 financial crisis and 2020 COVID-19 pandemic. Total energy consumption and CO_2 emissions follow a similar trend, with slight declines around 2020 due to the pandemic.

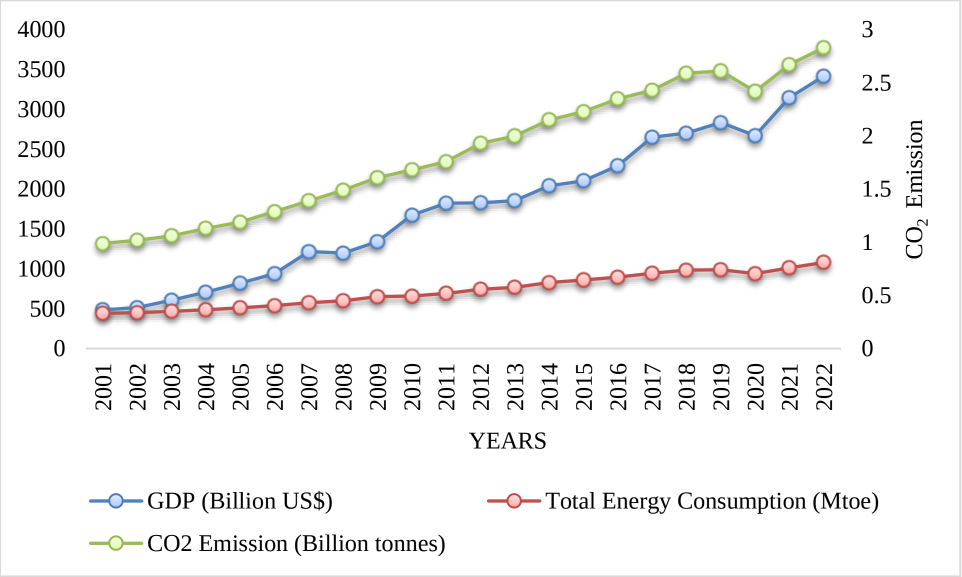

Fig. 3: Relationship between GDP, energy consumption and CO_2 emissions from 2001 to 2022

Table 7. represents relationship between GDP, Energy Consumption and CO_2 emission of five countries from 2001-2022 which indicates as China had the highest GDP growth at 1238.32%, with energy consumption up 257.01% and CO_2 emissions rising 205.63%; India saw 603.83% GDP growth, a 170.01% increase in energy consumption, and 185.86% higher CO_2 emissions. The USA achieved 143.28% GDP growth with only a 2.26% rise in energy consumption and a 14.38% reduction in CO_2 emissions; Germany had 109.97% GDP growth while reducing energy consumption by 15.99% and CO_2 emissions by 27.47%; Pakistan recorded 287.32% GDP growth, with energy consumption up 101.69% and CO_2 emissions increasing by 100%.

Table 7: Comparative relationship between GDP, Energy Consumption and CO_2 emission of five countries from 2001-2022

Country	GDP (Billions of US$)			Energy Consumption (Exajoules)			CO_2 Emission (Billion tonnes)		
	2001	2022	% change	2001	2022	% change	2001	2022	% change
India	485.44	3416.65	603.83%	13.47	36.37	170.01%	0.99	2.83	185.86%
USA	10581.93	25744.1	143.28%	93.31	95.42	2.26%	5.91	5.06	-14.38%
China	1333.65	17848.54	1238.32%	44.89	160.26	257.01%	3.73	11.40	205.63%
Pakistan	96.78	374.85	287.32%	1.78	3.59	101.69%	.10	.20	100%
Germany	1945.8	4085.68	109.97%	14.63	12.29	-15.99	.91	.66	-27.47%

5. CONCLUSION

The aim of this paper is to explore the relationship between energy consumption and economic growth in India. The gap between energy use and production has been growing, which reflects slow economic growth. Changes in energy consumption do not provide statistically significant information to predict changes in GDP in India based on granger causality analysis. The results of Granger Causality test represent the need for energy conservation policies that don't harm economic growth. The ordinary least squares method revealed a positive link between GDP and energy consumption & 1% increase in energy use raises GDP by 1.85%. This highlights India's dependence on energy for its economy. Energy shortages can negatively impact economic growth, income, and employment. Since 68.8% of the population lives in rural areas, they could benefit from using alternative energy sources like solar power, reducing reliance on foreign energy. There is a positive correlation between GDP, energy consumption, and CO_2 emissions, indicating that economic growth is tied to energy use and emissions. China and India experienced significant GDP growth accompanied by large increases in energy consumption and CO_2 emissions.

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