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Infrastructure and Its Impact on Economic Growth Using the Autoregressive Distributed Lag (ARDL) Model: India as a Case Study

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Abstract
This study examines the long- and short-term dynamic impacts of participatory investments in infrastructure (Transport and energy) on India's economic growth, as measured by GDP, from 1994 to 2023, employing the Autoregressive Distributed Lag (ARDL) model. The stationarity of time series variables was assessed by unit root tests, namely the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test, indicating that all variables are integrated of the first order. The estimation results for both long- and short-term connections demonstrate strong beneficial impacts of participatory investments in transportation and energy on GDP. Over the long term, the effects of participation investment in transportation surpass those of participatory investment in energy; conversely, in the short term, the opposite holds true. Furthermore, a cointegration relationship exists between participation investments in the transport and energy sectors and India's GDP. GDP necessitates roughly six years to revert to its equilibrium value in the long term after experiencing short-term disturbances in participatory investments. Additionally, the Toda-Yamamoto causality test revealed a unidirectional long-term causal relationship between GDP and participatory investment in transport, as well as from participatory investment in energy to GDP.

Keywords: Infrastructure, economic growth, autoregressive distributed lag model, cointegration, causal relationship

Introduction

Infrastructure is a fundamental component of contemporary life for a civilized economy and a mature society, acting as a conduit for social and economic transformation. It is essential to GDP and exerts a substantial beneficial influence on the economy, improving the business and investment environment. Significant investments are allocated to infrastructure in both developing and developed economies, particularly due to the digital revolution, which affects production aspects by lowering costs, enhancing efficiency, and eliminating time inefficiencies. Investment in infrastructure constitutes not an expenditure or consumption, but rather a strategic allocation towards future advancement and a crucial catalyst for economic growth and swift development. Investment in infrastructure, particularly in the transportation and energy sectors, is essential for economic growth as it enhances productivity, efficiency, and competitiveness. By reducing business costs, facilitating trade, encouraging innovation, and supporting sustainable development, infrastructure investments play a central role in driving long-term GDP growth. Moreover, infrastructure investments contribute to job creation, regional development, and overall improvement in living standards. Therefore, it is essential for countries, especially emerging economies like India, to prioritize infrastructure investments to unlock their full growth potential and ensure long-term prosperity.

Second: Literature Review Theoretical and Empirical

1. The Concept of Infrastructure

Infrastructure represents the fundamental framework that supports both the natural and human environment. It includes all infrastructures and services that facilitate national development and the establishment of essential facilities, including roads, bridges, electricity and water systems, healthcare and educational institutions, as well as other elements that define urban environments and support societal and economic functions. Infrastructure is defined as the structured systems and frameworks essential for the economy's functioning and sustainability. It reflects the nature, values, and institutions of a society, as well as its production patterns. Moreover, infrastructure maintains relative autonomy, contributing to national stability and growth, making it a key indicator for measuring development levels and national progress (Al-Husseini, 2019: 810) [1]. Infrastructure is described as a collection of core components and essential prerequisites that furnish facilities and services to underpin all economic and social activity. Its presence is a crucial condition for the success and sustainability of institutions and projects. Additionally, it is considered the basic resources that form the backbone of institutions, including buildings, facilities, water and electricity networks, equipment, and tools that create an optimal operational environment. Furthermore, infrastructure includes financial, human, material, knowledge-based, and informational capabilities that contribute to enhancing institutional output quality in alignment with organizational goals, steering institutions toward achieving their intended objectives (Atiya, 2020: 54) [2].

2. The Importance of Infrastructure Projects:

There is no doubt that infrastructure projects hold significant and multifaceted importance, including the following aspects (Oudah & Salman, 2024: 118-119):

a) Infrastructure projects are based on prioritizing initiatives that aim to achieve the vital interests of citizens, making their implementation closely linked to fulfilling these essential needs.
b) Infrastructure projects play a fundamental role in supporting economic development and attracting foreign direct investment (FDI) by enhancing a country's competitiveness. Conversely, the deterioration of the infrastructure sector sends a negative signal to foreign investors, leading to a decline in FDI inflows and adversely affecting economic growth and development.
c) Improvements in infrastructure contribute to job creation, as investments in constructing roads, bridges, and energy transmission and distribution lines serve as key pillars for achieving sustainable economic development.
d) Infrastructure projects strengthen the national economy by providing suitable economic and social foundations. Establishing a robust infrastructure system in any country ensures that all members of society benefit from its services, thereby promoting comprehensive development.

3. The Idea of Economic Expansion

Economic growth is a quantitative measure that indicates a prolonged rise in production over time. It is characterized as the sustained augmentation of a nation's output over a protracted duration and is intricately linked to the notion of economic growth, which denotes a transient or situational increase in production. Consequently, economic growth can be regarded as a phase of perpetual economic expansion. Economic growth, indicative of heightened production, is quantified by the growth rate of per capita income, reflecting each individual's contribution to the national output. Consequently, economic growth is evidenced by the increase in real national output over two periods, accompanied by a rise in per capita income. In the context of the relationship between growth and economic progress, growth may indicate economic advancement when the national production growth rate surpasses the population growth rate. If the growth rate of national output aligns with that of the population, no genuine economic advancement occurs. Nonetheless, if the population growth rate exceeds the national production growth rate, economic expansion will be accompanied by economic contraction (Ahmed, 2019: 202-203) [4].

4. The Importance of Economic Growth

The importance of economic growth is evident through its crucial functions and considerable effects on the national economy. It directly enhances the standard of living for all societal members and elevates their well-being by supplying an expanding amount of goods and services while simultaneously improving their quality. Furthermore, economic growth results in increased compensation for employees, aiding in the alleviation of poverty and enhancing the quality of healthcare and educational facilities provided to the populace. Economic growth is a crucial foundation for attaining a sustained rise in real GDP's average per capita share over time. It guarantees the enhancement of both the quality and quantity of products and services accessible to citizens while augmenting national output through the advancement of productive initiatives and heightened production. Consequently, economic growth is a quantitative metric to assess the relative alteration in the total magnitude of national output. Moreover, economic expansion improves the level of living by more effectively satisfying human wants, especially fundamental ones. Increasing real incomes enhances individual consumption, which favourably influences output levels and, in turn, fosters additional economic expansion. This increase also translates into improvements in the type and scale of social services provided, such as education and healthcare, while alleviating pressures caused by resource scarcity. Moreover, economic growth plays a crucial role in addressing economic challenges by increasing national production, which provides a deeper understanding of the inputs and outputs of the economy. It is a key indicator reflecting economic performance and fostering the sustainability of development (Al-Khatib, 2024: 783-784) [10].

5. The Relationship between Infrastructure and Economic Growth

Infrastructure is the foundation for achieving economic growth, as productive activities cannot function effectively without essential services such as electricity, telecommunications, and safe transportation. These services are crucial for ensuring the supply of raw materials to factories from their sources and for marketing products to target markets. Additionally, infrastructure stimulates investments and helps reduce production costs, thereby enhancing the efficiency and competitiveness of economic activities. The influence of infrastructure projects on economic growth is variable. For instance, electricity generation, telecommunications, and information technology projects are vital in improving the investment environment and supporting economic activities. In contrast, some projects have limited productive and developmental contributions, such as large sports stadiums, underutilised roads, and oversized administrative buildings. Economic growth is positively influenced by the quality of infrastructure services and the financial flows directed toward them, as these services enhance investment attractiveness and reduce production costs. The importance of infrastructure is particularly pronounced in low-income countries or during the early stages of economic development, where it contributes to increasing economic growth rates through the following mechanisms (Nasrallah & Abu Ziyadeh, 2019: 22-23) [9]:

- **Reducing Production Costs:** Essential services such as electricity, telecommunications, and information technology are fundamental components of the production process. The availability of these services lowers production costs and increases the added value of economic activities.
- **Stimulating Investment:** A government's inability to provide adequate infrastructure weakens investment attractiveness, forcing some businesses to bear the costs of providing these services themselves. This increases the required investment expenditures and raises production costs, ultimately reducing the private sector's competitiveness compared to other products in the market. Therefore, infrastructure is a key factor in achieving sustainable economic development and enhancing competitiveness in both domestic and global markets.

6. Findings of Empirical Studies

1. The study conducted by Mohammed Ahmed Matar, titled "Assessing the Role of Infrastructure Investment in Supporting Economic Growth in Egypt during the Period 2000–2020," Identified a substantial positive correlation between infrastructure investment and economic growth in Egypt, applicable in both the short and long term. The report advised the government to persist in implementing policies designed to enhance infrastructure investment, thereby broadening its reach and augmenting its efficiency.
2. The study by Dr. Taleb Ahmed and Mazen Deeb, titled "The Impact of Infrastructure Indicators on Economic Growth in Syria," confirmed a strong positive relationship between infrastructure indicators and GDP as an economic growth measure in Syria from 1995 to 2010. The study suggested that infrastructure variables could be represented by a single factor (the infrastructure factor), which links the studied variables to economic growth through a linear model. It also recommended improving infrastructure sectors such as transport, water, electricity, healthcare, and telecommunications while increasing investments in these areas due to their positive impact on economic growth.
3. The research titled "The Role of Infrastructure in Achieving Economic Growth in Palestine," conducted by Dr. Abdul Fattah Ahmed Nasrallah and Dr. Zaki Abdul-Muti Abu Ziyadeh, highlighted the significance of infrastructure in economic growth. It concluded that enhancing infrastructure services helps maintain sustainable economic growth rates by attracting domestic and foreign investments and increasing production. The study recommended directing investments toward infrastructure that stimulates productive and service investments, as well as completing the development of cities and industrial zones to attract investments and achieve sustainable development.
4. The study "Exploring the Relationship Between Infrastructure and Economic Growth: A Study on Sustainable Economic Development," by Dr. Walaa Mohammed Hassan, found that infrastructure development is a key factor in enhancing productivity and improving resource utilization efficiency, such as reducing transportation costs and stimulating economic activities. The study also emphasized that the relationship between infrastructure and economic growth is not unidirectional; economic growth can also influence infrastructure development. The main challenge is to achieve sustainable economic development without negatively impacting the environment while maintaining social equity. To achieve this, strategic decisions must balance economic development with environmental preservation.
5. The study by Reem Abdel Nasser Desouki El-Joujari, titled "Investment in Social Infrastructure and Its Impact on Economic Growth in Egypt," identified a direct positive relationship between public investment in social infrastructure (Particularly in education and healthcare) and the average per capita GDP in Egypt. It concluded that investments in social infrastructure are a crucial driver of economic growth by enhancing human capital and improving essential services. The study also found that the performance of social infrastructure sectors between 2000 and 2020 had a significant impact on economic growth in Egypt and recommended strengthening investments in these sectors to achieve sustainable economic development.
6. The study "The Impact of Infrastructure Investment on Economic Growth in Algeria: An Econometric Study for the Period 1980–2017," conducted by Mohammed Ramla, found that infrastructure investment had a significant and positive impact on economic growth in Algeria in both the short and long run. However, despite the importance of this effect, it was relatively weak compared to the large investments made during the study period. The study recommended improving the efficiency of infrastructure investments and enhancing strategic planning to achieve a greater impact on economic growth. It employed the Autoregressive Distributed Lag (ARDL) model to analyze the relationship between investment and growth.
7. The study by Anmar Ghaleb Kalib and Samar Lawrence Hassan, titled "Participatory Investment in Some Infrastructure Projects and Its Impact on GDP in Selected Countries," examined the transport and water and sanitation sectors as independent variables representing participatory investment and their effect on GDP as the dependent variable, using the Panel ARDL model. The main findings indicated a long-term positive impact, meaning a positive relationship between the transport sector and GDP. Additionally, a direct relationship was observed between the water and sanitation sector and GDP in the short run, while in the long run, the transport sector continued to have a

positive correlation with GDP. The study concluded that participatory investment is a vital tool that significantly and qualitatively contributes to the establishment, development, management, and efficiency improvement of infrastructure and public facilities.

Third: Data and Methodology

1. Research Data

The research variables include the Gross Domestic Product (GDP) at current US dollar value, the volume of participatory investment in the transport sector, and the volume of participatory investment in the energy sector for India, covering the period from 1994 to the end of 2023. These variables were achieved from the World Bank Group's online database (https://data.albankaldawli.org/). The data was transformed into a natural logarithm format ($\log_e = \ln$) before estimating the econometric model to make the data closer to a normal distribution and reduce data dispersion (Feng *et al*., 2014: 106). Table (1) presents a description of the research variables along with their expected direction of influence in model estimation.

Table 1: Description of research variables

Variables	Description	Measurement Unit	Variable Type	Expected Impact
GDP	Gross Domestic Product (Current)	Billion USD	Dependent	—
TRA	Investment in Transport with Private Participation	Billion USD	Independent	Positive
ENE	Investment in Energy with Private Participation	Billion USD	Independent	Positive

Source: Prepared by the researcher.

The study is predicated on the subsequent hypotheses

- There are positive effects of participatory investments in infrastructure (Transport and energy) on India's economic growth during the period (1994–2023).
- There is a long-term cointegration relationship between participatory investments in infrastructure and economic growth in India during the period (1994–2023).
- There are long-term causal relationships between participatory investments in infrastructure and economic growth in India during the period (1994–2023).

2. Research Model Specification

The research model demonstrates that GDP is a function of participatory investment in the transport and energy sectors. Based on the description of research variables in Table (1), the research model can be expressed as follows:

$$GDP_t = f(TRA_t, ENE_t)$$

$$GDP_t = \beta_0 + \beta_1 TRA_t + \beta_2 ENE_t + U_t \qquad (1)$$

By transforming the variables into natural logarithmic form, we obtain the following model:

$$\ln GDP_t = \beta_0 + \beta_1 \ln TRA_t + \beta_2 \ln ENE_t + U_t \qquad (2)$$

Where t = 1,2,...,30 represents the sequential years of the study period (1994–2023). β_0 represents the model's constant term, β_1 and β_2 represent the respective coefficients of participatory investment in transport and energy, and White Noise, which U_t represents, is the model's error term**.** It is considered randomly distributed with a mean of zero and a constant variance. The error term includes all random unobserved variables that influence total GDP.

3. Research Methodology

This study employs a widely applied econometric methodology, the Auto-Regressive Distributed Lag (ARDL) Model, developed by Pesaran *et al*. (2001) [25]. The ARDL model is considered the most suitable econometric approach compared to other methods when the variables are stationary at level I(0) or at the first difference I(1). Given the research objectives, which involve measuring and analyzing the long- and short-term dynamic effects of participatory investments in infrastructure (Transport and energy) on India's GDP during the period (1994–2023), the ARDL methodology is the most appropriate for capturing both short-term and long-term effects of independent variables on GDP. The ARDL methodology is especially advantageous for estimating both short- and long-run elasticities in research with limited sample sizes, while employing the Ordinary Least Squares (OLS) technique for cointegration analysis across variables (Duasa, 2007: 24) [8]. Equation (2) can be rewritten in the following model form:

$$\Delta \ln GDP_t = \beta_0 + \sum_{i=1}^{p} \beta_1 \Delta \ln GDP_{t-i} + \sum_{i=0}^{q_1} \beta_2 \Delta \ln TRA_{t-i} + \sum_{i=0}^{q_2} \beta_3 \Delta \ln ENE_{t-i} + \emptyset_1 \ln GDP_{t-1} + \emptyset_2 \ln TRA_{t-1} + \emptyset_3 \ln ENE_{t-1} + U_t \qquad (3)$$

The coefficients Φ_1, Φ_2, Φ_3 represent the long-run effects, while β_1, β_2, β_3 represent the short-run effects. The symbol Δ denotes the first difference of a variable, calculated as the current value at time (t) minus its previous value at (t-1). Equation (3) is referred to as the ARDL(p, q_1, q_2) model, where p represents the lag length of GDP, q_1 represents the lag length of participatory investment in transport, and q_2 represents the lag length of participatory investment in energy. Upon establishing the long-run relationship between the variables, the Error Correction Model (ECM) is utilized to ascertain the short-run relationship.

$$\Delta \ln GDP_t = \beta_0 + \sum_{i=1}^{p} \beta_1 \Delta \ln GDP_{t-i} + \sum_{i=0}^{q_1} \beta_2 \Delta \ln TRA_{t-i} + \sum_{i=0}^{q_2} \beta_3 \Delta \ln ENE_{t-i} + \Psi ECT_{t-1} + U_t \qquad (4)$$

The variable ECT_{t-1} represents the error correction term, which accounts for the residuals or errors of equation (3) at time (t-1). The pace at which short-term departures from equilibrium are adjusted towards long-term equilibrium is measured by the coefficient Ψ, which is the cointegration parameter. In other words, the cointegration parameter reflects the proportion of short-run errors that are corrected in each time period to restore long-term equilibrium. The variables undergo this adjustment process as a result of shocks, and this will eventually go away at a consistent rate.

A. Co-integration Test

To determine if the model variables are cointegrated over the long term, researchers employ the Bounds Test, which uses the F-statistic to assess the absence of cointegration as a null hypothesis. At the same time, according to Pesaran *et al*. (2001) [25], cointegration is suggested by the alternative theory. One set of critical values assumes that all model variables are stationary at level I(0), meaning no cointegration, and the other set of critical values assumes that all model variables are stationary at first difference I(1), meaning a cointegration relationship is present. Therefore, the test consists of two sets of critical values. It is assumed that the probability value (Prob.) of the F-test is less than the 5% level of significance ($\alpha = 5\%$). That would mean that the model variables are in a state of long-run equilibrium with one another and that we can reject the null hypothesis that there is no cointegration. In contrast, a greater probability value indicates the absence of cointegration and supports the acceptance of the null hypothesis.

B. CUSUM and CUSUMSQ tests

Using the CUSUM and CUSUMSQ tests, which stand for Cumulative Sum of Squares of Recursive Residuals, respectively, we may check if the model variables are related in the long run (Brown *et al*., 1975) [17]. According to earlier research (Pesaran & Shin, 1999; Pesaran *et al*., 2001) [26, 27], these tests accurately represent how well the ARDL model fits the data. The plotted residuals from the Error Correction Model (ECM) are examined using these tests; if they stay within the 95% confidence ranges, the outcomes show that the ARDL model coefficients are stable.

C. Causality Analysis: Causality analysis is an experimental approach that evaluates economic correlations among variables. Identifying cointegration links among a group of variables signifies the existence of causal relationships, which may be unidirectional or bidirectional. If the historical values of one variable affect the current value of another variable, indicating that the former has predictive information about the latter, then the first variable is deemed to cause the second, and vice versa (Bhaskara *et al*., 2008: 23) [15]. The Granger causality test is a method used to examine whether one variable helps predict another. However, for this test to be effective, the time series data must be stationary at level. If the integration process of the time series is not at level, the effectiveness of the Granger causality test becomes weak. The Toda-Yamamoto methodology is employed to resolve this issue, estimating a Vector Autoregression (VAR) model of order ($k + d_{max}$), where k denotes the best lag length and d_{max} signifies the maximum order of integration derived from the stationarity test. (Toda & Yamamoto, 1995: 233) [28].

Fourth: Results and Discussion

1. Descriptive Statistics

Table (2) displays the descriptive statistics for the research variables. The dependent variable, Gross Domestic Product (GDP), did not pass the Jarque-Bera test since the p-value was more than 5%. This suggests that GDP follows a normal distribution. The trend in GDP shows a steady linear increase from 1994 to 2023, with an annual growth rate of 114%, as illustrated in Figure (1). Additionally, the descriptive statistics reveal that the average participatory investment in the transport sector during the study period was $4.443271 billion, with the lowest investment recorded at $96.400 million in 2000 while the highest investment reached $22.03480 billion in 2012. The trend line in Figure (2) indicates a continuous increase in participatory investment in transport, with an annual growth rate of 0.25%. Similarly, the average participatory investment in the energy sector was $5.351405 billion, ranging from $240 million in 2001 to $34.47451 billion in 2018. Figure (3) shows that participatory investment in energy has been steadily increasing, with a growth rate of 0.10 percent each year.

Table 2: Descriptive statistics for research variables

Variables	GDP	TRA	ENE
Mean	1508.466	4.443271	5.351405
Median	1279.312	2.336915	2.020360
Maximum	3567.552	22.03480	34.47451
Minimum	327.2748	0.096400	0.240000
Std. Dev.	1031.582	5.531491	8.111738
Skewness	0.459163	1.781446	2.343103
Kurtosis	1.901789	5.564628	7.753770
Jarque-Bera	2.561740	24.08939	55.69857
Probability	0.278	0.000	0.000
Observations	30	30	30

Source: Data set that the researcher created using the statistical software (12.EViews).

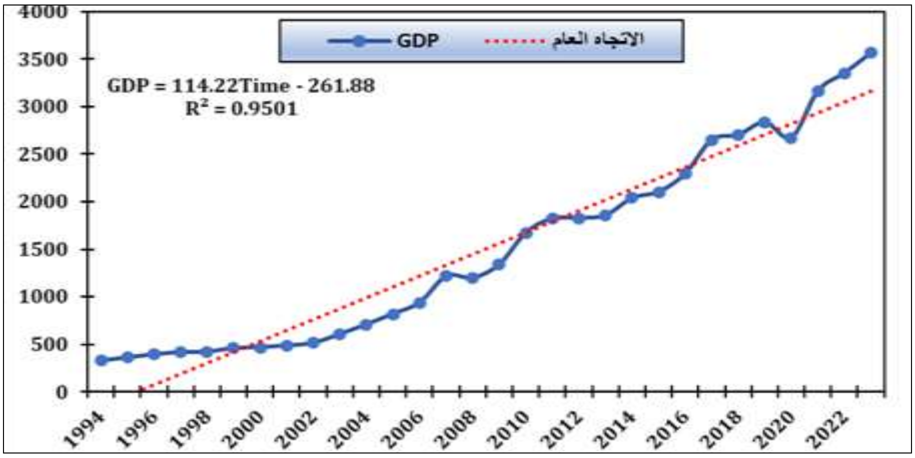


Fig 1: The general trend of India's GDP for the period (1994-2023) in billion dollars.

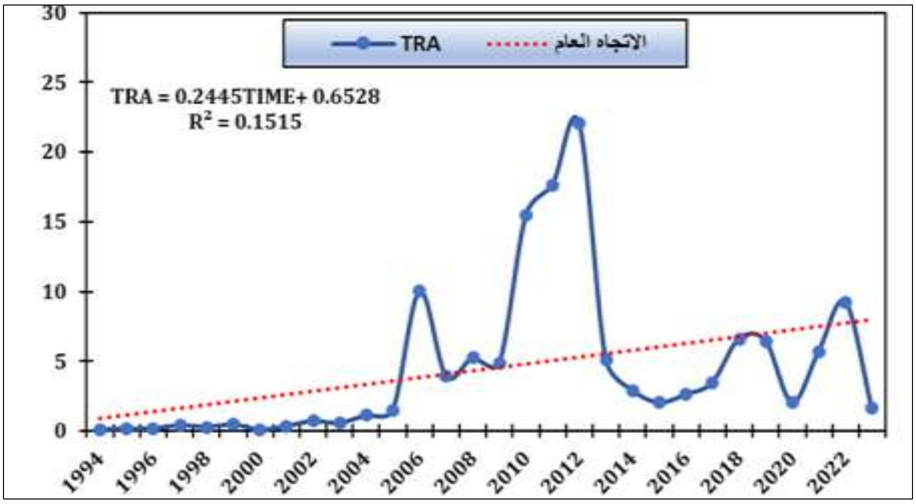


Fig 2: The general trend of shared investment in transportation in India for the period (1994-2023) billion dollars

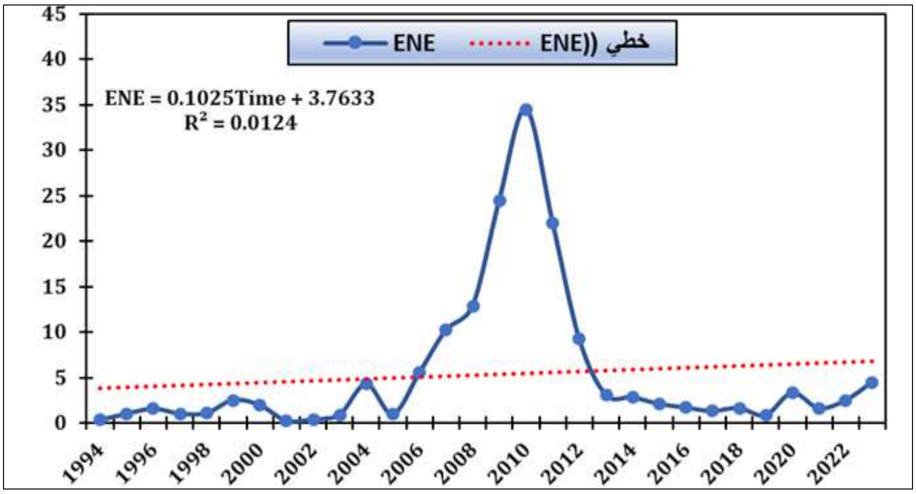


Fig 3: The general trend of joint investment in energy in India for the period (1994-2023) billion dollars

2. Model Variables Stationarity Test

Conducting a unit root test for each variable before estimating the ARDL model is essential, as the model requires that all variables be stationary at I(0), I(1), or both (Narayan, 2005: 1981) [23]. The unit root tests applied in this study include the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron (PP) test. The outcomes of both the ADF and PP tests demonstrate the lack of a unit root in the time series data for the model variables. Table (3) indicates that all variables in the model achieved stationarity at the first difference I(1).

Table 3: Outcomes of unit root examinations for the study variables from 1994 to 2023

Variables	ADF		PP		Integration Order
	Levels	1st differences	Levels	1st differences	
GDP	4.9836	-5.3976***	5.8378	-13.2973***	I(1)
TRA	-1.8605*	-5.6612***	-2.4234	-10.2688***	I(1)
ENE	-2.1087**	-3.3633**	-1.9708	-3.4103*	I(1)
*, **, *** significant at levels 10%, 5% and 1% respectively					

Source: Data set that the researcher created using the statistical software (12.EViews).

3. Determining the Optimal Lag Length

Prior to implementing the Bounds Test to assess the existence of cointegration among GDP, participatory investment in transport, and participatory investment in energy, it is essential to determine the suitable lag length for the variables. The Vector Auto-Regressive (VAR) model was employed to ascertain the ideal lag duration. Table (4) displays the selection criteria for determining the optimal lag length for the model. The model demonstrates optimal performance with the second lag length, in contrast to the first and third lags.

To further confirm the appropriateness of the second lag length for the model variables, the Inverse Roots of the AR Characteristic Polynomial were plotted, as shown in Figure (4). The figure indicates that all six roots had absolute values less than one, meaning they are located within a unit-radius circle. This confirms the optimal lag length selection, ensuring the validity and structural stability of the model while indicating the absence of heteroscedasticity issues in model residuals due to adopting the second optimal lag length (Nasrullah *et al*., 2021: 8) [24].

Table 4: Determining the optimal time lag gap for model variables according to VAR analysis

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-32.83430	NA	0.003160	2.756485	2.901650	2.798287
1	41.10478	125.1277	2.16e-05	-2.238829	-1.658169*	-2.071620
2	54.05200	18.92286*	1.64e-05*	-2.542462*	-1.526307	-2.249846*
3	60.93197	8.467655	2.11e-05	-2.379382	-0.927732	-1.961360
4	68.84351	7.911542	2.72e-05	-2.295655	-0.408510	-1.752225

* denotes the optimal Lag length of the variable
LR: sequential modified LR test statistic
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion
Source: Data set that the researcher created using the statistical software (12.EViews).

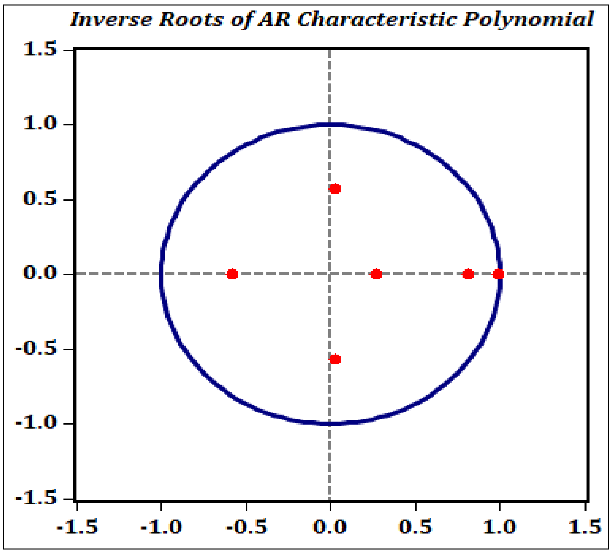


Fig 4: Inverse Roots of the AR Characteristic Polynomial with the Second Lag Length for Model Variables

4. Cointegration Test

Prior to determining the long-run and short-run correlations among the variables, the Bounds Test must be conducted to ascertain the existence of cointegration.

Table 5: Outcomes of the Cointegration Examination Among Model Variables Utilizing the Bounds Test

F-Bounds Test Null Hypothesis: No levels relationship				
Test Statistic	**Value**	**Signi. F**	**I(0)**	**I(1)**
F-statistic	10.70837**	10%	3.17	4.14
k	2	5%	3.79	4.85
		2.5%	4.41	5.52
		1%	5.15	6.36
** significant 1% level				

Source: Data set that the researcher created using the statistical software (12.EViews).

Table (5) shows that the **F**-statistic value (10.70837) is greater than the upper bound of I(1) at all significance levels. Thus, the null hypothesis of no cointegration is rejected, indicating that the long-run relationship coefficients for the model variables are neither equal nor zero. This confirms the presence of long-run cointegration between participatory investment in transport and energy on one hand and GDP on the other.

5. Estimate long-term and short-term relationships: Using the ARDL

Based on the nature of the data and study period, a total of 343 ARDL models were possible. The optimal model was found to have the seventh lag for GDP, the fourth lag for participatory investment in transport, and the second lag for participatory investment in energy, making the best-fit model ARDL (7, 4, 2). This model achieved the lowest Akaike Information Criterion (AIC) value (-6.9845) among all estimated models.

Table 6: Estimation Outcomes for the ARDL (7,4,2) Model in the Long and Short Term

Dependent Variable: GDP_t Selected Model: NARDL(7,4,2) Sample: 1994 2023				
Long-Run Relationship				
Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
TRA_t	0.447737	0.059502	7.52470**	0.000
ENE_t	0.377340	0.116241	3.24617*	0.014
C	0.607081	0.121787	4.98475**	0.001
Short-Run Relationship				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
ΔTRA_t	0.029821	0.008915	3.34493*	0.012
ΔENE_t	0.047381	0.008726	5.42979**	0.001
ECT_{t-1}	-0.162561	0.025294	-6.42679**	0.000
*, ** significant at levels 5% & 1% respectively				

Source: Data set that the researcher created using the statistical software (12.EViews).

Based on the p-value for the estimated t-test of the variable (TRA_t), which is less than the 1% significance level, there is a significant effect of participatory investment in transport on India's long-run GDP. The estimated long-run elasticity for investment in transport is (0.447737), indicating that a 1% increase in transport investment leads to a 0.447737% increase in GDP. This means that an increase of $10 billion in transport investment will raise GDP by approximately $4.477 billion (0.447737 × 10 = 4.47737). Similarly, in the short run, participatory investment in transport has a significant effect at the 1% level on GDP. Based on the estimated short-run elasticity, a $10 billion increase in transport investment results in an increase in GDP of $298.210 million. These findings align with economic theory, which suggests that investment in infrastructure development and economic growth has a positive relationship. The results also agree with several previous studies in this field, such as Mofekeng, Kalib & Hassan, and Ibrahimov. Similarly, studies by Unnikrishnan & Kattookaran (2020: 119) [29] and *et al.*, (2023: 7) support this relationship. However, the positive impact of participatory investment in transport on GDP varies between the long run and the short run, as shown below.

1. Participatory investments in transport infrastructure, such as roads, railways, ports, airports, and public transportation systems, significantly improve connectivity across the country. Efficient transport networks reduce time and costs associated with the movement of goods and people, directly increasing productivity and thereby enhancing overall GDP growth.
2. The building, operation, and repair of transportation infrastructure are directly impacted by the job opportunities created by participatory investments. On top of that, they indirectly boost employment opportunities in associated industries including transportation, manufacturing, retail, and services. Over time, these newly created jobs contribute to higher household incomes, increased consumption, and expanded employment opportunities, all of which support GDP growth.
3. Private sector participation in transport infrastructure often brings innovation, efficiency, and capital, which governments may struggle to provide on their own. Private investments typically focus on cost-effectiveness and operational efficiency, improving service quality (e.g., faster transportation times and lower costs). This enhances Indian companies' competitiveness in the global market, encourages greater investment in production, and ultimately boosts GDP.
4. Efficient transport infrastructure, particularly in ports, roads, and railways, plays a crucial role in enhancing India's international trade. Lower transportation costs increase the competitiveness of Indian exports, enabling companies to access international markets more effectively and at a lower cost. As trade volumes grow, India’s GDP benefits from higher exports and an improved trade balance.
5. A modern and efficient transport network makes India more attractive to foreign investors. Infrastructure quality is a key factor for international companies when deciding where to invest. Private investment in India's transportation networks makes the nation an attractive location for FDI, especially in the retail, logistics, and industrial sectors. Economic growth and GDP expansion are fueled by increased FDI, which provides capital, technology, and knowledge.

At the 5% level of significance, the data in Table (6) show that participatory investment in energy (ENE_t) has a long-term meaningful effect on India’s gross domestic product (GDP_t). A 1% increase in energy investment results in a 0.37734% increase in GDP, according to the long-run elasticity of energy investment, which is (0.37734). In other words, if energy investment were to grow by $10 billion, GDP would rise by about $3.773 billion (0.37734 × 10 = 3.7734). Similarly, at the 1% threshold of relevance, participatory investment in energy has a notable short-run impact on GDP. Based on the estimated short-run elasticity, a $10 billion increase in energy investment results in an increase in GDP of $473.810 million. These findings align with economic theory, which suggests that energy investment positively impacts GDP growth. The results are also consistent with numerous previous studies in this field, including Matar (2022: 114) [11], Mofekeng *et al*., Unnikrishnan & Kattookaran (2020: 119) [29], and Ibrahimov (2023: 415) [12]. The positive impact of participatory investment in energy on GDP varies between the long run and the short run, as outlined below.

1. Participatory investments in energy infrastructure (Such as power plants, renewable energy sources, and transmission and distribution systems) increase overall energy supply, ensuring more reliable and affordable electricity. This reliability is crucial for industries and businesses to operate without disruptions. When energy is readily available and reliable, production increases, leading to higher output in manufacturing, services, and agriculture, directly contributing to GDP growth.
2. Participatory investment in energy often drives technological advancements and improves efficiency in power generation, distribution, and consumption, leading to lower costs for both businesses and consumers. Reduced energy costs, especially for energy-intensive industries (Such as steel, cement, and chemicals), allow companies to lower operating expenses, reinvest savings in expansion, and increase productivity. These effects, in turn, fuel economic growth and GDP expansion.
3. With the global shift toward sustainable development, participatory investments in renewable energy (Such as solar, wind, and hydroelectric power) help India transition to a greener and more sustainable energy mix. Investments in renewables can reduce dependence on fossil fuels, lower carbon emissions, and improve energy security. This transition also creates new industries and job opportunities in the clean energy sector, further supporting economic growth.
4. Energy infrastructure, particularly in emerging sectors like renewable energy and energy storage solutions, is an attractive opportunity for foreign investors. Private sector involvement in energy infrastructure boosts investor confidence, leading to higher foreign direct investment (FDI) inflows. Increased FDI brings capital, technology, and expertise, significantly enhancing energy sector productivity, which in turn supports overall economic growth and GDP expansion.
5. Electric power stations, transmission lines, and renewable energy facilities are all examples of large-scale energy projects that provide a lot of jobs. These initiatives boost construction, engineering, and operation and maintenance jobs. Over time, this leads to a more skilled workforce in the energy sector, improving the productive capacity of the economy. Higher-income levels from these jobs also increase consumer spending, stimulating demand and GDP growth.
6. Guaranteeing a steady and inexpensive supply of energy can only improve the competitiveness of Indian companies, especially those that rely on energy. Investments in energy infrastructure lead to more consistent production schedules, lower production costs, and business expansion. This increases industrial output and business growth, both of which directly contribute to GDP growth.
7. By expanding investments in domestic energy production, especially renewable energy, India can reduce its reliance on energy imports, such as oil and gas. This can improve the country’s trade balance by lowering energy import bills, positively impacting the

overall economy. Reduced energy imports help preserve foreign exchange reserves, allowing resources to be allocated to other economic priorities, thereby boosting GDP growth.

8. Private sector participation often drives innovation, technology transfer, and advanced energy solutions. For instance, private investments in smart grids, energy-efficient technologies, and grid storage solutions can enhance power distribution efficiency and minimize energy losses. These innovations increase productivity across industries, particularly in industrial and commercial applications, further contributing to overall economic growth.

Table (6) demonstrates the existence of a long-run cointegration connection among the model variables, signifying a long-term equilibrium association between investment in the transport and energy sectors and GDP. The computed cointegration coefficient is negative and statistically significant at the 1% level, with a value of -0.165261. This indicator indicates the rate of GDP adjustment resulting from short-term fluctuations in participatory investments in transport and energy relative to their long-term equilibrium levels. Each year, 0.165% of any deviation will be rectified. Consequently, GDP is projected to take roughly six years to revert to its equilibrium value following disturbances in participatory investments, as determined by:

$$\frac{1}{0.165261} = 6.051 \approx 6\ \text{years}$$

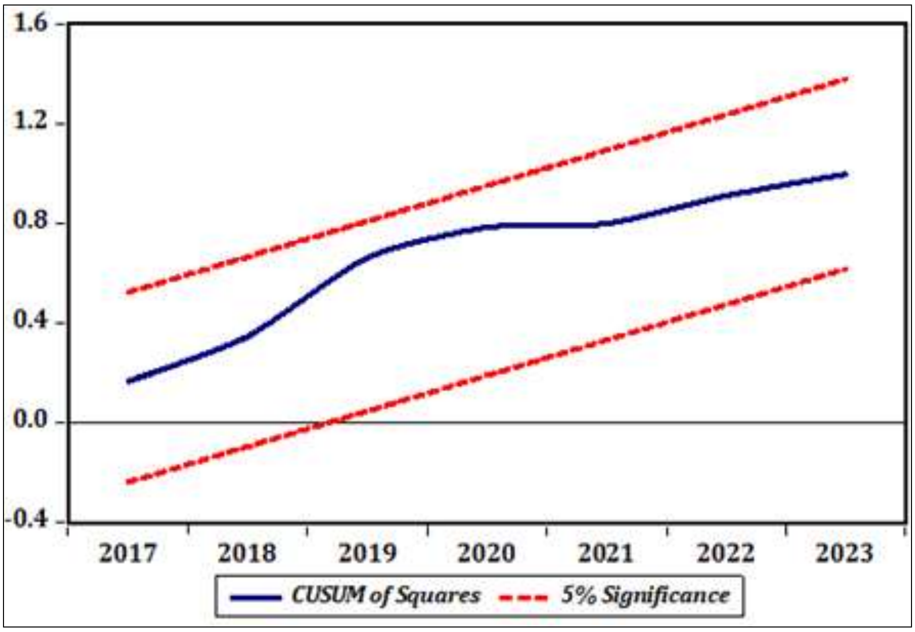
6. Diagnostic Tests for the Model: The diagnostic tests that were conducted on the derived econometric model to determine its stability and quality are displayed in Table (7). The Ramsey RESET test (Ramsey, 1969: 354) [27] confirms the correct model specification. The Engle's test is used to check for residual heteroscedasticity, while the Breusch-Godfrey (B-G) test (Breusch, 1978: 343) [16] is applied to detect serial correlation in the residuals (Breusch, 1978: 993) [16]. Additionally, the Jarque-Bera test (Jarque & Bera, 1980: 57) [21] evaluates the normality of the residuals, and the R^2 coefficient of determination is examined. The results indicate that the adjusted R^2 value exceeds 87%, while the R^2 value surpasses 94%, confirming the model's goodness of fit and its relevance to the data. The Ramsey F-test further supports the correctness of the estimated model. Findings from the ARCH test indicate that heteroscedasticity is not present, and those from the Breusch-Godfrey (B-G) test reveal that the residuals do not exhibit serial correlation. Meanwhile, the Jarque-Bera (χ^2) test indicates that the model's residuals follow a normal distribution.

Table 7: Outcomes of the Diagnostic Assessments for the ARDL (7, 4, 2) Model

Diagnostic	Statistic	Result
Model Quality	$R\text{-}square$	0.949
Model Quality	$Adjusted\ R\text{-}square$	0.874
Model Stability	$F - Ramsey\ reset$	0.685 (0.439)
Heteroscedasticity	$\chi^2 - ARCH$	0.031 (0.860)
Autocorrelation	$\chi^2 - B\text{-}G$	1.156 (0.561)
Residuals Distribution	$\chi^2 - J\text{-}B$	2.033 (0.362)

Source: Data set that the researcher created using the statistical software (12.EViews)

The figures within parentheses denote the p-values (Prob.) of the tests, all exceeding the 5% significance threshold. The model demonstrated structural stability in both long-run and short-run coefficients, as verified by the Cumulative Sum (CUSUM) test and the Cumulative Sum of Squares (CUSUMSQ) test, illustrated in Figure (3). The findings demonstrate that all residual GDP values fall within the 95% confidence interval, hence reinforcing the appropriateness of the ARDL(7,4,2) model for the research data.



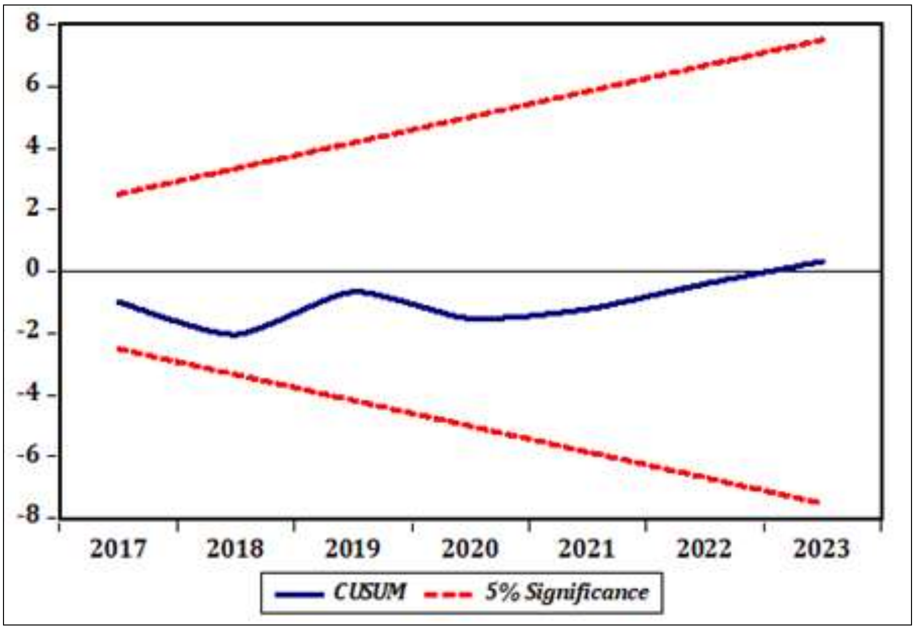


Fig 3: CUSUM and CUSUM of Squares for the Residuals of the ARDL (7, 4, 2) Model

7. Causality Test

The causality test is performed to ascertain whether participatory investments in transport and energy induce alterations in GDP over the long term, or the reverse. Table (3) indicates that the variables attained stationarity at the first difference, signifying that dmax = 1. Consequently, the Toda and Yamamoto causality test will be utilized. Furthermore, Table (4) demonstrates that the optimal lag time for the variables is two (k = 2), resulting in k + dmax = 3.

Table 8: Findings from the Model Variables' Causality Test

Null Hypothesis:	F-Statistic	Prob.	Direction of Causality
TRA does not Granger Cause GDP	2.047636	0.562	Not exist
GDP does not Granger Cause TRA	9.122411	0.028	$GDP \Longrightarrow TRA$
ENE does not Granger Cause GDP	8.078618	0.044	$ENE \Longrightarrow GDP$
GDP does not Granger Cause ENE	0.376314	0.945	Not exist
* significant at the 5% level			

Source: Data set that the researcher created using the statistical software (12.EViews)

As can be seen from Table (8) and the F-test probability values, which are below the 5% significance threshold, a long-run unidirectional causal relationship between GDP and TRA does in fact exist. This implies that India's GDP causes participatory investment in transport in the long run. In other words, past values of GDP contain valuable information for predicting future participatory investment in transport (TRA). This causality can be explained by the fact that if India's GDP continues to grow over several years, private sector investors will anticipate increasing demand for transport infrastructure, prompting them to undertake long-term investments in transport projects. The researcher suggests that, in the long run, India's GDP can drive investment in transport infrastructure through several channels:

1. Increased demand for transport infrastructure due to higher economic activity and trade expansion.
2. Improved government financial capacity, enabling greater public sector participation in public-private partnerships (PPPs).
3. Greater private sector confidence in the growing economy, leading to increased investment appetite.
4. Rising trade and urbanization, necessitating modern and expanded transport infrastructure.
5. Government reforms and policies that make private sector investment in transport projects more attractive.

Additionally, there is a long-run unidirectional causal relationship from ENE to GDP, indicating that investment in energy infrastructure drives India's GDP growth in the long run. This means that past values of participatory investment in energy (ENE) contain useful information for predicting future GDP (GDP) values in India. If participatory investment in energy leads to continuous improvements in energy infrastructure, this will, in turn, drive industrial production, job creation, and overall economic growth. Consequently, previous participatory investments in energy can be used to forecast future GDP growth in India.

The researcher believes that, in the long run, private sector participation in energy investments can significantly contribute to GDP growth through several mechanisms, including:

1. Increased energy supply enhances productivity across multiple sectors.
2. Private sector innovation drives energy efficiency and technological advancements.
3. Investments in renewable energy support long-term sustainable growth and energy security.
4. Job creation in the energy sector boosts household incomes and demand, stimulating economic growth.

5. Attracting foreign direct investment (FDI) and private capital fosters comprehensive economic growth.
6. Lower energy costs improve business competitiveness.
7. Energy infrastructure development enables higher production and economic expansion.
8. Improved rural energy access supports agricultural growth and income generation.

Conclusions

1. The Auto-Regressive Distributed Lag (ARDL) model effectively captures the relationship between investments in the transport and energy sectors and India's GDP from 1994 to 2023, in both the short and long term. These models exhibited substantial explanatory power and satisfactorily fulfilled all diagnostic econometric assessments.
2. There exists a long-term cointegration link between investments in the transportation and energy sectors and India's GDP. GDP necessitates roughly six years to revert to its equilibrium value in the long term after experiencing short-run disturbances in participatory investments.
3. In the long term, GDP is more influenced by transport investment than by energy investment; conversely, in the near term, energy investment exerts a higher effect on GDP than transport investment.
4. Participatory investment in transport infrastructure significantly enhances GDP development in both the short and long term through:

- Increased productivity due to improved connectivity and lower transportation costs.
- Job creation and economic diversification across multiple sectors.
- Enhanced trade and improved competitiveness of Indian exports.
- Lower supply chain and logistics costs.
- Encouraging regional development by integrating less developed areas into the economy.
- Attracting foreign direct investment (FDI) and promoting industrial growth.
- Boosting tourism and the services sector.
- Facilitating urban expansion and improving city infrastructure.
- Promoting sustainability and energy efficiency in the transport sector.

5. Participatory investment in energy infrastructure significantly enhances GDP development in both the short and long term through:

- Increasing energy supply and reliability, boosting business productivity and industrial output.
- Reducing energy costs, lowering operating expenses, and enhancing competitiveness.
- Transitioning to renewable energy, promoting sustainable economic development.
- Increasing capital inflows and luring foreign direct investment (FDI).
- Job creation and human capital development, leading to higher household income and consumption.
- Expanding industrial production, especially in energy-intensive sectors.
- Reducing dependence on energy imports, improving trade balance, and preserving foreign exchange reserves.
- Encouraging regional development by enhancing energy access in underserved areas.
- Driving technological advancement, improving efficiency and productivity across sectors.

6. In the long run, GDP causes participatory investment in transport, as sustained GDP growth in India increases demand for better transport infrastructure, builds private sector confidence, and encourages government policies that promote private sector participation in infrastructure development.
7. Participatory investment in energy can drive GDP growth in India, as private-sector energy investments significantly contribute to long-term GDP expansion by providing essential infrastructure, creating jobs, fostering innovation, and enhancing economic competitiveness.

Recommendations

1. Conducting broader econometric studies on the relationship between participatory investments in the transport and energy sectors and GDP can provide valuable insights into how infrastructure investments contribute to long-term economic growth. Accurate data collection, variable specification, model selection, and rigorous testing are crucial for obtaining reliable results. The findings of such studies can help policymakers make informed decisions to enhance private sector participation in infrastructure investment, leading to more sustainable and inclusive economic growth.
2. Future studies could look at topics like the function of various forms of private sector involvement (such as entirely private projects versus public-private partnerships, or PPPs) or the effect of technical advancement in the transportation and energy sectors on GDP growth.
3. India’s investment in the transport and energy sectors, with private sector participation, holds significant potential to positively impact GDP growth. By focusing on PPP models, sustainable infrastructure, regulatory improvements, and innovation, India can enhance the efficiency of the energy and transport sectors, leading to job creation, improved working conditions, and increased economic competitiveness. A greater GDP growth rate will be the ultimate result, both in the short and long term.

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