I J C R M
International Journal of Contemporary Research In Multidisciplinary

Research Article

Foreign Investment and Indian Clean Energy Transition: An Empirical Assessment

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DOI: https://doi.org/10.5281/zenodo.24033758

Abstract

The transition to cleaner energy in India has gained increasing importance given the rising demand for energy, economic development, energy security, and environmental sustainability. Foreign direct investment (FDI) can be an instrument to facilitate this transition by providing capital, technology, managerial expertise, and access to international production networks. The relationship between FDI and renewable energy consumption may differ in the short run and long run. This study empirically investigates the short-run and long-run relationship between foreign direct investment and renewable energy consumption in India using annual time-series data for the period 1990–2023. The dependent variable is renewable energy consumption, and the main explanatory variable is FDI. Trade openness and log GDP per capita are control variables. The study uses the Autoregressive Distributed Lag (ARDL) framework to investigate the short-run dynamics, long-run relationship, and the adjustment toward equilibrium. The results indicate a positive and statistically significant short-run link between FDI and renewable energy consumption ($\beta = 0.609$, $p = .026$). While the long-run coefficient of FDI is negative, it is statistically insignificant ($\beta = -1.489$, $p = .164$). The ARDL bounds test has an F-statistic (7.452) that is higher than the 1% upper-bound critical value (7.061), providing strong evidence of a long-run level relationship based on the F-statistic. The associated t-statistic of -3.311, however, is not conclusive. The error-correction coefficient is negative and statistically significant ($\beta = -0.265$, $p = .003$), indicating convergence to the long-run equilibrium. Approximately 26.5% of the disequilibrium is corrected within a year. The findings suggest that there is a positive association between renewable energy consumption and FDI in the short run, but no statistical evidence of a separate long-run relationship between FDI and renewable energy consumption. The study calls for redirecting foreign investment toward renewable energy, clean technologies, infrastructure, and sustained green investment. The study focuses on foreign direct investment, renewable energy consumption in India, the ARDL model, the clean energy transition, error correction, and sustainable development.

Manuscript Information

- **ISSN No:** 2583-7397
- **Received:** 17-08-2026
- **Accepted:** 04-11-2026
- **Published:** 07-11-2026
- **IJCRM:**5(6); 2026: 102-112
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- **Plagiarism Checked:** Yes
- **Peer Review Process:** Yes

How to Cite this Article

Soni S. Foreign Investment and Indian Clean Energy Transition: An Empirical Assessment. Int J Contemp Res Multidiscip. 2026;5(6):102-112.

Access this Article Online

www.multiarticlesjournal.com

KEYWORDS: Foreign direct investment, clean energy, environmental sustainability, renewable energy.

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1. INTRODUCTION

India's shift to cleaner and more sustainable energy has become a key element of its overall economic and environmental development strategy. The role of renewable energy in the Indian energy system has been increasing due to rapid economic growth, increasing energy demand, energy security concerns, and the need to reduce environmental pressures. "Renewable energy can contribute to diversification of the energy mix, reduce dependence on conventional energy sources, and move toward longer-term sustainability. At the same time, foreign direct investment (FDI) is an important source of external capital for developing economies. FDI can contribute to economic development via capital formation, technology transfer, managerial know-how, job creation, and integration into global production networks. Foreign investment can provide the financial resources and technologies required for renewable energy generation, electricity infrastructure, energy storage, and other clean-energy activities within the framework of the energy transition. But the relationship between FDI and renewable energy consumption is not necessarily straightforward. Foreign investment could be directed toward renewable energy sectors and environmentally efficient technologies, thereby promoting clean energy. In contrast, FDI can be concentrated in traditional or energy-intensive industries, and in this case more foreign investment does not necessarily mean more renewable energy consumption. Thus, the environment and energy implications of FDI depend not only on the volume, but also on the composition, sectoral allocation, technological content, and duration.

Another important issue is the distinction between short-run and long-run relationships. Macroeconomic variables tend to trend over time, and a relationship that is observed over a short time period may not continue to hold over the long term. Thus, a dynamic time-series framework is required to separate short-run changes from long-run equilibrium relationships. Background: The study investigates the association between FDI and renewable energy consumption in India from 1990 to 2023. The study uses the Autoregressive Distributed Lag (ARDL) approach to analyze the short-run dynamics, long-run relationships, and speed of adjustment to equilibrium. The study deliberately adopts a single-objective, parsimonious empirical framework. The key explanatory variable is FDI, with logged GDP per capita and trade openness included as controls.

2. REVIEW OF LITERATURE

FDI can support the transition toward renewable energy through capital provision, technology transfer, managerial expertise, and knowledge spillover. But its environmental impact is not necessarily the same; it depends on the sectoral and technological orientation of foreign capital. Golub et al. (2011) differentiate between FDI directed to environmental activities and traditional investment with cleaner technologies, and Doytch and Uctum (2016) demonstrate that the energy impacts of FDI are sector-dependent. These findings suggest that aggregate FDI may have both positive and negative implications for energy transformation.

Empirical studies show the positive role of FDI in renewable energy development. Apergis and Payne (2010) stress the interaction between renewable energy, FDI, and economic growth, whereas Paramati et al. (2016) demonstrate that FDI can help in renewable-energy production, especially when financial conditions are favorable. The technology transfer channel is also important. Shahbaz et al. (2015) propose that technology-intensive FDI can result in an increase in energy efficiency, and Sarkodie and Strezov (2019) highlight that the initial increase in energy demand associated with FDI may be followed by cleaner production and energy substitution. Further evidence from developing economies indicates that the FDI–environment relationship is context-specific. Yue et al. (2016) show that FDI in low-emission industries can improve eco-efficiency, while Baek and Koo (2009) demonstrate dynamic relationships between FDI, economic growth, and environmental outcomes in India and China. For example, in the case of India, Khan and Hayek (2017) differentiate between green and eco-destructive foreign investment, implying that the environmental effect of FDI is determined by its destination and composition. Institutional quality may also influence these outcomes, as better environmental governance can increase the contribution of FDI to green-energy development (Kim et al., 2019).

Notwithstanding these contributions, two important gaps remain. First, there is not enough evidence to conclude that the effect of FDI on renewable energy is different in the short run and long run. Second, the dynamic time series link between FDI and renewable energy consumption in India has not attracted much attention. The present study fills these gaps by using the ARDL framework on Indian data from 1990 to 2023 on an annual basis. The study investigates the short-run and long-run effects of FDI by controlling GDP per capita and trade openness.

GAPS IN RESEARCH

There are two important gaps, despite the growing body of literature on FDI, renewable energy, and environmental sustainability.

1. Short-run effects versus long-run effects: The existing studies show mixed evidence on the effect of FDI on renewable energy, but relatively little attention has been paid to the differentiation of the effects between the short run and the long run. In the case of India, it is important to distinguish short-run dynamics from long-run effects, as the benefits of foreign capital, technology transfer, and investment may be realized at different paces.

2. The Need for a Dynamic Empirical Framework The existing evidence is mainly based on cross-country panels or static models that may not be able to sufficiently capture the dynamic adjustment between FDI and renewable-energy consumption. Hence, there is a need for a time-series framework that can examine short-run dynamics and long-run relationships simultaneously. The present study fills this gap by employing the ARDL framework with FDI as the main explanatory variable and GDP per capita and trade openness as

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control variables, using the annual Indian data for the period 1990–2023.

Research Questions

The research question is addressed by the study: What is the relationship between foreign direct investment and renewable energy consumption in India in the short run and long run?

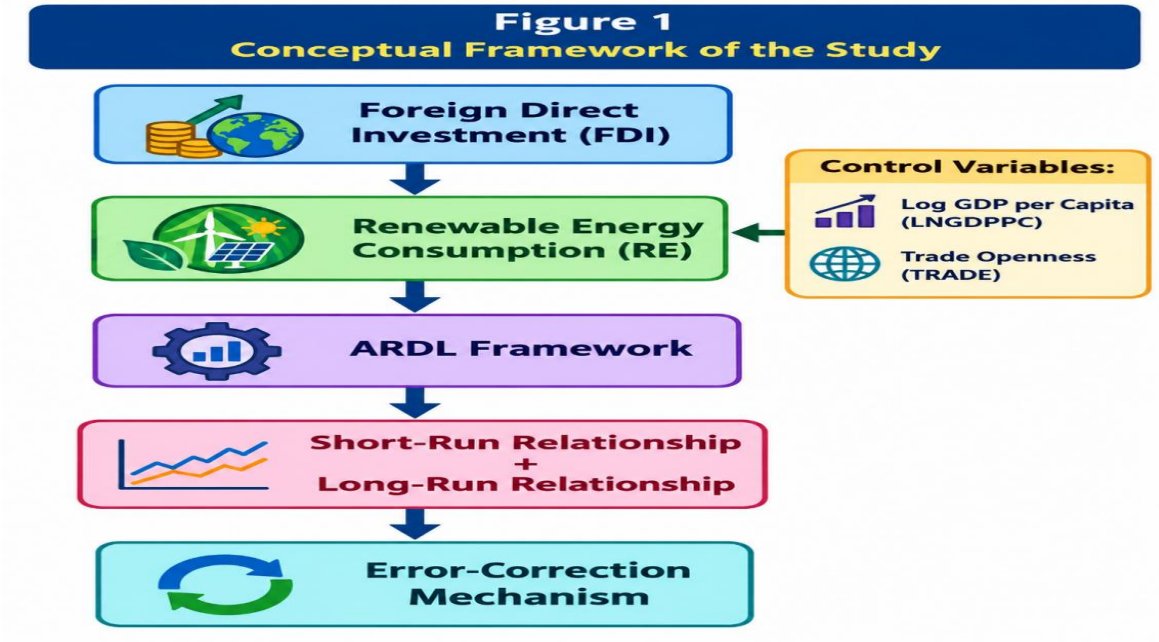
Research Hypothesis: The study uses non-directional hypotheses because the goal is to test the existence of a statistically significant relationship and not to impose a predetermined direction.

H_0: There is no statistically significant relationship between renewable energy, consumption, and foreign direct investment in India.

H_1: There exists a significant statistical relationship between foreign direct investment and renewable energy consumption in India.

The hypothesis is tested separately for the short-run and long-run FDI coefficients.

Theoretical Framework: The conceptual framework of the research assumes that FDI could be associated with renewable energy consumption. The control variables are the GDP per capita and trade openness.



Note. FDI is the key explanatory variable in the analysis, while the control variables are LNGDPPC and trade openness.

3. DATA AND METHODS

Data and Period of Study:

The study uses annual time series data for India for the period 1990–2023, thus making a total of 34 annual observations. The data includes the consumption of renewable energy, foreign direct investment, GDP per capita, and trade openness. The descriptive statistical analysis is based on 34 observations. The ARDL specification adopted includes lagged variables. The effective sample for estimation comprises 32 observations for the period 1992–2023.

The analysis is done by a sequential empirical procedure of descriptive statistics, correlation analysis, unit-root testing, ARDL lag selection, bounds testing, estimation of short-run and long-run coefficients, diagnostic testing, parameter stability analysis, and further robustness analysis.

Definition and Measurement of Variables

Table 1: Variables and Measurement

Variable	Symbol	Measurement	Role
Renewable Energy Consumption	RE	Renewable energy consumption (% of total final energy consumption)	Dependent variable
Foreign Direct Investment	FDI	FDI net inflows (% of GDP)	Main explanatory variable
GDP per capita	LNGDPPC	Natural logarithm of GDP per capita	Control variable
Trade Openness	TRADE	Trade (% of GDP)	Control variable

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Model Specification: In the long run, the relation can be written as

$RE_t = \beta_0 + \beta_1 FDI_t + \beta_2 LNGDPPC_t + \beta_3 TRADE_t + \varepsilon_t$

Were

- RE_t = use of renewable energy,
- FDI_t = Foreign Direct Investment,
- $LNGDPPC_t$ = natural log of GDP per capita,
- $TRADE_t$ = exposure to trade, and
- ε_t = error term.

The ARDL methodology is used to differentiate between short-run dynamics and long-run relationships. The chosen specification is ARDL (1,1,0,0).

4. RESULT AND DISCUSSION

Descriptive Analysis

Table 2: Descriptive Statistics, 1990–2023

Variable	N	Mean	SD	Minimum	Maximum
Renewable Energy Consumption (RE)	34	41.594	7.121	32.500	53.000
Foreign Direct Investment (FDI)	34	1.254	0.828	0.027	3.621
Log GDP per Capita (LNGDPPC)	34	6.734	0.717	5.713	7.797
Trade (% of GDP)	34	36.472	12.694	15.506	55.794

Note: N=34 annual observations (valid) The mean renewable energy consumption is 41.59% with a standard deviation of 7.12 percentage points. The values ranged from 32.50% to 53.00% during the period of study.

FDI averages 1.25% of GDP, ranging from 0.03% to 3.62%. It implies that there was considerable variation in the relative size of foreign investment during the period of the study. The average logged GDP per capita is 6.734. Average trade openness is 36.47% of GDP. The standard deviation of trade openness is found to be 12.69, which is relatively high and indicates a considerable variation in India's external economic integration.

Trend Analysis:

Use of Renewable Energy

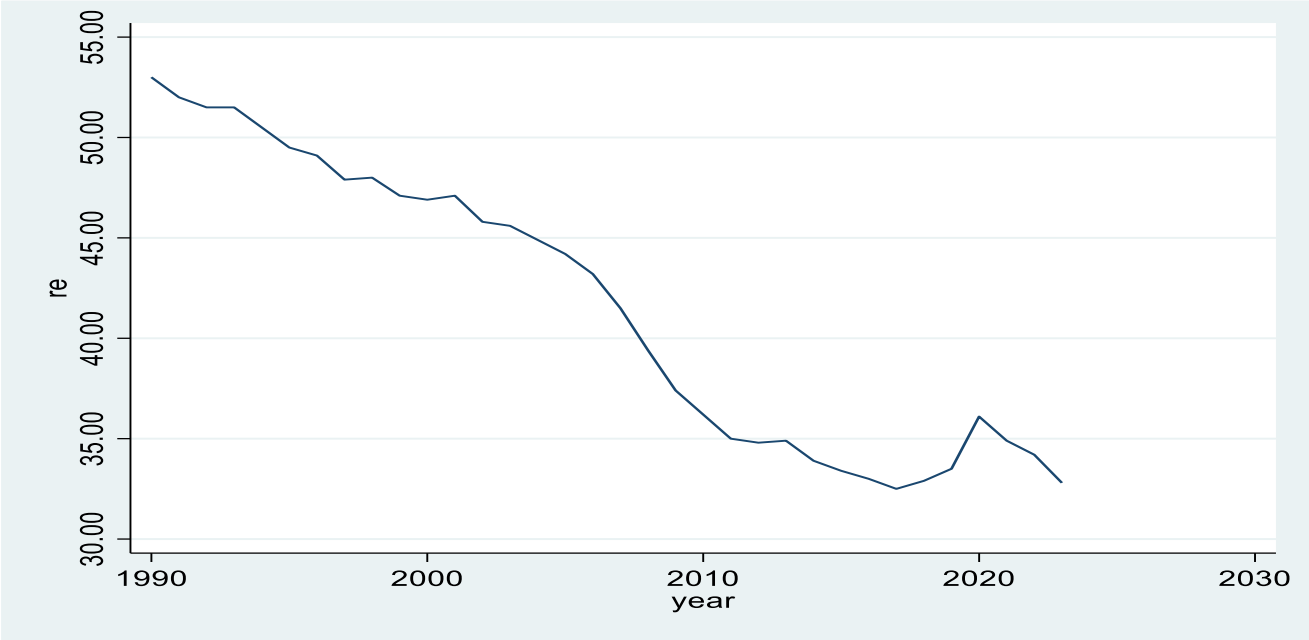


Figure 2: India Renewable energy comparative consumption trend 1990 -2023

The renewable energy series shows variation over the study period. It should be considered the changing pattern of renewable energy consumption to study its relationship with FDI in light of the dynamic properties of the series.

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Direct Foreign Investment

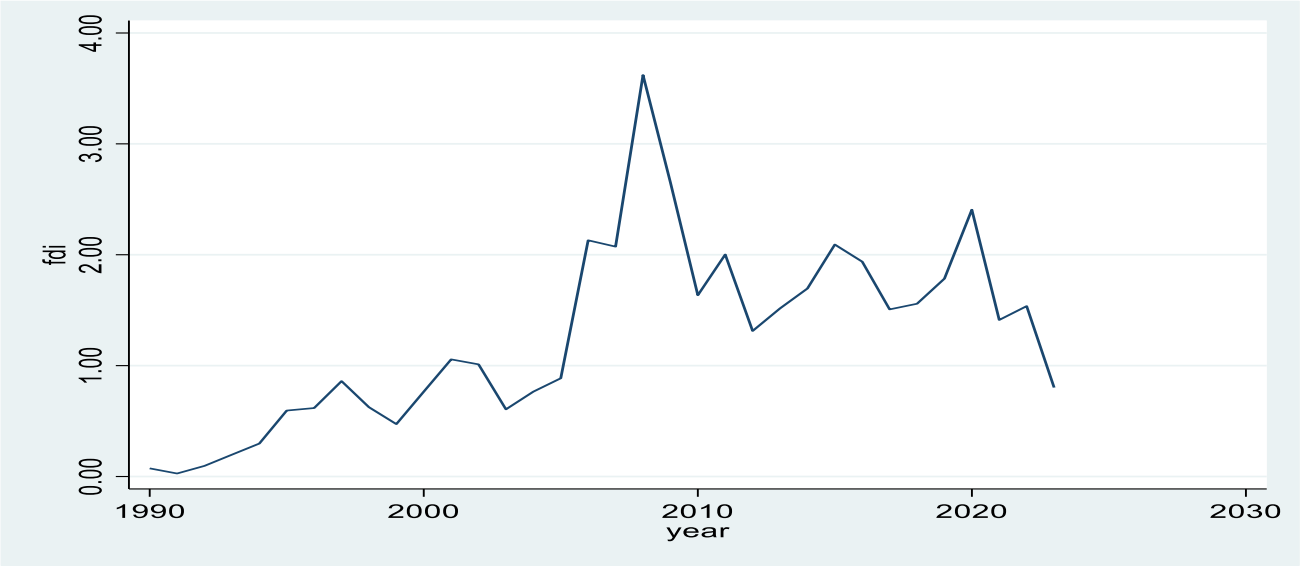


Figure 3: Foreign Direct Investment in India 1990-2023 (in USD)

The FDI is highly variable over the period of the study. The variation of the foreign investment pattern provides an empirical basis to investigate the association between the variation of FDI and the variation of renewable energy consumption.

GDP per capita log

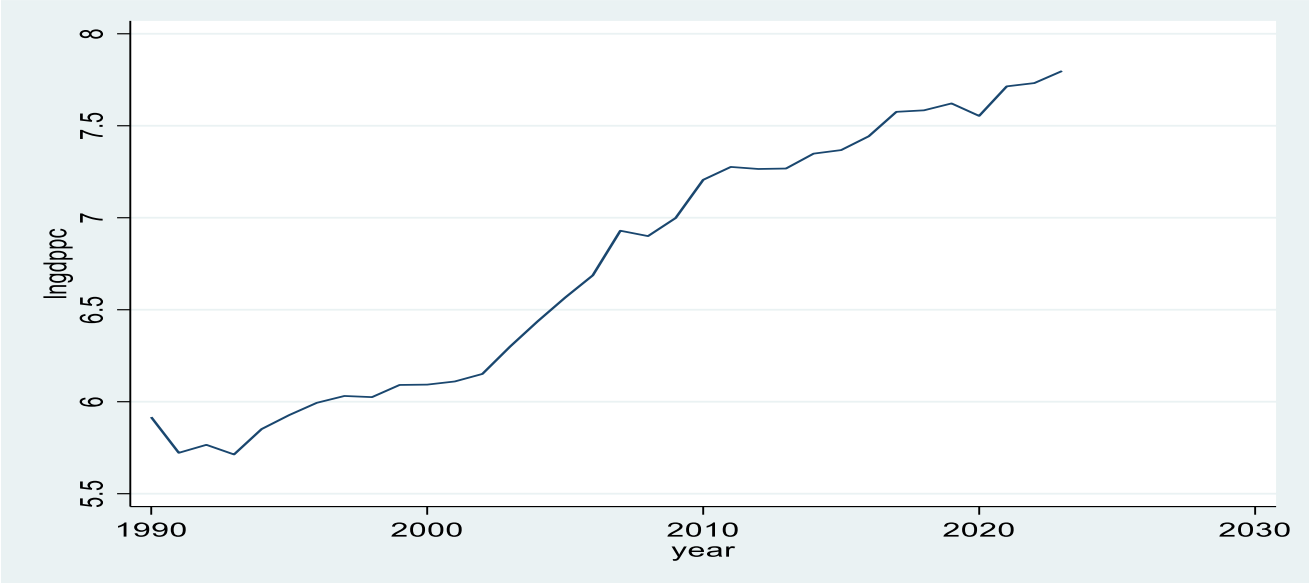


Figure 4: India Log GDP per Capita, 1990-2023. The series of log GDP per capita shows a clear upward trend in the long run, indicating the sustained growth of the Indian economy during the period of study.

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Openness to trade

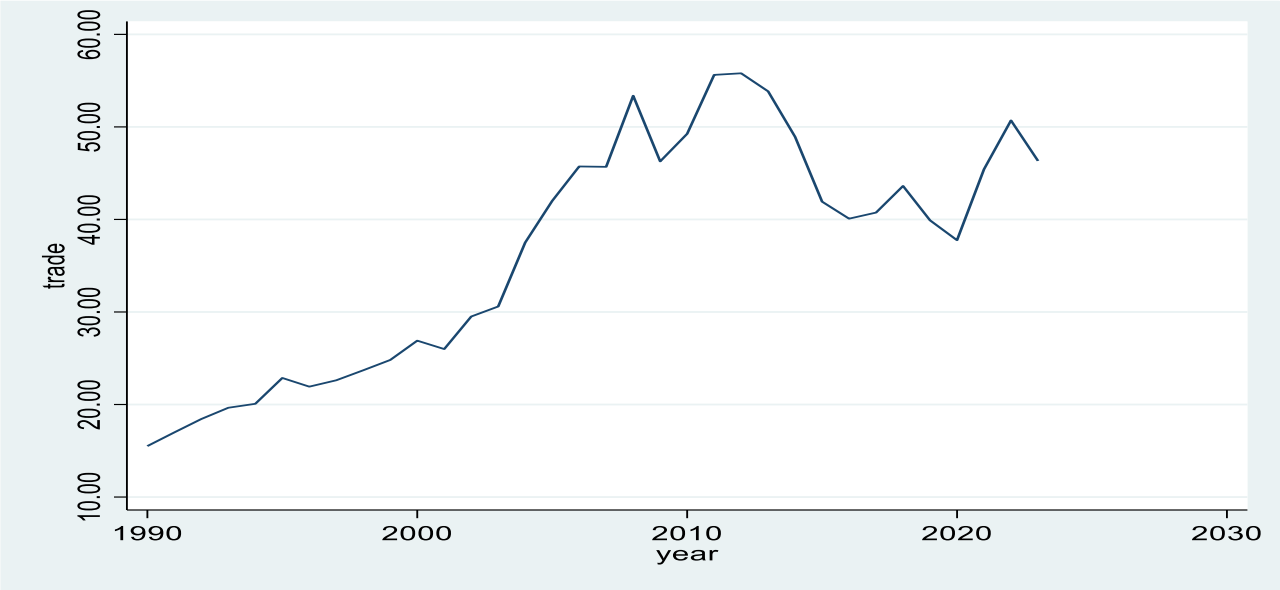


Figure 5: Trade Openness in India, 1990–2023 There is substantial variation in trade openness over time, perhaps indicating variation in India's integration with international markets.

Correlation Analysis

Table 3: Pairwise Correlation Matrix

Variable	RE	FDI	LNGDPPC	Trade
RE	1.000	−0.705***	−0.980***	−0.869***
FDI	−0.705***	1.000	0.679***	0.772***
LNGDPPC	−0.980***	0.679***	1.000	0.851***
Trade	−0.869***	0.772***	0.851***	1.000

Note. ***p < .001.

The unconditional correlation of RE and FDI is −0.705, which is a strong negative association. RE is also strongly negatively correlated with LNGDPPC and trade openness. However, correlation coefficients treat short-run and long-run relationships the same and do not imply causality. Furthermore, high correlations of trending macroeconomic variables may result from common time trends. Therefore, the correlation results should be interpreted together with the unit-root and ARDL results.

Unit Root Results

Table-4 Unit-Root Tests: ADF and Phillips-Perron

Variable	ADF Level p	ADF First Difference p	PP Level p	PP First Difference p
RE	.8025	.1100	.8707	.0011
FDI	.7427	.0040	.4984	< .001
LNGDPPC	.7420	.0050	.1077	< .001
Trade	.8624	.0023	.8596	< .001

The ADF and PP tests at all levels fail to reject the null hypothesis of a unit root for all variables. This means that the variables are non-stationary in levels.

Both the ADF and PP tests show that FDI, LNGDPPC, and trade are stationary at the first difference. In the case of RE, the ADF test with one lag gives a p-value of .1100, whereas the PP test strongly rejects the unit-root null with a p-value of .0011. The ADF test result on RE is sensitive to the lag choice. The first-difference ADF statistic is −3.986 at lag zero (p = .0015) and −2.523 at lag one (p = .1100). The PP test is sensitive but provides strong support for stationarity in first differences. Most significantly, none of the variables is I (2). Hence, the ARDL bounds-testing approach is suitable.

ARDL Lag Order

The lag structure was selected on the basis of Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC).

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Table 5: Selected ARDL Specification

Criterion	Selected Model	Value
AIC	ARDL (1,1,0,0)	68.559
BIC	ARDL (1,1,0,0)	77.353

Both information criteria choose the same specification, ARDL (1,1,0,0). The agreement provides additional support for the lag structure that was selected.

The final ARDL model was estimated for the period 1992-2023 with 32 observations.

Bound Test of ARDL

Table 6: ARDL Bounds Testing for Long-Run Level Relationship

Significance Level	I(0) Lower Bound	I(1) Upper Bound	F-Statistic
10%	2.988	4.166	7.452
5%	3.673	5.017	7.452
1%	5.332	7.061	7.452

Another test statistic: t = -3.311.

The F-statistic of the ARDL bounds test was 7.45. This is above the 1% level. I (1) upper bound critical value of 7.061. Thus, the F-statistic strongly supports the existence of a long-run equilibrium relationship among the variables. But the corresponding t-statistic is -3.311. This value lies between the relevant lower and upper bounds at conventional levels of significance. The p-value of the t-statistic is 0.127 for the I(1) bound. Hence, the t-bounds test is inconclusive. Hence, the evidence of the long-run relationship is mainly interpreted based on the F-statistic and the statistically significant error-correction coefficient rather than to claim that both the F-statistic and t-statistic separately support a long-run relationship.

ARDL Estimation Results.

FDI and Renewable Energy Nexus in the Short-Run

The short-run estimate of the FDI coefficient is βFDISR = 0.6094,
p = .026.

The coefficient is positive and significant at the 5% level. We estimate that a one-unit increase in FDI leads to an approximate 0.609 percentage-point increase in renewable energy consumption in the short run, conditional on the other components of the dynamic specification. This finding suggests that foreign investment can be associated with the increase in renewable energy consumption in the short run. Such an association can be a manifestation of the availability of additional capital, technology, investment resources, or international expertise. However, the coefficient should be interpreted as a statistical association within the ARDL framework and not as causality evidence.

Long-Run Relationship of FDI and Renewable Energy

The long-run coefficient of FDI is estimated to be βFDILR = −1.4888
with p = .164.

The estimated coefficient is negative but is not statistically significant at conventional levels. The study therefore does not provide sufficient evidence of a statistically significant long-run relationship between FDI and renewable energy consumption. This is an important finding, because it is different from the positive short-run FDI association. The results indicate that short-term variations in FDI may be associated with consumption of renewable energy, but this effect does not appear to be maintained as a statistically significant long-term effect of FDI.

Impact of GDP per Capita on the Long Run

The long-run coefficient of LNGDPPC is −4.8325 (p=.019). The coefficient is statistically significant at the 5% level and suggests a negative long-run relationship between logged GDP per capita and renewable energy consumption in the estimated specification.

The coefficient should be interpreted according to the semi-log functional form of the model, not as a simple percentage elasticity, because GDP per capita is in log form and renewable energy consumption is in percentage terms.

The long-run impact of trade openness is estimated to be a coefficient of trade openness = −0.2056, p = .055. The coefficient is negative and marginally significant at the 10% level but falls short of the traditional 5% significance level.

Thus, the model provides relatively weak evidence for trade openness to be negatively related to renewable energy consumption in the long run.

Error correction mechanism

The estimated coefficient of error correction is ECMt−1=−0.2652, p=.003. The coefficient is negative and statistically significant, indicating convergence to long-run equilibrium after short-run deviations. The coefficient indicates that around 26.5% of the disequilibrium in the previous period is corrected in 1 year. The coefficient suggests a rough adjustment period of 10.2652 ≈ 3.77. Therefore, a simple linear interpretation suggests that it would take 3.8 years to adjust toward the long-run equilibrium. This should be taken as an indicative horizon for adjustment and not as a precise prediction of the time needed for full adjustment.

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Diagnostic Tests

The Breusch-Godfrey LM test (p-value = 0.5111) does not provide evidence for first-order serial correlation in the residuals. The White test supports the null hypothesis of no heteroskedasticity at the 5% level (p-value = 0.1023). The Ramsey RESET test (F=2.80, p=0.0625) does not reject the null hypothesis of correct functional form at the 5% level but is borderline at the 10% level. However, the skewness-kurtosis test (joint p-value = 0.0019) rejects normality in the residuals. However, the absence of serial correlation and heteroskedasticity and the stability of the coefficients provide reasonable support for the overall model specification, but non-normality should be interpreted with caution due to the small sample size.

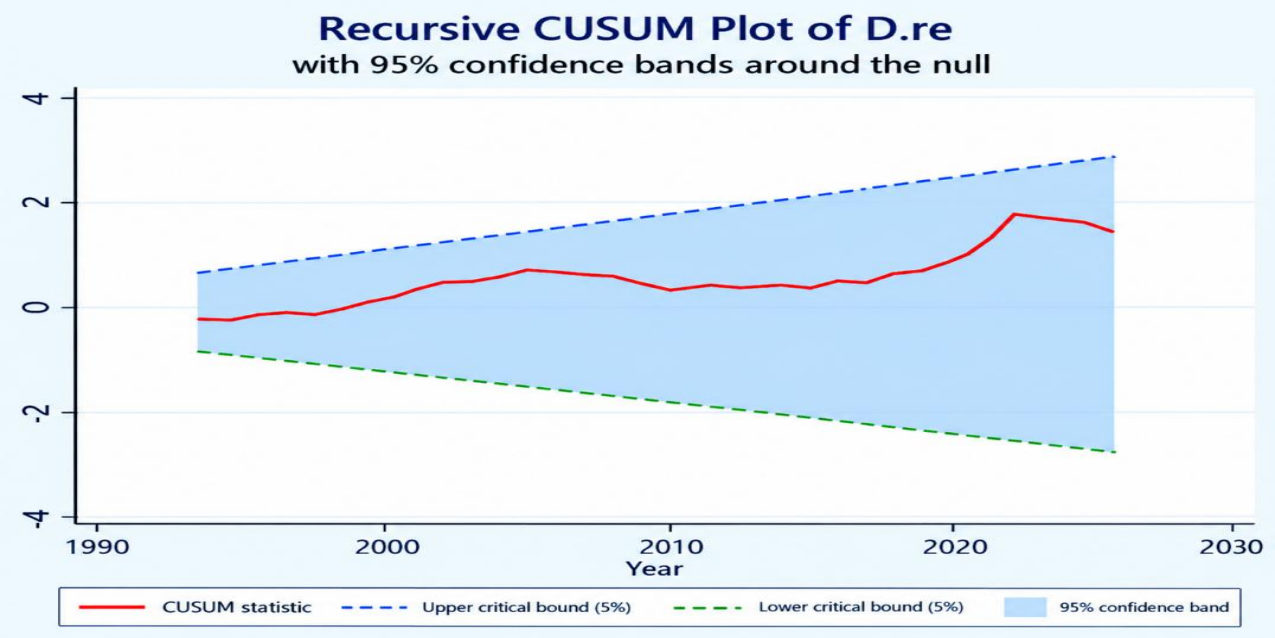


Figure 6: CUSUM test for parameter stability

The CUSUM statistic is 0.6655, which is less than the 5% critical value of 0.9479.

Hence, there is no evidence of parameter instability at the 5%. The result indicates that the estimated coefficients are relatively stable for the whole study period.

Multicollinearity:

The VIF results show that the explanatory variables do not have serious multicollinearity. The highest VIF is for trade with 4.85, followed by LNGDPPC with 3.63 and FDI with 2.49. The average VIF was 3.66.

These values are still lower than the commonly used threshold of 10, implying that multicollinearity is not severe enough to affect the model specification.

Supplementary Newey-West Robustness Analysis

We also conducted an additional static regression with Newey–West heteroskedasticity- and autocorrelation-consistent standard errors.

The FDI coefficient in the additional Newey–West regression is not statistically significant (p = .541). This is different from the ARDL model, which gives a positive and significant coefficient on FDI in the short run.

The difference is expected because the two methods estimate different relationships. The Newey–West specification is a static regression with HAC standard error, and it does not explicitly distinguish between short-run dynamics and long-run equilibrium effects.

Hence, the Newey–West results should be regarded as additional evidence and not as a robustness test for the ARDL short-run and long-run coefficients.

The contrast suggests, however, that the positive FDI association found by the ARDL model is essentially a dynamic short-run relationship, rather than a simple contemporaneous static relationship.

Hypothesis Testing: Testing the Hypothesis of FDI-Renewable Energy Relationship

Table 12: Testing the Hypothesis of FDI-Renewable Energy Relationship

Horizon	FDI Coefficient	p	Decision
Short run	+0.6094	.026	Reject H_0
Long run	−1.4888	.164	Do not reject H_0

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The coefficient of FDI is positive and significant at the 5 per cent level in the short run. Hence, the null hypothesis is rejected for the short-run relationship.
But the long-run coefficient of the FDI is statistically insignificant. Therefore, the null hypothesis of the long-run coefficient of FDI is not rejected.
Hence, the correct general conclusion is that the study finds evidence of a statistically significant short-run link between FDI and renewable energy consumption but does not find enough evidence to support a statistically significant long-run FDI relationship.

5. DISCUSSION SECTION

The major finding of the study is the dissimilarity between the short-run and long-run relationships between FDI and renewable energy consumption in India. The positive short-run coefficient indicates that FDI is associated with higher renewable energy consumption in the short run. One explanation is that foreign investment can bring in additional capital, technology, managerial expertise, and international know-how that facilitate investment in renewable energy activities. But the long-run FDI coefficient is negative and statistically insignificant. This means that the short-run association does not necessarily imply a statistically significant long-run relationship. This distinction is important from a policy perspective. The single growth of FDI volume may not ensure the continuous increment of renewable energy consumption. The environmental implications of FDI are likely to be the sectoral composition and technological orientation of the investment. The large error-correction coefficient suggests that the variables tend to converge toward their estimated long-run equilibrium. The adjustment process is moderate, with about 26.5% of disequilibrium corrected each year. It is also worth noting that the long-run coefficient of logged GDP per capita is significantly negative. The estimated model suggests that long-term economic development is associated with a declining share of renewable energy. This finding should not be interpreted as meaning that renewable energy necessarily decreases with economic growth. Rather, it shows an inverse statistical relation in the specific model and sample period. Trade openness also has a negative long-run coefficient, but the relationship is marginally significant at the 10% level. Thus, international economic integration alone does not necessarily lead to an increase in renewable energy consumption.

Implications for policy:

FDI support of green development: The positive short-run relationship between FDI and renewable energy shows that foreign investment can assist India in its transition toward clean energy. Policy, however, should focus on the quality of FDI and the destination, rather than on the simple increase of the aggregate flow of investment.

Encourage Investment in Renewable Energy: Foreign investment policies could offer more incentives for investment in renewable power generation, solar and wind projects, energy storage, electricity transmission, and supporting infrastructure.

Facilitate technology transfer: FDI can bring access to cutting-edge technology and managerial know-how. Policies that promote technology transfer and domestic technological capability can improve the contribution of foreign investment to India's clean-energy transition.

Conditions for Long-Term Investment The near-zero long-run coefficient for FDI suggests that short-term investment inflows may not always translate into sustained renewable-energy outcomes. Stable regulatory structures, predictable policies, efficient approval mechanisms, and long-term investment certainty are therefore important.

Structure of FDI: The results highlight that the composition of FDI could be more important than its aggregate volume. Investment in renewables, clean technologies, storage systems, grid infrastructure, and low-carbon manufacturing is more in line with India's long-term energy-transition objectives.

Harmonize Trade and Energy Policies: The negative long-run relationship between trade openness and renewable energy consumption implies that trade integration should be encouraged by policies that enable access to renewable technologies and equipment and clean-energy supply chains.

Limitations of the Study

- The sample is small, as it uses annual data for India for the period 1990-2023.
- The results show associations (not causation) in the ARDL analysis.
- The residuals are not normally distributed, but other diagnostics are satisfactory.
- Only aggregate FDI is considered. The sector-wise impacts of FDI need to be explored in future work.

6. CONCLUSION

The present study investigated the short-run and long-run relationship between foreign direct investment and renewable energy consumption in India, employing the annual data for 1990–2023 and the ARDL framework. The study has 34 valid annual observations, and the estimated ARDL model is fitted for the period 1992–2023 with 32 observations. The last specification includes renewable energy consumption as the dependent variable, FDI as the main explanatory variable, and logged GDP per capita and trade openness as control variables. The results show that there is a significant difference between short-run and long-run relationships. FDI is positively and statistically significantly related with renewable energy consumption in the short run with a coefficient of 0.6094 ($p = .026$). The estimated long-run FDI coefficient, however, is -1.4888 ($p=.164$) and is statistically insignificant. The ARDL bounds F-statistic of 7.452 is greater than the 1% I(1) upper-bound critical value of 7.061, thus providing strong evidence from the F-statistic for a long-run level relationship. However, the associated t-statistic of -3.311 is inconclusive. The long-run

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interpretation is thus primarily based on the F-statistic and the significant error-correction mechanism, rather than claiming confirmation from both bound statistics. The error-correction coefficient of −0.2652 (p = .003) indicates that approximately 26.5% of disequilibrium is corrected in one year. This indicates a strong tendency to settle down to the long-run equilibrium. Of the control variables, the long-run coefficient of log GDP per capita is statistically significant and negative, while the coefficient of trade openness is negative and marginally significant at the 10% level. Overall, the results suggest that FDI is associated with renewable energy consumption in the short run, but the evidence is not sufficient to establish a statistically significant long-run FDI relationship. The findings suggest that India's clean-energy transition should not be about attracting just more volume of foreign investment. Rather, more importance should be attached to the sectoral distribution, the technological content, the environmental orientation, and the long-term commitment of FDI. Hence, policies that channel foreign investment to renewable energy generation, energy storage, grid infrastructure, clean technology, and low-carbon manufacturing may be more effective in translating foreign investment into sustained clean-energy outcomes.

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