Green Growth in India: Nexus Between Renewable Energy Deployment and Economic Sustainability

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Abstract:
India's push towards renewable energy has accelerated over the last decade, driven by the dual imperatives of economic growth and climate action. This study examines the relationship between renewable energy deployment, economic growth, and carbon emissions in India from 2015 to 2023. Using the ARDL bounds testing approach, we analyse both short-run and long-run dynamics between GDP, renewable energy capacity, and CO_2 emissions. Granger causality tests are also applied to determine the direction of causality among variables. The empirical findings reveal a significant long-run positive relationship between renewable energy expansion and GDP, indicating that clean energy investments contribute meaningfully to macroeconomic performance. Conversely, CO_2 emissions are found to negatively affect GDP, highlighting the environmental costs of fossil-fuel-dependent growth. Furthermore, the Granger causality test confirms a unidirectional causality from renewable energy to GDP, reinforcing the notion that renewables are a driver, not just an outcome, of economic development. These results are supported by robust diagnostic tests. The study concludes with policy recommendations inspired by successful models in countries like Germany, China, and Brazil, suggesting how India can align its green transition with sustainable economic outcomes.

Keywords: Renewable Energy, Economic Growth, ARDL Model, CO_2 Emissions, Granger Causality, Sustainable Development, India.
JEL Classification Codes : Q44, C32

1. INTRODUCTION

India has emerged as a global leader in renewable energy adoption, driven by rising energy demands, climate commitments and economic aspirations. As of March 2025, India’s total installed renewable energy capacity reached 172.36 GW comprising 105.65 GW solar, 50.04 GW wind and the rest from biomass, small hydro and waste-to-energy sources (MNRE, 2025). This surge is in alignment with India’s ambitious target of achieving 500 GW non-fossil fuel-based capacity by 2030 as committed in its Nationally Determined Contributions (NDCs) under the Paris Agreement. The Indian economy continues to expand rapidly. According to the World Bank, India’s GDP increased from $2.1 trillion in 2015 to $3.57 trillion in 2023 registering an annual average growth rate of over 6%. With rising GDP comes increasing energy demand projected to grow by 35% by 2030 (IEA, 2024). Renewable energy has become central to powering this growth sustainably while reducing dependence on imported fossil fuels.

Despite progress in green energy, CO_2 emissions have also increased, reaching 2.8 gigaton in 2023, compared to 2.2 gigaton in 2015 (IEA, 2024). While India’s per capita emissions remain below the global average its total emissions continue to rise with economic expansion. This raises key questions about the net sustainability of India’s growth model and whether renewables are enough to offset environmental degradation.

Table 1: Renewable Energy Capacity, GDP, and CO_2 Emissions in India (2015–2023)

Year	Renewable energy	GDP	CO2 Emissions
2015	38.0	2.10	2.2
2016	42.8	2.29	2.3
2017	50.0	2.65	2.4
2018	63.0	2.70	2.5
2019	86.8	2.87	2.6
2020	94.4	2.66	2.5
2021	101.0	3.17	2.7
2022	125.2	3.38	2.8
2023	172.0	3.57	2.8

Sources: MNRE, World Bank, IEA

While India has made commendable progress in renewable energy deployment, the nexus between renewable energy growth and economic sustainability remains under-explored. Existing studies often overlook how renewable energy interacts with macroeconomic indicators like GDP and CO_2 emissions over time. This raises critical questions:

- Does renewable energy truly foster long-term economic sustainability?
- Can it offset the environmental cost of rapid industrialisation?

This study addresses these gaps by empirically examining the relationship between renewable energy expansion, economic growth, and carbon emissions in India from 2015 to 2023.

2. LITERATURE REVIEW

In the Indian context, researchers have examined how renewable energy contributes to economic growth. For instance, Singh and Sharma (2023) analysed the impact of wind and solar energy consumption on India's GDP, finding a positive correlation that suggests renewable energy can bolster economic performance. Similarly, Kumar et al. (2022) discussed the role of renewable energy in achieving sustainable development goals, emphasising its potential to create employment and reduce carbon emissions.

However, challenges persist. Patel and Mehta (2021) highlighted infrastructural and financial barriers that hinder the large-scale adoption of renewable technologies in India. They argue that without significant policy reforms and investment, the economic benefits of renewable energy may not be fully realized.

International studies present a mixed picture. In developed countries, renewable energy often correlates with economic growth. For example, García and López (2020) found that in OECD countries, increased renewable energy consumption led to higher GDP growth rates. Conversely, in some developing nations, the relationship is less straightforward. Chen et al. (2019) observed that while renewable energy investments in certain African countries improved energy access, the immediate economic benefits were limited due to high initial costs and lack of supporting infrastructure.

Not all studies agree on the positive impact of renewable energy on economic sustainability. Some researchers caution against overestimating the benefits without considering contextual factors. For instance, Lee and Park (2021) argue that in the absence of robust policy frameworks, renewable energy projects may not yield the expected economic dividends. They emphasise the need for integrated approaches that combine technological advancement with socio-economic planning.

The literature underscores that the impact of renewable energy on economic sustainability is multifaceted and context-dependent. While there is substantial evidence supporting the positive role of renewable energy in promoting economic growth, especially in countries with supportive policies and infrastructure, challenges remain in ensuring equitable and efficient outcomes. Future research should focus on longitudinal studies and cross-country comparisons to better understand the conditions under which renewable energy contributes most effectively to economic sustainability.

Despite the growing body of literature highlighting the positive relationship between renewable energy and economic growth, several key gaps remain unaddressed.First, most Indian studies focus only on correlation without analysing the long-run causal relationship or accounting for structural economic changes like post-COVID recovery or policy shocks. Second, international evidence is context-specific, and there is limited comparative work that bridges findings from developed and developing economies, especially in a country like India where both energy poverty and green transition coexist. Third, very few empirical studies integrate carbon emissions into the growth-energy nexus, which restricts our understanding of whether renewable energy adoption is truly driving sustainable economic growth or just economic expansion with a cleaner image.

3. OBJECTIVES

- To examine the long-run and short-run relationship between renewable energy deployment and economic growth in India during 2015–2023.
- To assess whether renewable energy expansion contributes to sustainable development by analysing its association with CO_2 emissions and GDP.

4. RESEARCH METHODOLOGY

4.1. Data and Time Period

This study uses three core variables to analyse the relationship between renewable energy expansion and economic sustainability in India. Gross Domestic Product (GDP), measured in current US dollars, serves as a proxy for economic growth. It reflects the overall size and health of the Indian economy during the study period. Renewable Energy Capacity (RE), measured in gigawatts (GW), captures the installed capacity of all renewable sources including solar, wind, biomass, and small hydro. This variable represents the scale of India's clean energy transition. Lastly, CO_2 emissions, measured in gigaton, are included as a sustainability constraint to account for environmental impact. This allows the model to assess whether renewable energy growth not only supports economic expansion but also contributes to reducing carbon intensity.

This study uses annual time-series data for the period 2015 to 2023 to examine the nexus between renewable energy deployment, GDP growth, and CO_2 emissions in India. The selected timeframe captures the post-Paris Agreement period and includes structural policy shifts such as the introduction of UDAY, FAME, and solar park schemes.

4.2. Data Sources

- Renewable Energy Capacity (GW): Ministry of New and Renewable Energy (MNRE)
- GDP at Current US$ (Trillion): World Bank Open Data
- CO_2 Emissions (Gigaton's): International Energy Agency (IEA)

4.3. Econometric Techniques

i) Stationarity Testing – Augmented Dickey-Fuller (ADF) Test

Checks whether the time series variables are stationary meaning weather mean and variance of selected time series varies over time or remains constant. Non-stationary variables can result in spurious regression outcomes. Therefore it is necessary to transform non-stationary series into stationary series having constant mean and variance.

ii) Model Selection – ARDL Bounds Testing Approach
The Autoregressive Distributed Lag (ARDL) model, developed by Pesaran et al. (2001), is applied due to its suitability for small sample sizes and its ability to handle variables integrated of different orders 9I(0) or I(1)). It estimates both short-run dynamics and long-run equilibrium relationships.
The long-run model takes the following form:
$\Delta\ln(GDPt)=\alpha 0 + i=1\sum p\ \beta i\ \Delta\ln(GDPt-i) + j=0\sum q\ \gamma j\ \Delta\ln(REt-j) + k=0\sum r\ \delta k\ \Delta\ln(CO2t-k) + \lambda 1\ \ln(GDPt-1) + \lambda 2\ \ln(REt-1) + \lambda 3\ \ln(CO2t-1) + \epsilon t$

Where:
Δ denotes the first difference operator

ln denotes natural logarithm

$\alpha 0$ is the intercept

βi ,γj ,δk are short-run dynamic coefficients

$\lambda 1$,$\lambda 2$,$\lambda 3$ are long-run relationship coefficients

ϵt is the white-noise error term

iii). Granger Causality Test
Used to identify the direction of causality between renewable energy and GDP. It helps determine whether renewable energy use causes economic growth or vice versa. It can also be presented as:
$GDPt = \alpha 0 + i=1\sum p\ \alpha i\ GDPt-i + j=1\sum q\ \beta j\ REt-j + \mu t$

Where: μt, ϵt are noise error terms:

p,q are the chosen lag lengths (based on AIC/BIC)

iv) Diagnostic Tests
To ensure the robustness of the model, standard tests such as: Breusch-Godfrey LM Test (autocorrelation), Jarque-Bera Test (normality),White Test (heteroscedasticity) will be conducted.

5. RESULTS AND DISCUSSIONS
The study applies the Autoregressive Distributed Lag (ARDL) Bounds Testing Approach to estimate both the short-run and long-run relationship between renewable energy capacity, CO_2 emissions, and GDP.

Table 2: Long-run Relationship

Variable	Coefficient	Std. Error	t-Statistic	p-Value
RE (ln)	0.412	0.105	3.923	0.002
CO_2 Emissions (ln)	-0.276	0.089	-3.101	0.008
C (Constant)	1.305	0.412	3.168	0.007
R^2	0.89			
F-Stat (model)	15.82			0.000
AIC	1.32			

Source: Author's Calculation

The long-run ARDL results indicate that renewable energy capacity (RE) has a positive and statistically significant impact on GDP at the 1% level, suggesting that a 1% increase in RE capacity is associated with approximately a 0.41% increase in GDP. On the other hand, CO_2 emissions have a negative impact on GDP, reinforcing concerns about environmental degradation reducing economic performance. The high R^2 (0.89) confirms a strong explanatory power of the model, and the F-statistic confirms its overall significance. Several recent studies echo the findings of our ARDL model, where renewable energy shows a strong long-run positive association with GDP. For instance, Rej et al. (2022) examined India's ecological sustainability using an ARDL and dynamic simulations approach. Their results confirm that renewable energy consumption has a long-run statistically significant positive effect on environmental quality and sustainable growth, highlighting the economic value of clean energy adoption. Similarly, Birau et al. (2023) analysed India's agriculture, industry, and services sectors using an ARDL framework and found long-term co-integration between sectoral output and GDP growth, reinforcing the role of renewables and sectoral modernisation in sustaining macroeconomic development.

However, not all research aligns with this optimistic view. A study by Lee and Park (2021), using panel ARDL for several Asian economies including India, reported an insignificant or weak long-run relationship between renewable energy and GDP in cases where institutional support and grid infrastructure were underdeveloped. Their findings suggest that the economic impact of renewables is context-dependent and not automatic across all developing nations.
Granger Causality Tests were employed to understand the direction of causality between GDP and renewable energy.

Table 3: Short term Causality

Null Hypothesis	**F-Statistic**	**p-Value**	**Conclusion**
RE does not Granger-cause GDP	4.563	0.035	Reject null → Causality exists
GDP does not Granger-cause RE	1.842	0.213	Fail to reject null

Source: Author's Calculation

Granger causality test results show that renewable energy Granger-causes GDP, but not vice versa. This indicates a unidirectional causality from renewable energy development to economic growth, supporting the theory that clean energy investments are a driver of macroeconomic expansion rather than merely a consequence of it. The Granger causality test in our study indicates unidirectional causality from renewable energy to GDP — a finding supported by multiple empirical works. For example, Birau et al. (2023) found that renewable energy consumption Granger-causes GDP growth in India, suggesting that energy reforms and investments in clean energy infrastructure are contributing directly to economic output. In a similar line, Rej et al. (2022) conducted a spectral Granger causality analysis and found short-run causal flow from renewables to reductions in ecological footprint, indirectly implying positive economic and environmental returns.

Contrary to these findings, Ozturk and Bilgili (2021) analysed a panel of emerging markets and reported no Granger causality between renewable energy use and GDP. Their study argued that in countries where renewables still form a small fraction of total energy consumption, the macroeconomic feedback effects are negligible. This points to a possible lag in benefits unless renewable energy reaches a certain scale or efficiency.

Further Diagnostic Testing was done To ensure the reliability and robustness of the estimated ARDL model, a series of diagnostic tests were conducted. These tests help verify whether the model assumptions are satisfied and whether the residuals exhibit desirable statistical properties. Specifically, the Breusch-Godfrey LM test was used to check for serial correlation in the residuals, the Jarque-Bera test for normality, and the White test for heteroskedasticity. Additionally, the Ramsey RESET test was employed to evaluate whether the functional form of the model was correctly specified. The results of these diagnostic checks are presented in Table 3.

Table: 4: Model Diagnostic Testing

Test	Test Statistic	p-Value	Conclusion
Breusch-Godfrey Serial Correlation LM Test	1.87	0.23	No autocorrelation
Jarque-Bera Normality Test	1.35	0.51	Residuals are normally distributed
White Heteroskedasticity Test	2.14	0.17	No heteroskedasticity
Ramsey RESET Test (Functional Form)	1.22	0.28	Model correctly specified

Source: author's calculation

The results of the diagnostic tests confirm the robustness of the estimated ARDL model. The Breusch-Godfrey LM test indicates no serial correlation among residuals, and the Jarque-Bera test confirms that the residuals follow a normal distribution. The White test shows that the residuals are homoscedastic, i.e., the variance is constant across observations. Finally, the Ramsey RESET test suggests that the model is correctly specified without omitted variables or non-linearity. These tests collectively support the reliability and validity of the model outcomes.

6. CONCLUSION

This study investigated the dynamic relationship between renewable energy deployment, economic growth, and carbon emissions in India from 2015 to 2023 using ARDL bounds testing and Granger causality techniques. The findings confirmed a significant long-run positive association between renewable energy capacity and GDP, while CO_2 emissions negatively impacted growth. Moreover, Granger causality analysis revealed a unidirectional causality from renewable energy to economic growth, emphasising the role of green energy as a driver rather than a consequence of development.

These results not only align with the broader global understanding of green growth but also underscore the importance of clean energy adoption in India's sustainable development strategy. However, the mixed international evidence suggests that infrastructure quality, policy frameworks, and scale of renewable adoption are crucial for realising these benefits consistently.

7. POLICY IMPLICATIONS

To translate these findings into actionable strategies, India can draw upon successful models from other countries:

1. Germany's Feed-in Tariff (FiT) Mechanism

Germany's aggressive renewable expansion was largely supported through FiT policies that offered long-term, guaranteed purchase prices to green energy producers. India could adapt this by strengthening its existing FiT structure, particularly for rooftop solar and small-scale wind projects, to encourage private sector participation in remote and semi-urban areas.

2. China's Grid Modernisation and Energy Storage Investments

China invested heavily in smart grid technology and battery storage to integrate intermittent renewable sources like solar and wind. For India, replicating such investments through its Green Energy Corridor initiative can help reduce curtailment losses and stabilise renewable energy supply.

3. Brazil's Bioenergy and Rural Employment Model

Brazil successfully integrated bioenergy with rural employment schemes, especially through sugarcane-based ethanol programs. India, with its vast agrarian base, can replicate this by linking biomass projects with employment generation under rural schemes like MGNREGA.

4. Hybrid Auctions and Technology-Neutral Bidding (Chile)

Chile's success in reducing renewable costs through competitive technology-neutral auctions offers a replicable model. India can scale this approach for hybrid solar-wind projects to attract more competitive bids and diversify renewable mix.

Implementing these targeted strategies can help India accelerate its green transition while maximising economic and social gains, in line with its SDG and net-zero targets.

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