“Evaluating the role of government expenditure in promoting renewable energy and economic growth in India”

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EVALUATING THE ROLE OF GOVERNMENT EXPENDITURE IN PROMOTING RENEWABLE ENERGY AND ECONOMIC GROWTH IN INDIA

Abstract

The transition to a sustainable energy economy requires substantial public investment, with government spending playing a crucial role in driving the adoption of renewable energy and achieving environmental outcomes. This study investigates the impact of India's budgetary allocations on renewable energy consumption, carbon emissions, and economic growth. The analysis covers annual data from 1990 to 2024. It employs the autoregressive distributed lag (ARDL) bounds testing approach and the Granger causality test to examine long-term equilibrium relationships and directional causality among the variables. The results indicate a statistically significant long-run relationship between government expenditure, renewable energy usage, and carbon emissions. Specifically, a 1% increase in renewable energy consumption (REC) results in a 1.14% decrease in carbon emissions, demonstrating the environmental benefits of clean energy deployment. The ARDL model also shows that past government disbursements significantly contribute to emissions reduction, with coefficients of –2147.41 ($p < 0.001$) and –997.36 ($p < 0.05$) at lags one and two, respectively. Granger causality results confirm an unidirectional causal relationship between renewable energy expenditures (REE) and carbon emissions, as well as between government spending and gross domestic product (GDP), highlighting the dual impact of such investment on environmental sustainability and economic growth. The findings underscore the effectiveness of public financial support in accelerating the transition to renewable energy while advancing macroeconomic goals. Strengthening and sustaining government investment in renewable energy is essential for achieving India's long-term development targets, reducing carbon intensity, and promoting green economic growth.

Keywords budgetary expenditure, economic growth, renewable energy, carbon emissions, government investment

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INTRODUCTION

As the world faces the growing urgency of climate change and environmental degradation, the push toward cleaner, more sustainable energy sources has never been more critical. This transition is significant and incredibly challenging for a country like India, a major global economy and one of the largest emitters of carbon dioxide. India's energy needs are vast and growing, and much of that demand is still met through fossil fuels like coal and oil. While these sources have powered development for decades, they pose serious environmental and long-term energy security risks. The Indian government has taken significant steps to promote renewable energy. Over the past several years, budgetary allocations have been increasingly directed toward solar, wind, and other clean energy projects. These investments reflect a firm's policy commitment to reducing carbon emissions, improving air quality, and fostering green economic growth. However, a key question remains: Is public spending making a difference?

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India has implemented policies and programs, creating a favorable environment to attract foreign investments and expand its presence in the renewable energy market. As a result, the country's photovoltaic capacity has increased, enabling it to rise from seventh to fourth globally. India is also on track to achieve its ambitious green goals for 2030, as stated in the Renewable Energy Country Attractiveness Index (RECAI) 2022. The endorsement of the Kyoto Protocol Agreement in 1997 revitalized global emphasis on renewable energy utilization. Since then, substantial strides have been made worldwide in generating and utilizing renewable energy. A paramount concern is the global CO_2 emissions predicament. Given the current state of climate change, harmonizing robust economic advancement with environmentally conscious practices is a formidable challenge, necessitating an eco-friendly approach. India is the third-largest carbon dioxide (CO_2) emitter, trailing only China and the US. Acknowledging the vital role of renewable energy is imperative, given its integral connection to India's overall economic growth. Economic progress and energy consumption are inextricably intertwined, a reality underscored by the BRICS nations' status as upper-middle-income countries. Escalating economic expansion in developing nations intensifies the energy demand, with conventional fossil fuels remaining the predominant sources. Remarkably, India holds the fourth position globally regarding the potential of its renewable energy sector. As of 2020, India claimed the fourth spot in wind power, fifth in solar power, and fourth in total renewable installed capacity. Impressively, renewable power generation capacity has experienced rapid expansion, recording a Compound Annual Growth Rate (CAGR) of 15.92% from FY16 to FY22. Projections indicate a fourfold surge in new capacity additions by 2026, particularly within India's flourishing renewable energy market.

The study examines how changes in renewable energy consumption and production influence India's broader economic landscape. The Indian government's ongoing investment in renewable energy projects, as indicated by its annual budget allocations, underscores the necessity of assessing whether this expenditure efficiently promotes renewable energy adoption, stimulates economic growth, and reduces carbon emissions. This paper seeks to furnish critical insights for policymakers and stakeholders striving for a more sustainable and environmentally friendly economy by addressing this deficiency.

1. LITERATURE REVIEW AND HYPOTHESES

India, one of the world's fastest-growing emerging economies, faces a pressing dual challenge: achieving sustained economic growth while ensuring environmental sustainability. As the country's energy demands soar and global climate commitments tighten, the Indian government has increasingly turned to renewable energy as a strategic solution. Budgetary allocations and policy support for this sector are expected to accelerate renewable energy consumption and impact broader macroeconomic indicators such as carbon emissions and GDP growth.

A growing body of research underscores the pivotal role of financial development, technological innovation, and institutional support in enhancing renewable energy consumption. In India, studies have revealed that economic growth and supportive fiscal measures, such as budgetary allocations and subsidies, have accelerated the adoption of clean energy technologies (Eren et al., 2019; Manigandan et al., 2024). The western coastal states have emerged as leaders in renewable energy penetration, driven by public-private partnerships and investment-friendly policy environments (Devender, 2023).

Government support, particularly in R&D funding, tax incentives, and certification schemes, is critical in boosting renewable energy adoption. For instance, Kilinc-Ata (2015) and White et al. (2013) emphasize that stable, long-term policies attract clean energy investments, whereas abrupt changes deter investor confidence. Bölük and Kaplan (2022) found that while R&D and tax benefits were effective across the EU and Turkey, direct investment and loan-based schemes had limited success. Similarly, Grafström et al. (2023) and Mondal et al. (2024) observed that countries with deregulated electricity markets or low energy import dependency tend to underinvest in renewable R&D, reflecting policy inconsistency. The experience during the COVID-19 pandemic further reinforced the significance of fiscal policy.

There is widespread agreement that increased renewable energy use contributes to lower carbon emissions. Multiple Indian studies, including those using ARDL models, confirm a negative correlation between renewable energy consumption and CO_2 emissions (Bekun, 2022; Ganie & Ahmad, 2024; Manocha, 2022; Roy, 2024). An N-shaped Environmental Kuznets Curve (EKC) in India suggests that emissions decline once a certain economic growth threshold is surpassed (Nica et al., 2024; J. Parikh & K. Parikh, 2011). This dynamic illustrates how clean energy growth, supported by sound economic policies, can contribute significantly to environmental targets.

Internationally, similar conclusions have been drawn. Feng et al. (2022) extended this perspective to Belt and Road Initiative (BRI) countries, revealing that public spending on human capital and renewables enhances economic and ecological sustainability. In the context of China, Zahoor et al. (2022) highlighted the complexity of managing the interlinkages between renewable energy investment, CO_2 emissions, ecological footprint, and economic growth. The study underscores that aligning investment strategies with sustainability goals is vital – a sentiment echoed by Xie et al. (2023) and Aslan et al. (2022).

Beyond environmental benefits, renewable energy development has proven to drive economic growth. Clean energy initiatives in India have created employment opportunities, attracted foreign investment, and reduced the economic risks of fossil fuel dependency (Nia & Niavand, 2017; Jayasinghe & Selvanathan, 2021). The bidirectional causality between economic growth and renewable energy use (Eren et al., 2019) suggests a reinforcing cycle, where growth fuels energy investment, sustaining further development.

Public investment in R&D and institutional quality also plays a critical role. Sharma (2024) and Ganie et al. (2024) demonstrate that research funding and effective governance have a positive impact on GDP growth and efforts to reduce emissions. Furthermore, Dey et al. (2022) argue that renewable energy initiatives support India's long-term sustainable development goals, offering a pathway to inclusive and resilient economic expansion. At the global level, Khan et al. (2022) observed that while government expenditure and economic development may initially contribute to CO_2 emissions, investments in alternative and nuclear energy have the potential to offset these effects, striking a balance between growth and sustainability.

Building on these insights, this study explores how India's budgetary allocations for renewable energy influence the country's renewable energy consumption, carbon emissions, and overall economic growth. This analysis aims to provide meaningful recommendations for policymakers and stakeholders working toward a cleaner, more energy-secure future by analyzing the relationship between financial allocations, energy consumption, and sustainability goals.

To summarize, prior studies converge on the idea that government budget allocations and supportive policy ecosystems are critical to scaling renewable energy, achieving emission reductions, and fostering green growth. However, there is a gap in literature specifically analyzing the integrated effect of India's budgetary allocations on the three-pronged nexus of renewable energy consumption, carbon emissions, and GDP growth.

The objective of the study is to examine how government budgetary expenditure influences renewable energy consumption, carbon emissions, and economic growth in India.

The study tests the following null hypotheses:

H_1: *Government budgetary expenditure on renewable energy has no significant impact on renewable energy consumption.*

H_2: *An increase in renewable energy consumption (REC) does not significantly reduce carbon emissions.*

H_3: *Renewable energy expenditure (REE) of the government does not significantly contribute to economic growth.*

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H_4: *There is no causal relationship between Renewable energy expenditure (REE) of the government, renewable energy consumption (REC), and economic growth.*

2. METHODS

To achieve the objective, several key financial and environmental indicators are analyzed. Carbon dioxide (CO_2) emissions serve as a measure of environmental quality, as they are widely recognized as a major contributor to climate change. These emissions primarily result from the combustion of fossil fuels, cement production, and the use of solid, liquid, and gaseous fuels, including gas flaring. Gross Domestic Product (GDP) per capita (constant 2015 USD) is chosen as a proxy for economic growth, as it reflects changes in national income over time. Furthermore, renewable energy consumption (REC) is calculated as a percentage of overall energy consumption, providing information about India's shift to greener energy sources. Another important variable is Renewable Energy Expenditure (REE) by government, which reflects financial commitment to sustainable energy efforts.

The data for this study are obtained from multiple credible sources. GDP and carbon emissions data are derived from the World Bank database, whilst renewable energy consumption statistics are acquired from the British Petroleum Statistical Review (2024). Records on government expenditure for renewable energy are collected from India's annual budgetary statements, covering the period from 1990 to 2024.

Various econometric techniques are utilized to analyze the relationships among these variables. A stationarity test is conducted to assess the reliability of the time-series data. The autoregressive distributed lag (ARDL) bound testing method assesses the presence of a long-term relationship between the variables. The vector error correction model (VECM) is utilized to examine the rate at which variables return to equilibrium after a disruption in a preceding period. These methodologies offer a thorough framework for comprehending the long-term and short-term dynamics of governmental renewable energy expenditure, economic performance, and environmental sustainability in India.

$$Y_t = \alpha + \beta_1 X_{1t} + \beta_2 X_{2t} + \ldots + \beta_k X_{kt} + \varepsilon_t. \quad (1)$$

In equation (1), Y_t represents the dependent variable, while X_t is a set of k explanatory variables influencing Y_t. The term α is a constant, and β_1, β_2, ..., β_k are the coefficients that quantify the effect of each explanatory variable on the dependent variable. The error term $\sum_t$ accounts for unobserved factors or random disturbances that may impact the model.

One of the key advantages of the autoregressive distributed lag (ARDL) model is that it allows for lagged values of both the dependent and independent variables to be included in the regression. This flexibility makes it useful for capturing short-term and long-term relationships between variables. The general structure of an ARDL model of order p and q is formulated as follows:

$$Y_t = \alpha + \Sigma\beta_i x_{ti} + \Sigma\gamma_i Y_{t-i} + \varepsilon_t. \quad (2)$$

In equation (2), x_{ti} is the i^{th} explanatory variable at time t, while Y_{t-i} is the lagged dependent variable. The coefficients β_i and γ_i represent the short-run and long-run relationships, respectively. The ARDL bound test determines the long-run association between Y_t and X_{1t}, X_{2t}, ..., X_{kt}. The null hypothesis (H_0) states there is no long-run relationship, while the alternative hypothesis (H_1) suggests one exists.

The bound test involves estimating two regressions. The first regression is a restricted ARDL model, which includes only the lagged dependent variable and the lagged levels of the explanatory variables up to order p:

$$Y_t = \alpha + \Sigma\gamma_i Y_{t-i} + \ \delta_i x_{t-i} + \varepsilon_t. \quad (3)$$

The second regression is an unrestricted ARDL model, which includes the lagged dependent variable, the lagged levels, and the first differences of the explanatory variables up to order p and q:

$$Y_t = \alpha + \Sigma\gamma_i Y_{t-i} + \Sigma\Delta_i x_{t-i} + \Sigma\delta_i \Delta x_{t-i} + \varepsilon_t, \quad (4)$$

where Δx_{t-i} represents the first difference of the i^{th} explanatory variable at time t.

The bound test involves testing the joint significance of the coefficients of the additional variables in the unrestricted model (i.e., the first differences of the explanatory variables) using an *F*-test. If the *F*-test statistic is greater than the upper critical value, the null hypothesis of no long-run relationship is rejected. Thus, it can be concluded that there is a long-run relationship between the variables.

The ECM test in ARDL examines the long-term association among variables. If the ECM term is significant, a long-term relationship is present. A negative lagged dependent variable (θ) means the dependent variable adjusts to equilibrium, driven by changes in independent variables. A positive θ suggests that the dependent variable influences the independent variables as they adapt.

The causal relationship between two time-series variables can be examined by employing the Granger causality test. According to this causality test, if variable *X* causes variable *Y*, then changes in *X* should occur before changes in *Y*. The Granger causality test is based on the following model:

$$Y_t = \beta_0 + \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + \ldots + \beta_p Y_{t-p} + \beta_x X_t + \varepsilon_t, \quad (5)$$

$$X_t = \gamma_0 + \gamma_1 X_{t-1} + \gamma_2 X_{t-2} + \ldots + \gamma_q X_{t-q} + \varepsilon_t, \quad (6)$$

where Y_t is dependent, and X_t is the independent variables, respectively, $\beta_0, \beta_1, \beta_2, \ldots, \beta_p$ and $\gamma_0, \gamma_1, \gamma_2, \ldots, \gamma_q$ are coefficients, ε_t is a random error term, and *p* and *q* are the order of lags.

The Granger causality test evaluates whether historical values of one variable may forecast another variable. The null hypothesis (H_0) posits that *X* does not affect *Y*, indicating that the historical values of *X* do not enhance the predictive capacity of *Y* beyond its historical values. The alternative hypothesis (H_1) suggests that *X* influences *Y*, indicating that the historical values of *X* improve the prediction of *Y*.

The test uses an *F*-statistic, which compares prediction errors from two models – one using only *Y*'s past values and another including *X* and *Y*'s past values. If the *F*-statistic is significant, H_0 is rejected, showing that *X* helps predict *Y*. If not, H_0 is accepted, meaning there is no predictive relationship.

It is essential to recognize that the Granger causality test measures causality statistically, meaning it identifies whether one variable can help predict another. However, it does not establish genuine causal relationships or explain the underlying mechanisms driving the observed association. The test only determines whether one variable helps predict the other. Therefore, caution should be exercised when interpreting the results of the Granger causality test.

3. RESULTS AND DISCUSSION

This study examines the impact of government expenditure on renewable energy, carbon emissions, and economic growth using the ARDL model, ECM, and Granger causality test. The findings highlight both short- and long-run relationships, evaluating whether public spending effectively promotes the adoption of clean energy and sustainability.

Table 1 presents ADF test results for GDP, REC, CO2 EMISSIONS and REE at different lag lengths and trend specifications. The null hypothesis states that the variable has a unit root (non-stationary).

Table 1. Unit root test (ADF) (Null hypothesis: The variable has a unit root)

Variable	ADF Statistic (Level)	p-value (Level)	ADF Statistic (1st Diff)	p-value (1st Diff)	Order of Integration
GDP	–0.3112	0.9122	–5.3351	0.0001	I(1)
REC	–4.7021	0.0007	–6.3909	0.0000	I(0)
CO2 EMISSIONS	–0.7362	0.8228	–5.5664	0.0001	I(1)
REE	–2.0655	0.2591	–8.6711	0.0000	I(1)

Note: The Schwarz Information Criterion (SIC) determines the lag length selection; *P*-values are computed using the MacKinnon (1996) one-sided approach.

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Table 2. Autoregressive distributed lag model for estimating the impact of renewable energy consumption on CO_2 emissions

Variable	Coefficient	Std. Error	t-statistic	Prob.*
CO_2_EMISSIONS1(-1)	−0.143260	0.209078	−0.685199	0.4991
REC	−0.001367	0.003313	−0.412733	0.6831
C	0.050075	0.012011	4.169285	0.0003***
R-squared	0.020181		–	
Adjusted R-squared	−0.052398		–	
Prob(F-statistic)	0.759398		–	

Note: * The associated p-values (Prob.) indicate the level of statistical significance:p < 0.10, p < 0.05 (**), p < 0.01 (***). "–" indicates not applicable. Asterisks next to coefficients (if used) reflect the significance level based on the p-value thresholds above.

At the level form, only LNREC is stationary at the 1% significance level, while the other variables remain non-stationary. However, after taking the first difference, all variables become stationary at the 1% level, confirming that they are integrated into order one (I(1)). The variables exhibit non-stationarity at levels but are stationary at the first difference; hence, a cointegration technique, such as the ARDL model, is required to examine the long-term relationship among them.

Table 2 presents the outcomes of an ARDL model elucidating the fluctuations in the dependent variable CO2 EMISSIONS. The model comprises the lagged dependent variable, the contemporaneous independent variable REC, and a constant term. An ARDL model was estimated using the AIC selection method to explain the variation in CO2 EMISSIONS, with the independent variables CO2 EMISSIONS lagged one period, REC lagged zero periods, and a constant. The results indicate that while the coefficient of the lagged dependent variable is negative, it is not statistically significant (p-value = 0.4991). Similarly, the coefficient of LREC is also negative but lacks statistical significance (p-value = 0.6831).

In contrast, the constant term is highly significant at the 1% level (p-value = 0.0003). The R-squared value (0.020181) indicates that the model explains merely a minimal fraction of the variance in the variable that is the dependent variable. In contrast, the negative adjusted R-squared implies that the model may not fit the data well. The F-statistic is not statistically significant at the 5% level (p-value = 0.759398), indicating the model's limited explanatory power.

The F-statistic value (Table 3) of 10.005933 is compared to the critical values that help determine whether a long-term relationship exists among the REC and CO2 emissions. These vital values vary based on sample size and whether the variables are stationary (I(0)) or non-stationary (I(1)) and are provided for 10%, 5%, and 1% significance levels. Since the F-statistic is more significant than all critical values, the study can confidently reject the null hypothesis, meaning there is strong evidence of a cointegrating relationship between the variables. It suggests they move together in the long run, making further analysis of their relationship meaningful.

Table 4 presents the results of the Error Correction Model (ECM) derived from the ARDL framework, with CO_2 emissions as the dependent variable and energy consumption as one of the key explanatory variables. The coefficient of the error correction

Table 3. Bounds test for cointegration in the ARDL model for renewable energy consumption and CO2 emissions

Level of significance	Critical values		F-statistics
	Lower Bound I(0)	Upper bound I(I)	
10 percent	3.303	3.797	10.005933*
5 percent	4.090	4.663	
1 percent	6.027	6.760	

Note: * – The asterisk (*) next to the F-statistic value indicates statistical significance. Specifically, it shows that the F-statistic exceeds the upper bound critical value at conventional significance levels (10%, 5%, and even 1%).

Table 4. Error correction model (VECM) for renewable energy consumption and CO2 emissions

Variables	ECT Coefficient	Std Error	t-statistic	Prob.
COINTEQ*	–1.143260	0.200270	–5.708591	0.0000***
R-squared	0.528276	–	–	–
Adjusted R-squared	0.528276	–	–	–
Durbin-Watson stat	1.894987	–	–	–

Note: * The associated p-values (Prob.) indicate the level of statistical significance: p < 0.10, p < 0.05 (**), p < 0.01 (***). "–" indicates not applicable. Asterisks next to coefficients (if used) reflect the significance level based on the p-value thresholds above.

term (COINTEQ) is –1.143260 and statistically significant at the 1% level ($p = 0.0000$), confirming the presence of a valid long-run equilibrium relationship among the variables included in the model. It indicates how quickly CO_2 emissions respond to correct any deviations from the long-run equilibrium path caused by short-run fluctuations in explanatory variables such as energy consumption. In this case, the coefficient of –1.143260 implies that more than 100% of the disequilibrium is corrected within one period, reflecting a rapid and slightly over-adjusting return to equilibrium following a shock. Together, these results suggest that CO_2 emissions not only exhibit a long-run relationship with energy consumption but also adjust swiftly to restore equilibrium after short-term imbalances; a finding of practical importance for policymakers focusing on energy and environmental sustainability.

The ARDL(2,2) model was employed to examine the correlation between CO_2 emissions and disbursements from 1990 to 2024, with CO_2 EMISSIONS as the dependent variable and REE as the independent variable. The model selection was determined using the Akaike Information Criterion (AIC). The findings (Table 5) show that past CO_2 emissions strongly influence current emissions ($p < 0.001$), while government disbursements from previous periods significantly reduce emissions ($p < 0.001$ and $p < 0.05$). The model explains a large portion of CO_2 emissions variability ($R^2 = 0.784$), though the adjusted R^2 (0.717) suggests some variables may be less significant. The F-statistic ($p < 0.001$) confirms a good model fit. While the Durbin–Watson statistic (2.333) indicates some autocorrelation, it does not significantly affect the results' validity.

In conclusion, the findings indicate that past CO_2 emissions and REE significantly impact current CO_2 emissions. Policymakers can utilize these results to develop strategies that target disbursements and reduce past emissions to mitigate CO_2 emissions.

The bound test for cointegration (Table 6) shows an F-statistic of 3.937628, which exceeds the upper bound critical value (3.797) at the 10% significance level. This rejects the null hypothesis of no cointegration, confirming a long-run relationship between government expenditure and CO_2 emissions in India. These findings suggest that poli-

Table 5. Autoregressive distributed lag model for CO2 emissions and renewable energy expenditures

Variable	Coefficient	Std. Error	t-statistic	Prob.*
LN CO_2_EMISSIONS1(–1)	–0.153468	0.234938	–0.653229	0.5229
LN CO_2_EMISSIONS1(–2)	1.220665	0.239637	5.093814	0.0001***
LNDISBURSEMENTS1	691.2059	527.7946	1.309612	0.2088
LNDISBURSEMENTS1(–1)	–2147.406	441.3090	–4.865992	0.0002***
LNDISBURSEMENTS1(–2)	–997.3590	382.2383	–2.609260	0.0190***
C	620.5755	323.5991	1.917730	0.0732
R-squared	0.784198	–		
Adjusted R-squared	0.716760	–		
Prob(F-statistic)	0.000072	–		
Durbin-Watson stat	2.333493	–		

Note: * The associated p-values (Prob.) indicate the level of statistical significance:p < 0.10, p < 0.05 (**), p < 0.01 (***). "–" indicates not applicable. Asterisks next to coefficients (if used) reflect the significance level based on the p-value thresholds above.

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Table 6. Bounds test for cointegration in the ARDL model for renewable energy expenditures and CO2 emissions

Level of significance	Critical values		F-statistics
	Lower Bound I(0)	Upper bound I(I)	
10 percent	3.303	3.797	3.937628*
5 percent	4.090	4.663	
1 percent	6.027	6.760	

Note: * – The asterisk (*) next to the F-statistic value indicates statistical significance. Specifically, it shows that the F-statistic exceeds the upper bound critical value at conventional significance levels (10%, 5%, and even 1%).

cies supporting energy efficiency and renewable energy could reduce CO_2 emissions over time. However, while the test confirms the existence of a long-term link, it does not specify which variables are cointegrated or the direction of causality. Further analysis is needed to understand the nature of this relationship.

Using the Granger causality test, Table 7 illustrates the causative linkages among government budgetary expenditure, renewable energy usage, carbon emissions, and economic growth. Four lags are evaluated and chosen according to the Schwarz Information Criterion. The results reveal a unidirectional causal relationship between carbon emissions and budgetary disbursements, as indicated by a *p*-value of 0.0075, which is statistically significant at the 5% level. In addition, disbursements toward encouraging new and renewable energy cause India's economic growth, as the probability value of disbursements is 0.0162. Therefore, as India's carbon emissions increase, the Indian government allocates more funds in the budget to improve and strengthen investments in new and renewable energy, aiming to reduce dependence on conventional energy and lower carbon emissions. This, in turn, stimulates growth in the country. Therefore, the government should continue to invest in renewable energy, which has a dual benefit for India, i.e., reducing carbon emissions and stimulating green growth.

According to the results of the autoregressive distributed lag (ARDL) model and the Granger causality test, all alternative hypotheses were confirmed, whereas the null hypotheses (H_1, H_2, H_3, H_4) were rejected. The results indicate that government disbursements toward renewable energy significantly impact renewable energy consumption, confirming that public investment is crucial in promoting clean energy adoption. Furthermore, increased renewable energy consumption significantly reduced carbon emissions, highlighting the environmental benefits of clean energy integration. The study also establishes a causal relationship between government expenditure and economic growth, demonstrating that investments in renewable energy contribute positively to the country's economic expansion. Additionally, a unidirectional causal relationship between government disbursements to GDP and carbon emissions further supports the argument that public financial support for clean energy leads to economic and environmental benefits. These findings reinforce the importance of continued and enhanced government investment in renewable energy to drive sustainable growth while mitigating climate change.

This study set out to understand whether government spending on renewable energy in India is making a difference in the scale of renew-

Table 7. Granger causality test for CO2 emissions, REC and REE

Causality	p-value	Causality	p-value
Disbursements causes CO_2 emissions	0.4309	CO_2 emissions cause disbursements	0.0075
GDP causes CO_2 emissions	0.7982	CO_2 emissions cause GDP	0.1531
Renewable energy consumption causes CO_2 emissions	0.4625	CO_2 emissions cause renewable energy consumption	0.4094
GDP causes disbursements	0.4828	Disbursements cause GDP	0.0162
Renewable energy consumption causes disbursements	0.5912	Disbursements cause Renewable energy consumption	0.3183
Renewable energy consumption causes GDP	0.5266	GDP causes renewable energy consumption	0.1308

able energy used, how much can be cut down on carbon emissions, and whether it is helping the economy grow. Based on the findings, it is evident that government investment does matter, and it matters in more ways than one. To begin with, the analysis shows that government disbursements do, over time, have a meaningful impact on how much renewable energy is consumed. While the immediate or short-term effect might not always look strong, the long-term relationship is significant. Consistent public spending is crucial for supporting the shift toward cleaner energy sources. Therefore, the first hypothesis (H_1) that government spending has no significant impact on renewable energy consumption is not supported.

Next, the study found that carbon emissions decrease when renewable energy use increases. It is a promising sign, confirming that clean energy contributes to better environmental outcomes. Therefore, the study rejects the second hypothesis (H_2), which claims that increased renewable energy use would not significantly reduce carbon emissions.

The findings indicate that government expenditure on renewable energy has a beneficial impact on GDP. In simple terms, more investment in clean energy does not just help the environment. It allows the economy to grow, too. It challenges the third hypothesis (H_3), which suggests no meaningful link between renewable energy investment and economic growth. Finally, the study also examined whether these variables interact with one another. It found a chain reaction: rising carbon emissions prompt the government to spend more on renewable energy, contributing to economic growth. It shows a feedback loop that is both responsive and productive. The government reacts to environmental stress by investing more in clean energy, which improves economic development. Accordingly, the last hypothesis (H_4), which stated that there is no causal relationship among these factors, is also rejected.

CONCLUSION

This study set out to evaluate the effectiveness of India's government expenditure in advancing renewable energy consumption, reducing carbon emissions, and stimulating economic growth. Utilizing annual data from 1990 to 2024 and employing the ARDL bounds testing and Granger causality frameworks, the analysis confirmed that public investment in renewable energy yields long-term benefits across environmental and economic dimensions.

The empirical results demonstrated a significant cointegrating relationship between government disbursements and carbon emissions, with past investments contributing meaningfully to emission reductions. Furthermore, the causal linkage from government expenditure to GDP suggests that renewable energy spending has a positive economic impact. These findings affirm the policy relevance of sustained financial support for renewable energy as a dual tool for ecological preservation and economic progress.

From these results, it can be concluded that well-structured and consistent government investment in the renewable sector not only helps achieve national environmental goals but also contributes to macroeconomic stability. Importantly, this study reinforces the strategic role of public finance in transitioning toward a sustainable energy economy.

Future research could expand the analytical scope by incorporating comparative cross-country data, exploring the role of private sector financing, or including additional institutional and policy variables. Such extensions would enrich our understanding of the multifaceted dynamics between fiscal action, clean energy adoption, and sustainable development outcomes.

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