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THE INCOME THRESHOLD IN THE ENERGY-GROWTH NEXUS: A PANEL GMM ANALYSIS OF RENEWABLE ENERGY IN DEVELOPING ECONOMIES

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ABSTRACT

This is an empirical study that examines the dynamic relationship between renewable energy consumption and economic growth in ten developing economies between 2000 and 2023 with financial development as a mediating variable and national income level as a moderating factor. The study is based on the Endogenous Growth Theory, with a detailed panel data approach, applying the System Generalized Method of Moments (GMM) to endogeneity, as well as cointegration tests and quantile regression to guarantee the strength of the study. The results indicate that there is a statistically significant and positive direct effect of the consumption of renewable energy on economic growth, which proves the contribution of clean energy to sustainable development. Nevertheless, the mediating effect of financial development as hypothesized is not found, which indicates that there are more complex or indirect transmission channels in the sampled countries. It is interesting to note that income level is a major positive moderator, which means that developing countries with higher income levels enjoy much more economic gains due to the adoption of renewable energy than their counterparts with lower income. These findings indicate the contingency and contextuality of the energy-growth nexus, which emphasizes the significance of economic development phases in the development of renewable energy policy. The paper ends with implications of customized, income-sensitive energy policies and improved financial system reforms to successfully utilize renewable investments to achieve long-term economic development.

Keywords: *Renewable energy consumption, economic growth, financial development, income moderation, endogenous growth, panel data, developing countries, sustainable development*

1. Introduction

In recent times, environmental sustainability and economic growth have become core concern for researchers and policymakers. As economies around the world are expanding, the reliance on conventional fossil fuel has increased. This caused a rapid increase in carbon dioxide (CO2) emissions and climate change (Kabir et al., 2023). This not only harms the eco-system but also threatens economic growth. Emerging economies such as China, India, Indonesia, Vietnam, South Africa, Egypt, Morocco, Brazil, Chile, and Mexico have seen rapid increase in their industrialization. This has made it harder to meet the targets of Paris Agreement, which aims to keep the global temperature below 1.5 degrees Celsius (Mathews & Wynes, 2023; Murshed et al., 2023). On the other hand, investment in renewable energy tends to minimize the environmental hazards and leads towards financial development by promoting industrial productivity and employment (Raihan et al., 2022). It was found in recent studies that economic growth is supported by financial development. It was seen that financial development positively impacts the economic growth of a country in the long run (Atoyebi et al., 2024).

Despite seeing the impact of renewable energy on economic growth and the impact of financial development. The relationship between the Renewable energy

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consumption and economic growth while financial development as mediator is still not examined. It was not found out how financial development mediates the impact on economic growth of a country as it moves towards renewable energy consumption. On the other hand, a novelty has been added to this research by adding income level as a moderator between renewable energy consumption and economic growth. To support this framework, Endogenous Growth Theory was added. Endogenous Growth theory shows how renewable energy consumption improves productivity, which leads towards better economic growth.

The objective of this research is to analyze the impact of (1) Renewable energy consumption on financial development (2) Financial development impact on economic growth of a country, (3) Renewable energy consumption impact on economic growth of a country with income level as a moderator.

After completing this research following research questions will be answered.

RQ1: What is the impact of Renewable energy consumption on financial development?

RQ2: What is the impact of financial development on economic growth of a country?

RQ3: How Income level moderates the relationship between renewable energy consumption and economic growth of a country

The significance of this study lies in its framework. As in this research not only does the impact of renewable energy on economic growth analyzed through financial development but it is also seen under the moderate effect of income level. Secondly data of around 10 countries ranging from year 2005 till 2023 is taken to see the growth in economy of a country as it uses renewable energy. Lastly, Endogenous Growth theory is used to support this model. It strengthens the relationship between the variables and makes it better

In upcoming section 2, it outlines the theoretical framework and hypothesis development. Section 3 includes the methodology. Section 4 includes the analysis and lastly, section 5 concludes the key outcomes.

2. Literature Review

The concept of the Endogenous Growth Theory frames the views of economic growth as being a factor brought about by internal forces like, accumulation of capital, technological advancement, innovations and efficiency of the institution (Romer, 1994). In this context, the use of renewable energy sources can be used to boost the growth of the economy through the adoption of cleaner technologies, increasing energy efficiency, and improving total factor productivity (Tilahun and Wang, 2025). Renewable energy as compared to the traditional energy sources promotes sustainable production frameworks that yield economic returns over time as well as minimizing the adverse externalities on the environment. Financial development reinforces this growth process making savings, as well as distributing capital more efficiently to productive investment especially in renewable energy technologies. An adequately-developed financial system would make credit more accessible, minimize the risks of investment, and facilitate capital formation based on innovations (Quoc and Le Quoc, 2025). Consequently, productive capacity and technological progress are mutually developed through the use of renewable energy and the financial development. In line with this, economic growth in this paper is formulated as an endogenous response to a combination between the consumption of renewable energy and the development of financial, which are in line with predictions made by endogenous growth theory.

The idea of sustainability has taken center stage in the economic agenda around the world following the growing carbon emissions, environmental degradation,

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and growing demand to attain sustainable development objectives (Denhere, 2022). Developing and emerging economies are still highly dependant on fossil fuels that subject them to high levels of environmental and economic risk; pollution, resource depletion, and climate-related risks (Mahmud et al., 2025). This dependency drives the reality of the need to shift to the consumption of renewable energy as a strategic measure towards sustainable economic growth. Empirical evidence shows that the use of renewable energy improves on the energy efficiency, lowers the emission of greenhouse gases, and makes the production process cleaner. Renewable energy consumption enhances productivity and boosts economic performance in long-term terms by reducing the energy-related inefficiencies, as well as, enabling technological upgrading (Yang et al., 2025). In addition, the cost of cleaner systems of energy saves environmental costs that can be counterproductive to economic activity in the long term. In line with these premises, the use of renewable energy resources will have a positive impact on economic growth which is the theme of the first hypothesis of the study.

H1: Renewable energy consumption has a positive impact on economic growth.

The growth in the use of renewable energy is vital in driving financial growth, as it enhances the financing requirements in the long-term, domestic savings mobilization, and the efficiency of financial intermediation (Qamruzzaman, 2024). The nature of renewable energy projects is most often capital-intensive; in addition, long-term and stable financing is always sought, which attracts financial institutions to expand credit facilities and create specialized green financing units (Onabowale, 2024). Consequently, there is more involvement of banks, institutional investors and capital markets in the financial markets, making the financial markets deeper. It is also the way to enhance innovation in green finance by creating financial tools, including green bonds, sustainability-linked loans, and investment funds with an environmental focus (Islam et al., 2023; Bi et al., 2025). The empirical data regularly indicate that the economies that are characterized by higher usage of renewable energy are also more likely to develop financially, since the financial systems are adjusted in such a way that they are able to sustain the investment in both productive and sustainable to the environment activities (Akbar et al., 2022).

Financial development, in its turn, is considered to be one of the central causes of the economic growth because it leads to better capital allocation, enlarging the scope of investment by the private sector, and technological innovations (Okolo et al., 2024). Proper operating financial systems augment the availability of credit to firms, which allows investments in productivity-enhancing technologies, business expansion, and creation of jobs. These forces increase household income, promotion of consumption, and aggregate demand, which leads to economic growth (Aimon et al., 2024). In addition, effective financial institutions decrease information asymmetries, transaction costs, promote entrepreneurship and innovation, which is vital to long-term growth and structural transformation (Jammeh, 2022; Olannye et al., 2023). As a result, financial development is an important transmission instrument with the help of which renewable energy consumption can stimulate economic growth.

H2: Financial development mediates the relationship between renewable energy consumption and economic growth.

Effects of renewable energy consumption on growth differ greatly in different countries based on the level of income (Alqaralleh and Hatemi-J, 2024). The economies with high income tend to receive a bigger economic advantage associated with the adoption of renewable energy sources because they have highly developed

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infrastructure, high technological potential, and well-developed financial markets, which permit investing large amounts of money in clean energy projects. Such benefits in the form of structure enable renewable energy to be better absorbed in productive sectors, which would increase the economic performance (Xu et al., 2024). Conversely, poor and emerging economy countries tend to have financial, technological, and institutional limitations that do not allow them to convert renewable energy use into long-term economic development. Stronger regulatory frameworks, better access to long-term finance, and more technological diffusion are usually needed by such countries to make full use of the growth-enhancing opportunity of renewable energy adoption (Makiela et al., 2022). In empirical studies, there is always a considerable agreement that income level is a critical moderating factor in the nexus between renewable energy and growth, as it determines the efficacy of renewable energy investments in various economic settings (Michailidis et al., 2025; Jamil, 2022). This means that the income level would ensure that the relationship between renewable energy use and the growth of the economy would be moderate, which is what influenced the final hypothesis of the study.

H3: Income level moderates the relationship between renewable energy consumption and economic growth.

Figure 01: Conceptual Framework

3. Methodology

3.1. Data Construction and Sample Rationale

An empirical study based on the use of a balanced panel of ten strategically chosen developing economies, including China, India, Indonesia, Vietnam, South Africa, Egypt, Morocco, Brazil, Chile, and Mexico over the time horizon of 2000-2023. The resultant of this 24-year longitudinal structure is a fully representative sample of 240 country-years, which was intentionally designed to identify important periods of economic change, energy policy change, and financial market change in the Global South. The sample of the constituent nations was chosen on the basis of their representative position as emerging economies with vivid industrial growth, growing energy consumption patterns, and proven intentions on integrating renewable energy,

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therefore, making them an analytically viable group that could be used to explore the hypothesized nexus.

3.2. Variable Specification and Measurement Protocols

[Table 1: Data Variables]

Variable Type	Symbols	Variables Measurement	Sources
Dependent Variable	EG	Economic Growth	GDP per capita growth (annual %)
Independent Variable	REC	Renewable Energy Consumption	Renewable energy consumption (% of total final energy consumption)
Mediator	FD	Financial Development	Domestic credit to private sector (% of GDP)
Moderator	IL	Income Level	GNI per capita, Atlas method (current US$)
Control Variable	INF	Inflation	Inflation, consumer prices (annual %)
Control Variable	TO	Trade Openness	Trade (% of GDP)
Control Variable	FDI	Foreign Direct Investment	Foreign direct investment, net inflows (% of GDP)

3.3. Econometric Architecture and Analytical Sequence

The quantitative research is conducted in a systematic series of model specifications aimed at strictly testing the hypothesized theoretical relationships. The econometric specification that includes both the temporal and cross-sectional fixed effects, is formulated in the following way:

In which i and t are country and year indices respectively, mu i is time-independent country-specific shocks, lat t la t are shared common shocks, and eit -t is the idiosyncratic disturbance term. This initial formulation of the study allows preliminary testing of the direct relationship between renewable energy and growth (H1).

In order to test the mediating process discussed in H2 such as financial development moderating the effect of renewable energy use on economic growth empirically, a sequential estimation model is used. Stage one specification looks at the antecedent relationship:

$$\ln EGit=\beta 0+\beta 1\ln RECit+\beta 2\ln FDit+\beta 3\ln ILit+\beta 4\ln INFit+\beta 5\ln TOit+\beta 6\ln FDIit+\mu i+\lambda t+\varepsilon it$$

The subsequent structural equation integrates the mediator into the growth model:

$$\ln FDit=\alpha 0+\alpha 1\ln RECit+\alpha 2\ln ILit+\alpha 3\ln INFit+\alpha 4\ln TOit+\alpha 5\ln FDIit+\mu i+\lambda t+uit$$

The fact that both pathway coefficients 1 and 2 are statistically significant and that there is a measurable attenuation of the direct effect 1 of 2 of its original value 1 are empirically substantiated.

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The testing of conditional relationships that are assumed in H3, i.e., national income level moderates the renewable energy-growth nexus, requires adding an interaction term which results in a moderated regression specification as shown below:
$\ln EGit=\delta 0+\delta 1\ln RECit+\delta 2\ln ILit+\delta 3(\ln RECit\times \ln ILit)+\delta 4\ln INFit+\delta 5\ln TOit+\delta 6\ln FDIit+\mu i+\lambda t+\omega it$
Statistical significance of the interaction coefficient $\delta 3$ would indicate that the marginal effect of renewable energy consumption on economic growth is contingent upon the prevailing income stratum, thereby validating the moderating hypothesis.

3.4. Estimation Methodology and Robustness Protocol

The analytical methodology uses multi-method estimation strategy so as to achieve consistency and strength. The first estimation is through pooled Ordinary Least Squares (OLS) and thereafter both Fixed Effects (FE) and Random Effects (RE) estimators are then done to explain the unobserved heterogeneity. The Hausman specification test offers a formal reasoning on the choice of FE and RE formulations in accordance with the correlation of individual effects and regressors.

To deal with the endogeneity issue, which arises due to the possibility of simultaneous economic growth, energy usage, and financial development, the analysis applies System Generalized Method of Moments (GMM) estimator. Blundell and Bond (1998) have created this dynamic panel model that employs the interior tools of lagged levels and differences, which is capable of alleviating the prejudices that are related to reverse causality and time-varying unobserved confounding factors.

An extensive diagnostic program makes the inferential conclusion valid. The cross-sectional dependence is determined through the Pesaran (2004) CD test, where the second generation panel unit root tests, namely the Cross-sectionally Augmented Dickey-Fuller (CADF) and cross-sectional Im-Pesaran-Shin(CIPS) test is used to determine the properties of integration. The residual based cointegration tests developed by Pedroni (1999) and Kao (1999) are used to study long-run equilibrium relationships and the Westerlund (2007) error-correction method is used to complement the tests. It is checked through Pesaran and Yamagata (2008) test (slope homogeneity) and Quantile Regression analysis (distributional heterogeneity) that approximates relationship (conditionally) using the relationship across the whole response distribution and not just at the conditional mean.

Any calculation process has been performed in Stata 18.0, and strict consideration has been given to the assumptions and asymptotic characteristics of each estimator. Such a multi-layered methodological procedure is necessary to guarantee that the empirical data obtained are not only statistically sound but can also be interpreted in theory, as a part of the endogenous growth theory.

4. Results

4.1. Descriptive Statistics and Preliminary Diagnostics

The descriptive statistics give us a summary on the dataset that entails 240 observations in a span of 24 years in ten developing countries. The economic growth (lnEG) has a high variability, with mean of 2.392 and standard deviation of 1.094 which shows that it varies considerably among countries and years. The results of renewable energy consumption (lnREC) and financial development (lnFD) exhibit moderate variability with the mean of 2.977 and 4.123 respectively. The income level

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(lnIL) has the largest mean value (8.248), and the dispersion is also low meaning it is more stable among the samples. The control and variable variables that are likely to vary are the inflation (lnINF) and the trade openness (lnTO) that have negative minimum values which represent deflation and capital outflow periods respectively. This data proves that the dataset is suitable to analyze using panel analysis as it represents a variety of economic states of different developing economies at the stages of renewable energy transition.

[Table 2: Descriptive Statistics]

Variable	Obs	Mean	Std. Dev.	Min	Max
lnEG	240	2.392	1.094	-13.441	3.121
lnREC	240	2.977	.671	1.589	4.055
lnFD	240	4.123	.594	2.505	5.245
lnIL	240	8.248	.885	6.016	9.677
lnINF	240	1.735	1.166	-14.142	3.572
lnTO	240	3.999	.445	3.096	5.229
lnFDI	240	1.629	.918	-11.506	2.686

4.1.2. Correlation Matrix and Multicollinearity Diagnostics

The correlation matrix shows that, there are very low inter-variable correlations with coefficients of between -0.038 and 0.054, which means that the independent variables do not have a linear relationship. All the values of Variance Inflation Factor (VIF) are relatively close to 1.0, which is significantly lower than the traditional level of 5.0. This will verify the fact that there are no issues of multicollinearity because the estimates of regression coefficient will be stable and statistically dependable. The exceptionally low correlation coefficients between renewable energy use, financial development, and income level (less than 0.06) imply that these variables represent different aspects of economic development as it is possible to identify the specific impact of each of them on economic growth cleanly.

[Table 3: Correlation Matrix and VIF Values]

Variables	VIF	lnREC	lnFD	lnIL
lnREC	1.004	1.000		
lnFD	1.003	0.054	1.000	
lnIL	1.001	-0.038	-0.005	1.000

4.1.3. Cross-Sectional Dependence Test

Pesaran CD tests show that there is a strong cross-sectional dependence on all the variables (p=0.000). Its CD statistics are ranging between 3.992 and 29.108 respectively in financial development and income level with mean correlation coefficients (ρ) between 0.12 and 0.89. This implies that there is a high degree of interrelatedness of the developing economies used as samples and this is probably due to economic integration of the world economy and due to regional trade and due to exposure to both international financial markets and the international energy price shocks. The cross-sectional dependence is the violation of the traditional assumption of independent errors of the traditional panel estimators and necessitates application of second-generation econometric methods to account interdependence.

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[Table 3: Pesaran CD Test Results]

Variable	CD-test	p-value	Average Joint T	Mean ρ	Mean abs(ρ)
lnEG	+17.817	0.000	24.00	+0.54	0.54
lnREC	+7.592	0.000	24.00	+0.23	0.52
lnFD	+3.992	0.000	24.00	+0.12	0.68
lnIL	+29.108	0.000	24.00	+0.89	0.89

4.2. Cointegration Analysis

4.2.1. Pedroni Cointegration Test

The Pedroni cointegration test gives a solid evidence of a long term equilibrium correlation between the variables in the panel. All three test values, which are Modified Phillips Perron t (-3.0461, p=0.0012), Phillips Perron t (-10.2518, p=0.0000) and Augmented Dickey Fuller t (-10.5309, p=0.0000) are statistically significant at the 1 percentile. This rejection of the null hypothesis in diverse specifications indicates the fact that the growth of the economy, the use of renewable energy, financial development, and the control variables in the sampled developing economies are in a steady long-run cointegrating relationship.

[Table 4: Pedroni Cointegration Test Results]

Statistic	Value	p-value
Modified Phillips–Perron t	-3.0461	0.0012
Phillips–Perron t	-10.2518	0.0000
Augmented Dickey–Fuller t	-10.5309	0.0000

4.2.2. Kao Cointegration Test

The Kao cointegration test also confirms the cointegration in the panel. The five statistics are all found to be significant and the p-values are significantly lower than standard values: Modified Dickey Fuller t (2.6662, p=0.0038), Dickey Fuller t (1.9252, p=0.0271), Augmented Dickey Fuller t (3.2224, p=0.0006), Unadjusted Modified Dickey Fuller t (-20.4703, p=0.0000), and Unadjusted The fact that there is such a close coalescence of results between the various adjustments, and specifications, goes to support the conclusion that the variables move together in the long run, to be able to estimate long-run equilibrium models.

[Table 5: Kao Cointegration Test Results]

Statistic	Value	p-value
Modified Dickey–Fuller t	2.6662	0.0038
Dickey–Fuller t	1.9252	0.0271
Augmented Dickey–Fuller t	3.2224	0.0006
Unadjusted Modified Dickey–Fuller t	-20.4703	0.0000
Unadjusted Dickey–Fuller t	-13.5221	0.0000

4.2.3. Westerlund Cointegration Test

The Westerlund cointegration test, which employs a variance ratio statistic, also confirms cointegration within the panel. The variance ratio statistic of -2.6616 is significant at the 1% level (p=0.0039), providing additional evidence against the null hypothesis of no cointegration. This result is particularly valuable as the Westerlund test accounts for cross-sectional dependence, ensuring that the finding of a long-run

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relationship is robust to the interconnectedness observed among the developing economies in the sample.

[Table 6: Westerlund Cointegration Test Results]

Statistic	Value	p-value
Variance Ratio	-2.6616	0.0039

4.3. Main Econometric Results – System GMM Estimation

4.3.1. Direct Effect of Renewable Energy on Economic Growth (H1)

A statistically significant positive correlation exists between the renewable energy consumption and economic growth, and this is observed with the System Generalized Method of Moments (GMM) estimator which takes care of the endogeneity problem and adds dynamics to the study. The coefficient of lnREC is 0.232(p=0.007), which is significant at the 1 per cent level and thus proves Hypothesis 1. The slope of the lagged dependent variable (-0.149, p=0.000) is negative and significant, which means the convergence of the growth rate, with economies that grow at a higher rate having a slower subsequent growth. Significantly more variance is estimated by this dynamic specification than by the static models, as the chi-square is 157.574, indicating that the endogeneity and dynamics are important in the determination of renewable energy-growth nexus.

[Table 7: System GMM Results – Direct Effect]

lnEG	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
L	-.149	.013	-11.25	0	-.175	-.123	***
lnREC	.232	.086	2.71	.007	.064	.4	***
Mean dependent var		2.383	SD dependent var			1.141	
Number of obs		220	Chi-square			157.574	

*** p<.01, ** p<.05, * p<.1

4.3.2. Mediation Analysis: Role of Financial Development (H2)

The mediation analysis makes subtle discoveries on the role of financial development. Although the renewable energy consumption has a positive and significant coefficient (0.386, p=0.017), its financial development has a negative but insignificant coefficient (-0.109, p=0.827). This trend fails to substantiate the mediation hypothesis (H2) since financial development does not seem to propagate the impact of renewable energy on the growth in this sample. The greater strength of the renewable energy coefficient in the mediated model (the coefficient rose to 0.386) also tends to indicate the possibility of suppression effects, implying that the financial development may be mediated in more complicated ways, other than just via a simple mediation. The poorer fit of the model (chi-square=61.949) to the direct effects model also casts doubt on the adequacy of the mediation model.

[Table 8: System GMM Results – Mediation Test]

lnEG	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
L	-.189	.024	-7.86	0	-.236	-.142	***
lnREC	.386	.162	2.38	.017	.068	.703	**
lnFD	-.109	.499	-0.22	.827	-1.086	.868	

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Mean dependent var	2.383	SD dependent var	1.141
Number of obs	220	Chi-square	61.949

*** p<.01, ** p<.05, * p<.1

4.3.3. Moderation Analysis: Role of Income Level (H3)

The moderation analysis gives great support to Hypothesis 3. The coefficient of the interaction between the consumption of renewable energy and the income level (lnREC_lnIL) is positive and statistically significant (0.061 with p=0.007). This is to show that the correlation between renewable energy and economic growth is moderated positively by income level: higher-income developing countries benefit more in terms of growth through the use of renewable energy. The convergence trend is retained by the large negative coefficient of the lagged dependent variable (-0.197, p=0.000). The model fit (chi-square=108.714) indicates that the model is able to effectively capture the effects of conditional relationships, that is the levels of national economic development determine the effect of renewable energy development.

[Table 9: System GMM Results – Moderation Test]

lnEG	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
L	-.197	.027	-7.39	0	-.249	-.145	***
lnREC_lnIL	.061	.023	2.70	.007	.017	.105	***
Mean dependent var		2.383	SD dependent var			1.141	
Number of obs		220	Chi-square			108.714	

*** p<.01, ** p<.05, * p<.1

4.4. Robustness Checks

4.4.1. Quantile Regression Analysis

The quantile regression analysis reveals that the positive relationship between renewable energy consumption and economic growth holds robustly across the entire distribution of growth rates. The coefficient of 0.114 is statistically significant at the 1% level (p=0.000), with tight confidence intervals (0.066 to 0.162). Unlike mean-based estimators that might be influenced by extreme values, quantile regression demonstrates that renewable energy's growth effect is consistent whether countries are experiencing low, moderate, or high growth periods. This distributionally robust finding strengthens the empirical support for Hypothesis 1 and suggests that renewable energy investments contribute to economic growth across diverse economic conditions in developing countries.

[Table 10: Quantile Regression Results]

lnEG	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
lnREC	.114	.024	4.72	0	.066	.162	***
Constant	2.171	.074	29.45	0	2.025	2.316	***
Mean dependent var		2.392	SD dependent var			1.094	

*** p<.01, ** p<.05, * p<.1

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5. Conclusion, Future Direction and Limitations

5.1 Conclusion

The study presents solid empirical knowledge of the multifaceted nexus between renewable energy consumption, financial development, income level and economic growth between 2000 and 2023 in ten developing economies. Based on the sophisticated panel econometric models, such as, System GMM and quantile regression, the results suggest that the use of renewable energy will greatly facilitate economic growth, hence, Hypothesis 1 is confirmed. Nevertheless, the mediating role of financial development (H2) was not proved, which indicated that the transmission mechanisms are probably more indirect or they depend on the other institutional factors. Notably, the analysis has shown a strong correlation in favor of Hypothesis 3, which states that the income level modifies the relationship between renewable energy and growth in a positive way, which implies that the advantage of renewable energy investments is more significant to higher income developing countries. These findings highlight the need to look at the stages of economic development in developing energy transition policies.

5.2 Future Directions

The next research directions might be to further this investigation by involving more countries (both developed and least-developed) in order to compare various impacts by income groups. Also, it may be explored that non-linear relationships, threshold effects or institutional quality, governance, and technological innovation may be of deeper insight. Heterogeneous effects on growth may be realized by use of disaggregated renewable energy sources (solar, wind, hydro etc.). Longitudinal case studies or mixed-method might also be used to put the quantitative results in perspective and determine causal mechanisms underlying the relationships observed.

5.3 Limitations

This research project has a number of limitations. To begin with, the sample size is limited to ten developing countries, which can have an impact on the applicability of the findings to other areas or economic settings. Second, although the research uses strict econometric techniques, the research results may be affected by the potential omitted variable bias, i. e., political stability, education, or infrastructure quality. Third, official financial development by domestic credit to the private sector might not be a complete measure of the multidimensional aspect of financial systems. Lastly, the data set finishes in 2023, and the changes in global policies of energy, technological progress, and climate agreements can change the dynamics under analysis in the following periods.

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Appendix A: Additional Diagnostic Tests

A.1. Panel Unit Root Test

Second-generation panel unit root tests (CADF and CIPS) consider cross-sectional dependence in testing the stationarity. At levels, mixed results are given out by most variables, some of which depict non-stationary statistics (e.g., lnIL CIPS: -0.175) and others depict stationary statistics (e.g., lnEG CIPS: -3.226). Nonetheless, all the variables are shown to be integrated of order one, I (1), after first differencing where they all become stationary at the 1% level of significance. This trend confirms the cointegration analysis and the error-correction or dynamic specifications to identify the relationship between short and long-run dynamics.

[Table A1: CADF and CIPS Unit Root Test Results]

Variable	CADF (At Level)	CADF (First Difference)	CIPS (At Level)	CIPS (First Difference)
lnEG	-2.109	-3.759***	-3.226**	-5.488***
lnREC	-2.030	-3.238***	-1.174	-3.785***
lnFD	-2.085	-2.680***	-1.736	-3.863***
lnIL	-1.127	-2.585***	-0.175	-2.571*

A.2. Slope Heterogeneity Tests

The outcome of the Pesaran-Yamagata (2008) and Blomquist-Westerlund (2013) tests of slope heterogeneity give a consistent and strong evidence of slope homogeneity among the countries in the panel. The Pesaran -Yamagata statistic of -1.319 and its adjusted counterpart of -1.410 have a p-value of 0.187 and 0.158, respectively. Equally, Delta and adjusted Delta values of -0.169 and -0.181, which are provided by the BlomquistWesternlund test with a Heteroskedasticity and Autocorrelation Consistent (HAC) estimator, have p-values of 0.866 and 0.857. As all the p-values are much more than the traditional level of significance (e.g., 0.05), one cannot reject the null hypothesis about the homogeneity of the slopes. It means that the correlation among renewable energy use, financial development, income level and economic growth are statistically the same in the ten developing economies. This observation confirms the homogeneity of data and agrees to the extrapolation of the estimated coefficients to the sampled nations.

[Table A2: Pesaran-Yamagata and Blomquist-Westerlund Test Results]

Slope Heterogeneity Test (Pesaran–Yamagata, 2008)

Statistic	Value	p-value
Delta	-1.319	0.187
Adj.	-1.410	0.158

Slope Heterogeneity Test (Blomquist–Westerlund, 2013 – HAC)

Statistic	Value	p-value
Delta	-0.169	0.866
Adj.	-0.181	0.857