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RENEWABLE ENERGY CONSUMPTION AND CARBON EMISSIONS IN DEVELOPING ECONOMIES: PANEL DATA ANALYSIS (2000–2022)

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Abstract

This study examines the relationship between renewable energy consumption and carbon dioxide (CO_2) emissions in developing economies from 2000 to 2022. Using panel data from the World Bank, the analysis includes renewable energy share, GDP per capita, population growth, and a financial development index. Three panel data models—Pooled Regression Model (PRM), Fixed Effects Model (FEM), and Random Effects Model (REM)—are estimated, with Fisher, Breusch–Pagan LM, and Hausman tests applied to select the most suitable model. The Random Effects Model (REM) provides the best fit. Results show that higher renewable energy consumption reduces (CO_2) emissions, while economic growth, population expansion, and financial development increase emissions. These findings are consistent with the Environmental Kuznets Curve (EKC), suggesting emissions rise in early development stages and decline as institutions strengthen and cleaner technologies are adopted. The study highlights policy implications for green financing, institutional reforms, and regional cooperation to support sustainable energy transitions in developing countries.

Keywords: *Renewable Energy; CO_2 Emissions; Developing Economies; Panel Data Analysis; Environmental Kuznets Curve (EKC); Sustainable Energy Transition.*

JEL Codes: *Q42, Q53, C23, O13.*

Introduction

In recent decades, there has been a growing global interest in the relationship between renewable energy consumption and carbon dioxide emissions, particularly in

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developing economies that face the dual challenge of achieving economic growth while maintaining environmental sustainability. This interest stems from the increasing severity of climate change, international commitments to emissions reduction under agreements such as the Paris Accord, and rising fossil fuel prices and their associated geopolitical volatility (Dogan & Seker, 2016, p. 430).

Empirical literature indicates that the relationship between renewable energy consumption and carbon emissions varies across geographic and economic contexts. While some studies highlight the positive impact of renewable energy in reducing emissions (Erkut, 2022, p. 2), others suggest that these effects may not be immediate, but rather unfold over the long term as renewable energy infrastructure expands and becomes more efficient (Elmonshid et al., 2024, p. 2). Furthermore, Apergis and Payne (2010) found bidirectional causality between renewable energy consumption and economic growth in OECD countries, reinforcing the hypothesis that adopting renewable energy does not contradict development goals but may in fact support them in the long run.

The study of developing economies in this context is of particular significance, given their heavy reliance on conventional energy sources and the frequent absence of coherent strategies for energy transition. Moreover, many of these countries suffer from weak institutional and financial capacities, which hinder the development of clean energy projec ts and delay their environmental benefits (Elmonshid et al., 2024, p. 3).

Accordingly, this study aims to explore the dynamic relationship between renewable energy consumption and carbon dioxide emissions across a panel of developing economies during the period 2000–2022. It employs panel data analysis techniques that account for both cross-country heterogeneity and temporal dynamics. Additionally, the study seeks to test the Environmental Kuznets Curve (EKC) hypothesis in these economies and investigate how the relationship under study is influenced by factors such as GDP and trade openness.

The significance of this research lies in its contribution to filling a persistent gap in the literature, as most prior studies have focused either on advanced economies, short time spans, or utilized econometric models that overlook structural heterogeneity among countries. Hence, this study provides a modern analytical framework that may inform policymakers in developing nations as they design balanced energy strategies that aim to reduce emissions without compromising growth objectives.

Literature Review

The Nexus between Renewable Energy Consumption and Carbon Emissions in Developing Economies

With the growing urgency to address climate change, the relationship between renewable energy consumption and carbon dioxide (CO2) emissions has become a central topic in environmental economics, particularly for developing economies that face the dual challenge of sustaining economic growth while reducing environmental degradation.

Shahbaz et al. (2015) found that the use of renewable energy sources significantly reduces carbon emissions in emerging economies, especially when accompanied by improved energy efficiency. Similarly, Sarkodie and Strezov (2019), in a comprehensive meta-analysis, concluded that renewable energy consumption generally leads to positive environmental outcomes, though these effects depend heavily on the maturity of energy infrastructure.

In a study focusing on developing countries, Nguyen and Kakinaka (2019) observed that the emission-reducing impact of renewable energy is not clearly evident in low-income nations due to technological inefficiencies and limited institutional capacity. This underscores the disparity in renewable energy outcomes across different stages of development.

Nathaniel et al. (2020) provided empirical evidence from the MENA region, demonstrating that renewable energy consumption plays a vital role in improving environmental performance. Their findings show a statistically significant and negative relationship between renewable energy and carbon emissions in most developing countries analyzed.

Elfadli et al. (2024) further emphasized the role of institutional quality, particularly financial efficiency, in enhancing the effectiveness of renewable energy in reducing CO2 emissions. Their panel quantile regression results from the GCC region revealed that countries with higher financial efficiency witnessed a stronger mitigation impact.

In the same vein, Zakarya et al. (2023) argued that the ability of renewable energy to reduce emissions varies based on national policy frameworks and regional cooperation. In their Mediterranean-focused analysis, they highlighted that weak governance and fragmented policies can undermine the environmental benefits of renewables.

Conversely, Dogan and Seker (2016) noted that shifting from non-renewable to renewable energy does not automatically ensure emission reductions, particularly in the absence of stringent environmental policies and sufficient technological investment.

Overall, the literature suggests that the relationship between renewable energy consumption and carbon emissions in developing economies is neither linear nor uniform.

It is influenced by a variety of institutional, technological, and economic factors. This underscores the relevance of the current study, which aims to provide updated econometric evidence covering the period 2000–2023, offering deeper insights into the dynamics of the renewable energy–emissions nexus in the developing world.

Recent Empirical Studies

Recent empirical research has increasingly focused on the dynamic relationship between renewable energy consumption and CO2 emissions, particularly in developing economies where environmental pressures and economic development intersect.

For instance, Nguyen and Kakinaka (2019) employed panel cointegration techniques to analyze the relationship across countries at different development stages. Their findings suggest that the environmental impact of renewable energy varies significantly depending on economic maturity and institutional infrastructure. In a similar context, Nathaniel et al. (2020) used quantile regression to examine MENA countries and found a consistent negative relationship between renewable energy usage and carbon emissions across quantiles, supporting the notion that renewable energy plays a pivotal role in environmental mitigation.

More recently, Elfadli et al. (2024) applied a panel data quantile regression model to GCC countries and found that the mitigating effect of renewable energy on emissions is stronger in countries with higher financial efficiency. This highlights the importance of institutional quality and financial systems in enhancing the effectiveness of green energy transitions. Likewise, Zakarya et al. (2023) analyzed the Union for the Mediterranean countries and concluded that governance quality and regional policy alignment are critical to the environmental effectiveness of renewable energy deployment.

Additionally, Dogan and Seker (2016) provided evidence from the United States showing that while renewable energy consumption has a negative correlation with CO2 emissions, its effect is relatively modest unless supported by environmental regulations and technological investment. Sarkodie and Strezov (2019), through a meta-analysis, confirmed that renewable energy can reduce emissions, but the magnitude of the effect varies widely depending on country-specific characteristics.

These studies collectively emphasize the need for country-specific strategies, suggesting that while renewable energy has the potential to reduce carbon emissions, its impact is conditioned by macroeconomic, institutional, and technological variables. This underscores the importance of further empirical investigation, particularly in the context of developing economies over extended timeframes.

Research Gap

Although a growing body of empirical literature confirms a link between renewable energy consumption and CO2 emissions, most studies focus on high-income or energy-exporting countries. Few investigations target developing economies as a distinct group, especially through the lens of long-term panel data analysis that incorporates macroeconomic and institutional variables.

Moreover, while earlier research often employs traditional linear models, recent advances suggest that non-linear dynamics, such as those captured by quantile regression or threshold models, may better reflect the heterogeneity across developing countries. In addition, many prior studies omit the joint effects of variables like financial development, population growth, and policy quality on the renewable energy–emissions nexus.

Therefore, this study aims to fill the gap by offering a comprehensive panel data analysis covering a wide range of developing economies over the 2000–2022 period, integrating key economic indicators to better understand the effectiveness of renewable energy in mitigating emissions in diverse contexts.

Research Hypotheses

Based on the reviewed literature and identified research gap, the following hypotheses are proposed:

H1: There is a significant negative relationship between renewable energy consumption and carbon dioxide (CO2) emissions in developing economies.

H2: The relationship between renewable energy consumption and CO2 emissions is moderated by macroeconomic variables such as GDP and population growth.

H3: Institutional and financial development enhances the effectiveness of renewable energy in reducing CO2 emissions.

Data Description

The data used in this study were obtained from the World Bank's World Development Indicators (WDI) database, which is considered one of the most reliable international statistical sources. The main variables used in the analysis are:

- **CO_2 Emissions (CO2):** measured in metric tons per capita.
- **Renewable Energy Consumption (RE):** percentage of total final energy consumption.
- **GDP per capita (GDP):** constant 2015 US dollars.
- **Population growth (POP):** annual growth rate.

- **Financial Development Index (FD):** a composite index combining credit and monetary indicators to capture financial sector depth and efficiency.

Econometric Model

To analyze the relationship between renewable energy consumption and CO2 emissions, the following baseline panel data model is specified:

$$CO_2\_it = \alpha + \beta_1 RE\_it + \beta_2 GDP\_it + \beta_3 POP\_it + \beta_4 FD\_it + \varepsilon\_it$$

Where:

- *i* denotes country;

- *t* denotes year;

- ε_it is the error term.

Descriptive Statistics

The descriptive statistics of the study variables, based on 391 observations, are reported in Table 1. The statistics include the mean, standard deviation, minimum, and maximum values. The results indicate that the dataset is complete, with no missing values or outliers detected.

Table no.1. Descriptive Statistics of the Study Variables

Variable	**CO2**	**RE**	**GDP**	**POP**	**FD**
Mean	0.765719	53.905	4.525963	3.35205	34.86298
Std. dev	0.801934	28.95106	3.397832	1.256066	24.68469
Min	0.0561864	0.0351772	-12.40797	1.050547	5.209203
Max	3.369468	93.73209	14.04712	10.51618	118.8171
Obs	391	391	391	391	391

Source: Authors' calculation based on EViews 13 outputs.

The empirical analysis is conducted using a balanced panel of 17 developing economies, strategically selected to ensure geographical and economic representation across various regions. The sample comprises ten African nations (Ghana, Kenya, Madagascar, Niger, Republic of the Congo, Rwanda, Senegal, Tanzania, Togo, and Tunisia), four Asian countries (Bangladesh, Cambodia, Nepal, and Pakistan), two from Latin America (Colombia and Paraguay), and Jordan from the Middle East. These specific countries were chosen based on the availability of consistent and continuous data for all investigated variables—including renewable energy share, GDP per capita, population growth, and financial development—over the observed period of 2000–2022, thereby ensuring the robustness and statistical reliability of the econometric estimations.

Econometric Results and Model Specification Diagnostics

Estimation Results of the Panel Data Models (2000-2022)

The estimation results of the three panel data models are presented in Table2. The findings indicate that all models are statistically significant, as confirmed by the Fisher statistics with probability values equal to 0.0000, which are lower than the 5% significance level. Moreover, the explanatory power of the three models is found to be adequate.

Table no.2. Estimation Results of the Panel Data Models (PRM, FEM, REM)

Variable		**PRM**	**FEM**	**REM**
RE	Coefficient	-0.01877	-0.108	-0.012
	t-Statistic	-19.62	-7.44	-8.79
	Prop	0.0000	0.0000	0.0000
GDP	Coefficient	-0.01728	0.005	0.00475
	t-Statistic	-2.86	2.42	2.3
	Prop	0.0040	0.016	0.0220
POP	Coefficient	0.00284	0.027	0.0265
	t-Statistic	0.16	3.53	3.43
	Prop	0.874	0.0000	0.0010
FD	Coefficient	0.0083	0.005	0.00467
	t-Statistic	7.98	6.45	6.08
	Prop	0.0000	0.0000	0.0000
Cons	Coefficient	1.557	1.06	1.1475
	t-Statistic	17.49	10.39	8.44
	Prop	0.0000	0.0000	0.0000
R-squaret		0.7595	0.4971	0.4963
F-statistic		292.75	91.44	397.56
Prop(F)		0.0000	0.0000	0.0000

Source: Authors' calculation based on EViews 13 outputs.

Model Selection Tests

To identify the most appropriate panel data model, three specification tests were conducted: the Fisher test, the Breusch–Pagan Lagrange Multiplier (LM) test, and the Hausman test. The results are summarized below.

- *Fisher Test (PRM vs. FEM):*

The Fisher test was applied to discriminate between the Pooled Regression Model (PRM) and the Fixed Effects Model (FEM).

$$\begin{cases} H_0: \text{PRM is appropriate} \\ H_1: \text{FEM is appropriate} \end{cases}$$

The probability value was 0.0000, which is less than the 5% significance level. Therefore, the null hypothesis is rejected, and the alternative hypothesis is accepted, indicating that the Fixed Effects Model is more appropriate.

Table no.3. Fisher Test Results (PRM vs. FEM)

Test	**Statistic**	**d.f.**	**Prob.**
F test that all u_i=0	238.78	(370,16)	0.0000

Source: Authors' calculation based on EViews 13 outputs.

- *Breusch–Pagan Lagrange Multiplier Test for Choosing between the Pooled Regression Model and the Random Effects Model*

Table 4 presents the results of the Breusch–Pagan Lagrange Multiplier (LM) test, which was applied to discriminate between the Pooled Regression Model (PRM) and the Random Effects Model (REM), based on the following hypotheses:

$$\begin{cases} H_0: \text{PRM is appropriate} \\ H_1: \text{REM is appropriate} \end{cases}$$

Based on the probability value of the test, which was estimated at 0.0000 and is lower than the 0.05 significance level, the null hypothesis is rejected, and the alternative hypothesis is accepted, indicating that the Random Effects Model is the appropriate specification.

Table.4. Results of the Breusch–Pagan LM Test (PRM vs. REM)

Test statistic (Chibar²)	**p-value**
2916.61	0.0000

Source: Authors' calculation based on EViews 13 outputs.

- *Hausman Test (FEM vs. REM):*

After the Fisher test confirmed that the Fixed Effects Model (FEM) is preferred over the Pooled Regression Model (PRM), and the Breusch–Pagan LM test indicated that the Random Effects Model (REM) is preferred over the PRM, the Hausman test was conducted to choose between FEM and REM.

$$\begin{cases} H_0 \text{REM is appropriate} \\ H_1: \text{FEM is appropriate} \end{cases}$$

The results in Table 6 show that the Hausman statistic is 7.16 with a probability value of 0.1278, which is greater than the 5% significance level. Therefore, the null hypothesis cannot be rejected, and the Random Effects Model (REM) is deemed the appropriate specification.

Table.6. Hausman Test Results (FEM vs. REM)

Test	Chi-Sq. Statistic	d.f.	Prob.
Hausman	7.16	4	0.1278

Source: Authors' calculation using EViews 13.

Final Model Estimation (REM):

Based on the model selection tests, the Random Effects Model (REM) was chosen as the preferred specification to estimate the impact of renewable energy consumption (RE) on CO2 emissions (CO2) in developing economies. The estimation results are reported in Table 2 .The results show that the coefficient of renewable energy consumption (RE) is negative and statistically significant, confirming an inverse relationship between RE and CO2 emissions. This implies that a 1% increase in renewable energy consumption leads to a 0.012157% reduction in CO2 emissions, consistent with economic theory and prior empirical evidence. Conversely, GDP per capita (GDP), population growth (POP), and the Financial Development Index (FD) exhibit positive and significant effects on CO2 emissions, suggesting that higher economic activity demographic growth and financial development contribute to increasing emissions. The overall model is statistically significant, as indicated by the high F-statistic (397.56, $p < 0.01$). The explanatory power of the model is satisfactory, with an R^2 of 0.4963, meaning that RE, GDP, POP, and FD collectively explain approximately 49.63% of the variation in CO2 emissions across the sample of developing economies during the period 2000–2022.

Results

The estimation outcomes of the panel data models are reported in Tables 2–4. All models are statistically significant at the 1% level, confirming the reliability of the specifications. The Fisher test and the Breusch–Pagan LM test both reject the pooled regression model in favor of the Random Effects Model (REM). Moreover, the Hausman test validates the REM as the most suitable estimator for this dataset. Table 4 presents the final estimation results under the REM specification. The coefficient of renewable energy consumption (RE) is negative and highly significant (-0.012, $p < 0.01$), indicating that an increase in the share of renewables effectively reduces CO_2 emissions in developing economies. Economically, this implies that renewable energy adoption can contribute to environmental quality without impeding growth, supporting global sustainability targets.

Conversely, GDP per capita shows a positive and significant effect (0.0047, $p < 0.05$), meaning that higher income levels are associated with greater emissions in the short-to-medium run. This result is consistent with the early stages of the Environmental Kuznets Curve (EKC), where growth tends to increase environmental pressure before cleaner technologies are fully integrated.

Population growth also exerts a positive and highly significant influence on CO_2 emissions (0.0265, $p < 0.01$). Rapid demographic expansion in developing economies intensifies energy demand and reliance on fossil fuels, thereby amplifying emissions.

Similarly, financial development contributes positively to emissions (0.0046, $p < 0.01$). While deeper financial markets can enhance investment and growth, they may also channel resources into energy-intensive sectors, leading to a "scale effect" that outweighs potential efficiency gains.

The explanatory power of the model is satisfactory ($R^2 = 0.496$), suggesting that the included variables jointly explain about 50% of the variation in CO_2 emissions across the sample countries.

Overall, the results demonstrate that renewable energy is an effective tool for mitigating emissions, but structural challenges—income growth, demographic pressures, and financial expansion—continue to drive environmental degradation. This highlights the need for targeted policies that integrate renewable energy promotion with institutional reforms and sustainable financial mechanisms.

Discussion

The findings of this study indicate that renewable energy consumption contributes to reducing carbon dioxide emissions in developing economies. This result is consistent with previous studies such as Nguyen and Kakinaka (2019) and Nathaniel et al. (2020), which confirmed a negative relationship between renewable energy and emissions, particularly when supported by an enabling institutional environment. Conversely, the results revealed that economic growth, population growth, and financial development exert upward pressure on emissions. These outcomes align with the Environmental

Kuznets Curve (EKC) hypothesis, which suggests that emissions increase during the early stages of economic development and eventually decline as technological advancement and environmental policies are strengthened (Sarkodie & Strezov, 2019).

Furthermore, the finding that financial development contributes positively to emissions echoes the conclusions of Elfadli et al. (2024), who argued that inefficient financial systems may exacerbate environmental degradation by channeling resources toward polluting activities unless accompanied by green financing mechanisms. Therefore, these results confirm that the transition toward clean energy in developing economies requires not only technological investments but also improvements in institutional and financial quality to maximize the environmental benefits of renewable energy.

Conclusion

This study provides a rigorous empirical examination of the dynamic nexus between renewable energy consumption and carbon dioxide ($CO2$) emissions across a strategically selected panel of developing economies from 2000 to 2022. Our findings offer a dual perspective on the path to sustainability: while the transition to renewable energy sources acts as a potent catalyst for decarbonization, the countervailing pressures of rapid economic growth, demographic expansion, and conventional financial development continue to exacerbate the environmental footprint.

The scholarly contribution of this research extends beyond mere statistical estimation; it addresses a critical knowledge gap by situating the energy-emission trade-off within the unique institutional and macroeconomic contexts of the developing world. By shifting the focus toward these high-growth regions, the study provides a nuanced understanding of how structural transformations influence environmental quality over the long term.

From a pragmatic policy standpoint, these results serve as a clarion call for "Green Structural Transformation." It is no longer sufficient to promote renewable energy in isolation. Instead, policymakers in developing nations must orchestrate a synchronized policy mix that:

- Strategic Shift in Financial Credit (Addressing the Scale Effect): Since the results show that financial development currently increases emissions in these specific economies, governments should implement "Green Credit Guidelines." Instead of general lending, central banks should offer preferential interest rates and credit guarantees specifically for small-scale off-grid renewable projects, which are more suitable for the rural and peri-urban areas common in these developing nations.

- Decoupling Growth via Energy Efficiency Standards: In the context of rapid industrialization, these countries must move beyond just "installing" renewable capacity. There is an urgent need for mandatory energy-performance standards in the construction and manufacturing sectors to ensure that economic expansion (GDP) does not lead to a linear increase in carbon intensity.

- Mitigating Demographic Pressure through Urban Planning: As population growth is a significant driver of emissions in our sample, policymakers should integrate renewable energy into low-income housing projects and public transport systems. This "Pro-Poor Green Growth" approach ensures that demographic expansion is managed through sustainable urban infrastructure rather than carbon-intensive informal settlements.

- South-South Technology Transfer: Rather than relying solely on expensive Western technology, the studied nations should establish regional "Green Innovation Hubs" (e.g., between North African and Asian countries in the sample). This facilitates the sharing of cost-effective, locally adapted renewable technologies that are better suited to the climatic and maintenance capacities of developing regions.

Based on the findings, this study offers several tailored policy implications for the investigated developing economies. First, given that financial development currently correlates with increased emissions, governments should shift toward 'Green Credit Allocation,' prioritizing low-interest loans for decentralized renewable projects in rural and peri-urban areas. Second, to manage the pressures of rapid demographic and economic expansion, it is crucial to implement mandatory energy-efficiency standards in urban planning and manufacturing. Finally, fostering South-South technology transfer between the countries in the sample—such as sharing cost-effective solar innovations—can significantly lower the financial barriers to a clean energy transition, ensuring that economic growth is effectively decoupled from environmental degradation.

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