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Evaluating the Impact of Renewable Energy Consumption on Economic Growth in Emerging Economies: A Dynamic Panel Data Analysis

Abstract. *Decarbonisation, achieved through the switch to renewable energy sources, is critical to tackling issues related to climate change. However, the process is costly, especially for emerging economies, where financial constraints and competing priorities must be taken into consideration. Policymakers are tasked with addressing these complexities by developing strategies that efficiently distribute resources and encourage investment from the private sector. This analysis explores the connection between the use of renewable energy and economic expansion in 18 developing nations, using data from the World Development Indicators spanning the years 2000 to 2023. The findings indicate an absence of a statistically significant relationship between the utilisation of renewable energy and economic growth. Nonetheless, the analysis reveals a robust and consistent link between capital formation and economic expansion, underscoring the significance of investment as a crucial catalyst for growth. The findings indicate that although the adoption of renewable energy is essential for sustainability, its immediate economic advantages in emerging markets are constrained. It is essential for those in positions of authority to focus on approaches that harmonise environmental objectives with the overarching necessity to foster economic growth and optimise resource use.*

Keywords: *renewable energy, economic growth, capital formation, emerging economies, dynamic panel data analysis, sustainable development.*

JEL Classification: O13, C33, O44, Q28, Q43.

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1. Introduction

The transition from fossil fuels to renewable energy sources is a major objective for most countries around the world, given the growing concern about climate change, partially caused by the consumption of coal, oil, and other fossil fuels (Tudor, 2024). Energy production based on fossil fuels is the main source of greenhouse gas (Mason et al., 2022).

The health crisis, geopolitical tensions, and extreme weather events have amplified concerns about climate change and highlighted the importance of accelerating efforts toward sustainability goals and environmental protection globally (Tudor and Sova, 2021). Climate change and energy production are linked if we consider the process of fossil fuels combustion that generates carbon dioxide and methane emissions.

Nearly 80% of global energy primary production still relies on fossil fuels and this process is causing GHG emissions that have a major contribution to human-caused climate change (Murphy, 2024). Thus, to reduce these emissions and mitigate climate change, scientists identified green sources of energy – such as wind, solar, nuclear, and geothermal- that produce significant less pollution. To achieve climate policy targets, governments are focusing on obtaining energy from renewable sources by developing carbon-free energy technologies. These are based on critical resources such as rare minerals, necessary to produce batteries, solar panels, and wind turbines (Jora et al., 2024). Xiong et al. (2014) consider that energy resources are essential for economic development, because economic growth primarily depends on energy consumption.

As green energy can be produced locally, it can help reduce fossil fuels imports and it can represent a catalyst for investments and job creation, thus contributing to GDP growth. The significant increase in the green finance sector can be an indication of the correlation between renewable energy and economic growth (Guliyev and Tatoğlu, 2023).

Emerging economies, characterised by significant trends of industrialisation and urbanisation, face many environmental challenges while having a growing energy demand. According to Apergis & Payne (2010), renewable energy sources offer a viable solution to meet this growing demand while mitigating the adverse effects of climate change. The case of emerging countries is of crucial interest, as they face several distinctive challenges in the process of green transition, because the level of investments is significantly lower compared to developed nations. In 2024, The World Economic Forum has initiated the Network to Mobilize Clean Energy Investment in Emerging Markets and Developing Economies, a platform designed to assist EMDEs in applying the best practices for financing green energy solutions (WEF, 2024).

Existing empirical evidence reveals inconclusive results concerning the correlation between renewable energy consumption and economic growth in emerging economies. Certain research results indicate a unidirectional correlation from renewable energy use to economic growth (Yılancı et al., 2021), but others propose a bidirectional causality (Jia et al., 2023; Apergis and Payne, 2010). However, other research has highlighted that the adoption of renewable energy infrastructure can sometimes be detrimental to economic growth due to the associated costs (Taşkın et al., 2020). Moreover, prior studies frequently neglect the possibility of nonlinear dynamics or do not investigate the interaction effects that could more accurately represent the intricacies of this connection. The absence of unanimity underscores a notable gap in the literature that the present study seeks to fill.

Against this backdrop, the current study aims to examine the relationship between renewable energy consumption and economic growth in emerging economies, employing dynamic panel data analysis to provide new insights into this critical policy area. Particularly, using data from 18 emerging economies spanning 2000–2023, the research explores whether renewable energy adoption promotes economic growth while accounting for key determinants such as capital formation, education expenditure, trade openness, and population growth. The analysis makes use of System GMM to account for potential endogeneity and provide robust parameter estimates. Adding to the existing literature while accounting for the intricacies of the growth process, the study expands the baseline model by including quadratic components for capital creation and educational expenditure. These additions account for anticipated non-linear consequences, such as lower investment and spending returns. Additionally, interaction terms between renewable energy consumption and capital formation are incorporated to investigate the potential existence of synergistic effects, emphasising the relationship between renewable energy adoption and wider economic variables and contributing new findings to the emerging markets literature.

The results show no statistically significant link between economic growth and renewable energy consumption, implying that its economic advantages might be postponed or context-specific. With declining returns at higher investment levels, the results, nevertheless, highlight the important role capital development plays in promoting economic growth. Little interaction between renewable energy and capital creation is observed, which emphasises the difficulty of matching environmental and economic goals in developing nations. These insights can enable legislators to create answers that address the twin issues of advancing economic development and switching to environmentally friendly energy sources.

The study proceeds with a review of the relevant existing literature, followed by an outline of the research methodology. The findings and potential policy implications are then presented, and the study concludes with a synthesis of key insights.

2. Literature review

There are multiple advantages for using renewable energy – reduction of the negative effects of fossil fuels on the environment and diversification of supply sources, which leads to the increase of energy security. Erst & Young published the

Renewable Energy Country Attractiveness Index (RECAI) in 2023 and we observe that many countries have accelerated the process of renewable energy adoption to reduce dependence on imported energy, considering geopolitical tensions and economic uncertainty. This report ranks the top 40 markets in the world based on investment attractiveness and renewable energy implementation opportunities. The countries that occupy the first three positions are the US, Germany, and China (EY, 2023).

The most attractive country in terms of investment opportunities in renewable sources is the United States, where the Inflation Reduction Act provided incentives for developing solar energy production. The second position is held by Germany, where we noticed substantial growth of onshore wind energy production. For China, positioned on the 3rd place, we observed an increase of the offshore wind sector, despite the fact that the government apparently cut off subsidies.

Table 1 presents the overall technology-specific scores regarding the use of renewable technologies for the top 10 countries investing in renewable energy sources.

Table 1. Technology-specific scores

Rank	Country	RECAI score	Onshore wind	Offshore wind	Solar PV	Solar CSP	Biomass	Geothermal	Hydro	Marine
1	United States	72.9	58.3	50.7	58.5	46.5	40.4	46.8	39.5	20.6
2	Germany	72.3	56.4	43.2	57.2	32.3	50.4	37.1	41.6	21.1
3	China	70.7	53.3	45.2	61.6	55.2	49.6	24.3	50.9	17.9
4	United Kingdom	69.8	58.3	52.5	49.8	15.7	54.9	36.3	39.9	35.4
5	France	69.6	55.4	44.1	54.9	24	46.4	39	42.1	38.6
6	India	69.1	53.9	24.5	62.9	34.5	43.4	22	48.1	20.1
7	Australia	68.7	53.5	33.4	56.9	46.7	41.1	15.5	26.9	25.4
8	Spain	66	52.8	27.1	53.6	29.4	40	15.7	23.4	23.3
9	Netherlands	64	53.6	38.8	46.9	15.8	51.1	24.7	27.6	16.6
10	Japan	63.9	50	42	48.8	19.3	56	44.8	38	23.3

Source: Ernst & Young, (2023).

In order to better understand the overall picture of the way different renewable energy technologies are implemented in the top 10 countries according to the RECAI 61 methodology, we graphically represented the comparison between them.

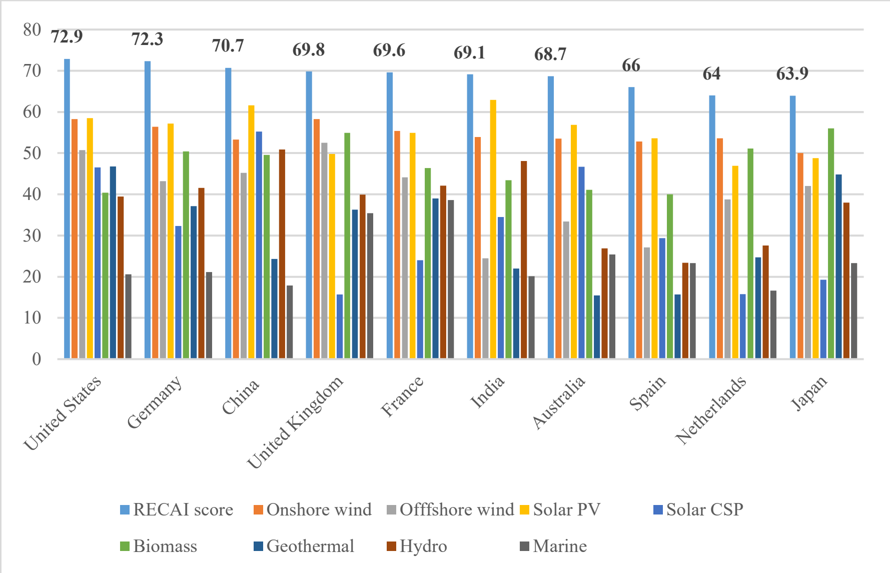

Figure 1. Comparison of technology specific score of top 10 countries
Source: by the authors, based on data from Ernst & Young, (2023).

Transition to clean energy sources like hydro, wind, and solar, is essential for sustainable economic growth (Ram et al., 2022). Using energy from renewable sources can have a positive impact on economic growth by reducing dependence on fossil fuels, improving energy security, creating jobs, and stimulating innovation in clean technologies (Saqib et al., 2023).

An important role in accelerating the transition to clean energy is attributed to geopolitical tensions and economic uncertainty, that led to very volatile fossil fuel prices. We conducted a bibliometric analysis to observe the manner in which the link between renewable energy consumption and economic growth is explored in the scientific literature. A search on this topic in the Scopus database shows that between 2005 and 2024, 1,213 articles addressing "renewable energy consumption" and "economic growth" have been published, of which 1,020 (84%) have been published in the last five years. This demonstrates a global interest in energy issues, which is linked to a wide range of topics such as renewable energy, economic growth, sustainability, trade openness, and environmental quality.

A paper by Qiang, W. et al. (2023), which is the most cited in this area of interest, investigates the effect of several factors (human capital, trade openness, renewable energy consumption, revenues from natural resource exploitation) on carbon emissions at the global/local level. The conclusions reflect the fact that renewable energy consumption has a mitigating effect on CO_2 emissions in most countries and investments in renewable energy sources are a solution for reducing pollution.

Currently, there has been a growing interest for studying the correlation between renewable energy consumption - economic growth. Further on, we will explore the main types of results that are presented in the papers in this field.

One category of studies finds that renewable/non-renewable energy consumption positively impacts economic growth. Doytch and Narayan (2021) examined the impact of non-renewable and renewable energy consumption on economic growth, differentiating between output growth and service growth. They concluded that renewable energy drives growth in the service sector in high- and middle-income economies. Ivanovski et al. (2021) used non-parametric modeling techniques for OECD and non-OECD member states. The results showed that both renewable and non-renewable energy consumption positively influence economic growth in non-OECD countries. However, only non-renewable energy consumption is positively corelated with economic growth in OECD countries. Tugcu and Topcu (2018) examined the long-term and short-term relationships between economic growth and total energy consumption, renewable/non-renewable energy consumption in G7 countries. They identified a causal relationship between energy consumption and economic growth. Another study by Tuna and Tuna (2019) analysed the impact of energy consumption on economic growth in ASEAN-5 countries and the results show that energy policies have a significant impact on economic development.

In the study elaborated by Dogan et al. (2020), the effect of renewable energy consumption on economic growth in OECD countries is measured over quantiles. The results of panel quantile regression indicate that for middle, high-middle, and higher quantiles, the effect is negative, and for lower and low-middle quantiles the effect is positive. Wang and Wang (2020) considered the case of OECD countries to investigate the relationship between renewable energy and economic growth, and the results of panel threshold models show that increased renewable energy consumption contributes to economic growth. Chen et al. (2020) explored the impact of renewable energy on economic growth for a sample of 103 countries and they concluded that after a certain threshold of renewable energy consumption, the effect on economic growth is positive or it can be negative if the consumption does not exceed that threshold.

Other studies refer to the relation between non-renewable energy and economic growth and Mohammadi and Parvaresh (2014) investigated this link for 14 oil-exporting countries during 1980-2007. The results show that traditional energy consumption has a positive effect on the growth of production in the long-term. Another example is the study conducted by Shahbaz et al. (2018) for India, on the asymmetric relation between energy consumption and economic growth (using a nonlinear ARDL bounds testing approach). The main conclusion states that negative shocks in the energy sector induce negative effects on economic growth. Awodumi and Adewuyi (2020) used a nonlinear ARDL method to study the effect of non-renewable energy on economic growth and carbon emissions in the top five African oil-producing countries (Algeria, Angola, Egypt, Gabon, and Nigeria) for the period 1980-2015. They found an asymmetric effect of per capita energy consumption (oil and natural gas) on output growth in each of their sample countries except Algeria. Alqaralleh and Hatemi-J (2023) studied the dynamic impact of both non-renewable and renewable energy sources on economic growth for eight countries, using capital stock and labour force as control variables. The results show that the consumption of renewable energy has a positive impact on economic growth.

A second category of studies found no correlation between energy consumption and economic growth. For example, a study conducted on G7 countries by Salamaliki and Venetis (2013) used sequential causality testing to assess the impact of non-renewable energy consumption on economic growth. They found that non-renewable energy consumption has no effect on real GDP. Wang et al. (2020) identified a decoupling relationship between economic growth and fuel consumption in China and India. Mensah et al. (2019) consider that between non-renewable energy consumption and economic growth there is a bidirectional causality relationship.

According to Apergis & Payne (2010) cited in Mohammadi & Parvaresh (2014) there are four types of hypotheses that can be defined for the study of energy consumption – economic growth relationship: (1) neutrality – no causal relation, (2) conservation – unidirectional causality, growth determines energy consumption, (3) growth – unidirectional causality, energy consumption determines economic growth, (4) feedback – bidirectional causality between the two concepts.

We identify a third category of studies (Jia et al., 2023; Chen et al., 2020) that found a bidirectional causal relationship, suggesting that not only does renewable energy consumption drive economic growth, but economic growth also encourages further investment in renewable energy. This feedback loop underscores the importance of capital formation in sustaining this relationship.

The existing literature includes conflicting results regarding the existence of a uni- or bidirectional relationship between renewable energy consumption and economic growth, as Ozturk (2010) also points out.

After a meticulous analysis of the existing literature review, considering the methods and results previously achieved in researching the correlation between energy consumption and economic growth, we defined our research methodology, which is presented further on.

3. Model specification

3.1 Model Description and Hypothesis

This study uses an unbalanced panel dataset from the World Development Indicators (WDI) to investigate the relationship between renewable energy use and economic growth in 18 growing economies from 2000 to 2023. Economic growth, measured as the yearly percentage growth rate of GDP per capita, is the dependent variable. Renewable energy use, provided as a proportion of total final energy consumption, is the key independent variable. To account for other growth-influencing factors, the analysis includes key control variables such as gross capital formation (a proxy for physical asset investment), education expenditure (a measure of human capital investment), trade openness (a measure of integration with the global economy), and population growth (to capture demographic dynamics). Brazil, India, Turkey, Mexico, South Africa, Indonesia, the Philippines, Thailand, Vietnam, Argentina, Malaysia, Nigeria, Egypt, Pakistan, Kenya, Peru, Colombia, and Chile comprise a vast collection of expanding economies. These countries were chosen based on their different economic systems, rapid development trajectories, and prominent positions in global marketplaces. Brazil, India, Turkey, and Mexico, for example, are big foreign trading partners with great economic expansion potential, making them vital to understanding growth patterns. South Africa, Indonesia, and Vietnam, with their rising industrialisation and urbanisation, pose special barriers and opportunities for renewable energy adoption. In the same vein, Argentina, Malaysia, and Chile provide perspectives from economies with sophisticated infrastructure and relatively high levels of human capital, while Nigeria, Egypt, Kenya, and Pakistan underscore the relationship between renewable energy and growth in areas that are influenced by substantial demographic shifts and infrastructural constraints. These countries show how renewable energy consumption affects economic growth in developmental and structural situations. The final dataset comprises 347 observations.

The descriptive statistics for the key variables, shown in Table 2, enhance our understanding of the data's distribution and variability, laying a comprehensive groundwork for the econometric analysis.

Table 2. Descriptive statistics

	n	mean	sd	median	mad	min	max	range	skew	kurtosis	se
gdp_growth	347	2.48	3.54	2.97	2.77	-12.22	11.97	24.19	-1.13	2.78	0.19
renew_energy	347	26.16	17.68	26.8	22.24	2	81.6	79.6	0.9	0.71	0.95
capital_formation	347	22.53	5.69	21.69	5.06	10.85	39.79	28.93	0.81	0.25	0.31
education_expenditure	347	4.23	1.08	4.26	1.06	1.69	7.66	5.97	0.2	0.04	0.06
trade_openness	347	65.58	40.05	53.77	24.68	21.46	220.41	198.95	1.56	2.02	2.15
population_growth	347	1.27	0.65	1.19	0.42	-1.04	3.08	4.12	0.16	0.9	0.03

Source: Authors' processing.

The sample exhibits significant variation in GDP growth, with an average of 2.48% and a standard deviation of 3.54%, reflecting diverse economic performance. The negative skewness of -1.13 indicates that some countries underwent economic contractions. Renewable energy consumption averages 26.16%, with a range of 2% to 81.6%, highlighting considerable disparities in adoption levels. The slight positive skew (0.90) suggests that the majority of countries utilise minimal renewable energy, with only a few exhibiting higher adoption rates.

Capital formation averages 22.53%, with a skewness of 0.81, suggesting a concentration of values near the lower end of the distribution. The model incorporates a quadratic factor to address diminishing returns, illustrating the nonlinear relationship between capital generation and growth. Education expenditure exhibits greater stability, with a mean of 4.23% and minimal variation among countries. Trade openness exhibits considerable variation, with an average of 65.58% and a broad range reflecting differing degrees of global economic integration. Population growth averages 1.27%, exhibiting negligible skewness (0.16), which suggests consistent demographic trends throughout the sample.

3.2 Empirical Model Specification

3.2.1 Baseline Model

The baseline model evaluates how renewable energy use influences economic growth, controlling for capital development, education spending, trade openness, and population growth. Employing lagged GDP growth as an independent variable, a dynamic panel model is used to represent the possible persistence of economic growth. The baseline model is as follows:

$$\begin{aligned} \text{GDP Growth}_{it} = {} & \alpha + \beta_1 \text{GDP Growth}_{i(t-1)} + \beta_2 \text{Renewable Energy}_{it} \\ & + \beta_3 \text{Capital Formation}_{it} + \beta_4 \text{Education Expenditure}_{it} \\ & + \beta_5 \text{Trade Openness}_{it} + \beta_6 \text{Population Growth}_{it} + \varepsilon_{it} \end{aligned}$$

where i represents the country, t represents time, and $\varepsilon_{it}$is the error term.

Furthermore, the potential endogeneity of the lagged dependent variable and certain explanatory factors is addressed through the application of Generalised Method of Moments (GMM) estimates (Dumitrescu et al., 2023).

3.2.2 Model Expansion with Quadratic Terms

Quadratic terms for capital formation and education expenditure were incorporated into the model to investigate potential non-linear relationships, especially regarding diminishing returns. The model has been expanded to include additional components.

$$\begin{aligned} \text{GDP Growth}_{it} = {} & \alpha + \beta_1 \text{GDP Growth}_{i(t-1)} + \beta_2 \text{Renewable Energy}_{it} \\ & + \beta_3 \text{Capital Formation}_{it} + \beta_4 \text{Capital Formation}_{it}^2 \\ & + \beta_5 \text{Education Expenditure}_{it} + \beta_6 \text{Education Expenditure}_{it}^2 \\ & + \beta_7 \text{Trade Openness}_{it} + \beta_8 \text{Population Growth}_{it} + \varepsilon_{it} \end{aligned}$$

The addition of the quadratic factors allows us to reflect declining returns to both capital creation and education expenditure, which may display non-linear effects on economic growth as investments increase.

3.2.3 Interaction Effects

Interaction factors between renewable energy consumption and capital creation were included in a future development of the model to evaluate whether there are any synergistic benefits between adoption of renewable energy and more general capital investments. Specification for the model is:

$$\begin{aligned}\text{GDP Growth}_{\text{it}} = {} & \alpha + \beta_1 \text{GDP Growth}_{\text{i(t}-1)} + \beta_2 \text{Renewable Energy}_{\text{it}} \\ & + \beta_3 \text{Capital Formation}_{\text{it}} \\ & + \beta_4 (\text{Renewable Energy}_{\text{it}} \times \text{Capital Formation}_{\text{it}}) \\ & + \beta_5 \text{Education Expenditure}_{\text{it}} + \beta_6 \text{Trade Openness}_{\text{it}} \\ & + \beta_7 \text{Population Growth}_{\text{it}} + \varepsilon_{\text{it}}\end{aligned}$$

This extension aims to study if, taken together, the adoption of renewable energy sources and capital creation could have a more influence on economic development than when taken separately.

3.3 Estimation Strategy

A lagged dependent variable in dynamic panel data models may create endogeneity due to the error term. In addition, missing variable bias, measurement error, or simultaneity may make independent factors, such as capital production and education spending, endogenous. The robust System GMM estimator integrates level and first-difference equations to improve parameter estimation efficiency. Particularly, the System GMM estimator assumes level and first-difference transformations. This dual method controls unobserved country-specific effects and time-invariant elements that could corrupt the estimate process. Moreover, Sargan tests for over-identification assess instrument validity, whereas Arellano-Bond tests for first- and second-order serial correlation validate model specification.

4. Empirical results and discussion

4.1 Empirical Results

The estimation results from dynamic panel models that employed System GMM to capture the correlation between the use of renewable energy and economic growth in a large sample of emerging economies are covered in this part. Both linear and non-linear dynamics, as well as possible synergistic effects between the adoption of renewable energy and capital formation, were clarified by the baseline model, which was expanded with quadratic factors, and the interaction model. A series of diagnostic tests, such as the Sargan, Arellano-Bond, and Wald tests, confirm the reliability of the findings. Visualisations are employed to enhance the estimation results, facilitating a clearer comprehension of the relationships among the key variables under examination.

The relationship between renewable energy use and GDP growth is intriguing. The near-horizontal line of fit in the scatter plot (Figure 2) shows no correlation between renewable energy utilisation and economic development. Visual evidence confirms estimation conclusions that renewable energy use does not statistically affect economic development in all model parameters. These findings suggest that renewable energy may not benefit emerging countries in the short run, despite its importance for long-term sustainability. This may be because it is still being adopted or because the economic benefits won't emerge for some time, beyond this study's timeline.

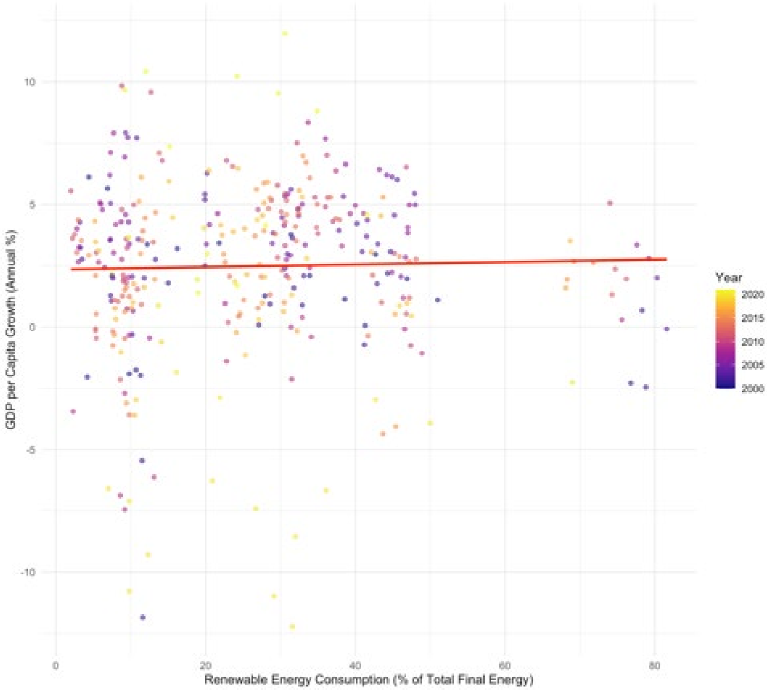

Figure 2. Scatter Plot of Renewable Energy Consumption and Economic Growth in Emerging Economies (2000–2023)
Source: World Development Indicators (WDI);
Visualisation Created by Authors in R Software.

The relationship between capital formation and economic growth demonstrates a significantly stronger correlation, as evidenced by the second scatter plot (Figure 3).

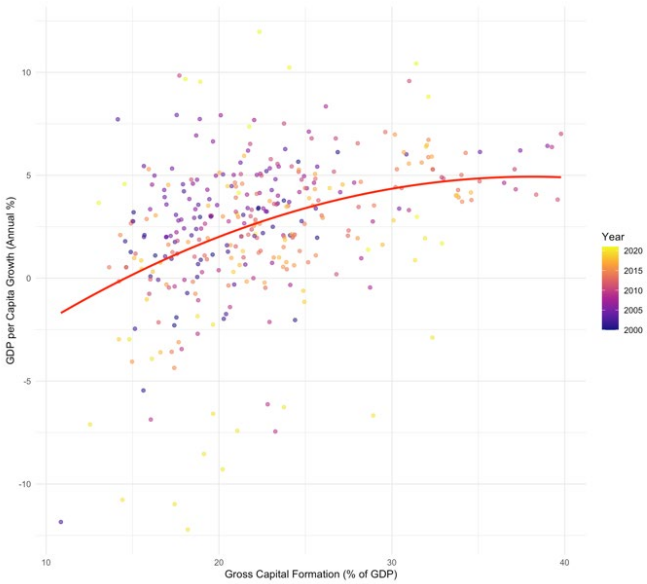

Figure 3. Scatter Plot of Capital Formation and Economic Growth in Emerging Economies with Quadratic Fit (2000–2023)
Source: World Development Indicators (WDI);
Visualisation Created by Authors in R Software.

The quadratic fit demonstrates the diminishing returns associated with capital formation. Lower levels of capital investment exhibit a positive and significant correlation with growth, highlighting the critical role of capital formation in fostering economic progress. As investment rises, the growth rate eventually levels off and subsequently decreases, as indicated by the downward slope of the fitted line. The observed pattern supports the conclusions of the extended model, indicating that the negative and significant quadratic term for capital formation suggests that excessive capital investment may lead to diminished marginal returns.

The visual analysis of these relationships supports the scientific findings, offering a clearer comprehension of the interactions among renewable energy, capital development, and economic growth.

The implications of these correlations will be further examined, particularly with regard to policy recommendations for developing nations, when we go on to the specific estimation results.

The baseline model (Table 3) demonstrates a statistically significant and positive relationship between capital production and economic growth, confirming the basic significance of physical investment in fostering development within the sample of emerging economies. The statistically insignificant consumption of renewable energy suggests either a prolonged lag beyond the scope of this analysis or a minimal impact on development. Interestingly, the negative coefficient for delayed GDP growth suggests a reversion to the mean, decreasing growth in nations with strong preceding period growth.

Table 3. Baseline Model Results

Variable	Coefficient	Std. Error	z-value	p-value
Lagged GDP Growth (1st lag)	-0.2174	0.0371	-5.82	< 0.001
Lagged GDP Growth (2nd lag)	-0.3938	0.0433	-9.1	< 0.001
Renewable Energy	0.0647	0.0463	1.4	0.162
Capital Formation	0.3628	0.0811	4.47	< 0.001
Education Expenditure	-0.9243	0.2419	-3.82	< 0.001
Trade Openness	0.0101	0.0088	1.15	0.249
Population Growth	-0.8726	0.7181	-1.22	0.224

Source: Diagnostic Tests for Baseline Model: Sargan Test (p-value): 1.00; AR(1) Test (p-value): 0.0033; AR(2) Test (p-value): 0.2670; Wald Test (p-value): < 0.001.

The inclusion of quadratic components in the expanded model improves the understanding of capital creation dynamics and their relationship with economic growth. Table 4 displays the results of this expanded model. The falling returns on investment become clearer when capital formation is expressed in quadratic terms. Development is still primarily the result of capital formation, but the negative quadratic term implies that after a certain point, more investments provide progressively lower growth returns. This result adds a great deal of nuance to policy suggestions by highlighting the significance of focused and balanced investment strategies. Spending on education continues to have a negative correlation with development, which may indicate inefficiencies in the educational systems or lag effects that the current model ignores.

Table 4. Expanded Model with Quadratic Terms

Variable	Coefficient	Std. Error	z-value	p-value
Lagged GDP Growth (1st lag)	-0.2238	0.0436	-5.13	< 0.001
Lagged GDP Growth (2nd lag)	-0.4054	0.0472	-8.59	< 0.001
Renewable Energy	0.0038	0.0244	0.16	0.876
Capital Formation	1.1124	0.4259	2.61	0.009
Capital Formation^2	-0.0163	0.0081	-2.02	0.044
Education Expenditure	-4.1658	1.9848	-2.1	0.036
Education Expenditure^2	0.3479	0.2178	1.6	0.110

Variable	Coefficient	Std. Error	z-value	p-value
Trade Openness	0.0027	0.0101	0.26	0.791
Population Growth	-1.0661	0.7286	-1.46	0.143

Source: Diagnostic Tests for Quadratic Model: Sargan Test (p-value): 1.00; AR(1) Test (p-value): 0.0048; AR(2) Test (p-value): 0.2914; Wald Test (p-value): < 0.001.

The subsequent model included interaction factors for renewable energy and capital investment to examine potential synergies. This interaction model's results are in Table 5.

Table 5. Interaction Model Results

Variable	Coefficient	Std. Error	z-value	p-value
Lagged GDP Growth (1st lag)	-0.2174	0.0371	-5.82	< 0.001
Lagged GDP Growth (2nd lag)	-0.3938	0.0433	-9.1	< 0.001
Renewable Energy	0.0647	0.0463	1.4	0.162
Capital Formation	0.3628	0.0811	4.47	< 0.001
Renewable Energy × Capital Formation	-0.0024	0.0023	-1.02	0.309
Education Expenditure	-0.9243	0.2419	-3.82	< 0.001
Trade Openness	0.0101	0.0088	1.15	0.249
Population Growth	-0.8726	0.7181	-1.22	0.224

Source: Diagnostic Tests for Interaction Model: Sargan Test (p-value): 1.00; A R(1) Test (p-value): 0.0033; AR(2) Test (p-value): 0.2670; Wald Test (p-value): < 0.001.

Few synergies exist between renewable energy use and capital production when interaction parameters are introduced. Capital formation consistently boosts economic growth, while renewable energy does not. Renewable energy, while essential for sustainability, may not directly affect economic growth in the short term or in the scenarios explored in this study.

4.2 Discussion

Our study explored the relation between renewable energy consumption and economic growth in 18 emerging economies, using an unbalanced panel dataset from the World Development Indicators (WDI) covering the period from 2000 to 2023.

The scatter plot of renewable energy consumption versus economic growth indicated a lack of evident correlation between these two variables. The estimation results consistently show no statistically significant relation between renewable energy consumption and economic growth in all model specifications.

While several previous studies found a bidirectional causal relation between energy consumption and economic growth (Alqaralleh& Hatemi-J, 2022) and some studies found that both renewable and non-renewable energy consumption promote economic growth in non-OECD countries (Ivanovski, 2021), our findings are consistent with the results identified in the second category of studies mentioned in the literature review section, which support the fact that energy consumption has no significant effect on economic growth (Salamaliki & Venetis 2013; Mensah et al. 2019). We can explain the lack of perceptible correlation between the consumption of renewable energy and economic growth by the relatively early stage of using this type of energy or by the fact that the benefits of the adoption of renewable energy on economic growth appear over a longer period of time compared to the time interval analysed. Also, it is more likely to link energy consumption in general to the national output rather than renewable energy, as the latter usually implies more costs and investments.

According to the results obtained, there is a statistically significant and positive relationship between capital formation and economic growth, confirming the essential role of investments in stimulating economic growth in the case of the 18 emerging economies. This can be interpreted in a broader context, as previous studies (Chen et al., 2020; Jia et al., 2023) suggest the importance of capital formation in sustaining a bidirectional relationship between renewable energy consumption and economic growth. Furthermore, some studies suggest foreign capital inflows play a crucial role in boosting renewable energy investments, thus increasing the consumption and thereby contributing to economic growth (Qin & Öztürk, 2021). This is particularly relevant for developing countries, where domestic capital may be insufficient to meet the investment needs for renewable energy infrastructure. The relationship between renewable energy, capital formation, and economic growth is characterised by a complex interplay of factors. Evidence suggests that capital formation is essential to promote renewable energy consumption, which in turn can lead to sustainable economic growth. Policymakers should focus on measures that enable capital investment in renewable energy to harness its full potential for economic development.

5. Conclusions

Recently, at global level, discussions on climate change effects and the importance of mitigating them by increasing environmental protection actions and focusing on sustainable development have led most developed/emerging countries to adopt measures to reduce their carbon footprint. This fact has generated changes in the global strategies of governments and companies with respect to energy efficiency and renewable energy sources. For example, the European Green Deal has committed EU member states to a clean and circular economy.

The transition to renewable energy sources is a necessary condition for sustainable economic development. To achieve this goal, a series of measures are needed to ensure the existence of financing opportunities and to streamline procedures for issuing authorisations for energy installations from renewable sources. All these measures and policies imply financial costs, so governments want to know whether in the future these investments will pay off.

Our research results show the direct impact of capital formation on economic growth, while renewable energy remains statistically insignificant. These findings suggest that renewable energy, while essential for sustainable development, may not yet directly contribute to economic growth in the short term or in the contexts explored in this study. This type of findings may seem discouraging to policy makers, making it hard for them to further promote regulations that encourage investments in renewable energy sources. But keeping in mind the fact that the world's commitment to sustainable development should not be abandoned to the pursue of immediate gains, governments should further invest in renewable energy sources, even if the direct link with economic growth is not demonstrated.

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