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The Impact of Renewable Energy and Technology Access on Economic Performance in Zambia

El impacto de las energías renovables y el acceso a la tecnología en el desempeño económico de Zambia

Tryson Yangailo
PhD in Business and Management, The University of Zambia, Zambia
Golden Key South Africa Individual Member.
https://orcid.org/0000-0002-0690-9747
ytryson@yahoo.com

ABSTRACT

This study examines the impact of renewable energy and other related variables on economic performance in Zambia, focusing on data from 2000 to 2022. The primary objective is to assess how various aspects of renewable energy, including consumption and access, affect GDP and its growth. Using the Jamovi software, a descriptive statistical analysis, a regression analysis, and a correlation analysis were conducted on data from the World Bank and the International Renewable Energy Agency. The study reveals that while renewable energy consumption negatively affects GDP growth, access to clean cooking technologies significantly promotes it. In addition, the share of renewable energy in electricity generation and access to electricity are positively correlated to improvements in rural electrification. However, the share of renewable energy in electricity generation does not have a significant direct impact on GDP. These findings suggest that strategic investments in renewable energy must be balanced with efforts to improve access to clean technologies to maximize economic benefits. Policymakers should focus on improving rural electrification and integrating renewable energy projects into broader infrastructure development. The study underscores the importance of targeted policies and technological advances to optimize the economic impact of renewable energy. Recommendations include investing in renewable energy initiatives with a focus on long-term economic outcomes, improving rural electrification policies, and exploring further research on technological innovations and their economic impacts. The study contributes to the existing literature by providing a detailed analysis of the role of renewable energy in economic performance in the Zambian context, highlighting both its potential and limitations. Its innovation lies in the use of comprehensive data analysis techniques and triangulation to provide actionable insights for policy development and future research.

Keywords: renewable energy; economic performance; policy implications; economic history.

JEL Codes: Q42; Q43; Q48; O11; O33

RESUMEN

Este estudio examina el impacto de las energías renovables y otras variables relacionadas en el desempeño económico de Zambia, centrándose en datos de 2000 a 2022. El objetivo principal es evaluar cómo los diversos aspectos de las energías renovables, incluidos el consumo y el acceso, afectan al PIB y su crecimiento. Utilizando el software Jamovi, el estudio realiza estadísticas descriptivas, un análisis de regresión y un análisis de correlación sobre datos del Banco Mundial y la Agencia Internacional de Energías Renovables. El estudio revela que, si bien el consumo de energía renovable afecta negativamente el crecimiento del PIB, el acceso a tecnologías de cocina limpias promueve significativamente su crecimiento. Además, la proporción de energía renovable en la generación de electricidad y el acceso a la electricidad están correlacionados positivamente con las mejoras en la electrificación rural. Sin embargo, la proporción de energías renovables en la generación de electricidad no tiene un impacto directo significativo en el PIB. Estos hallazgos sugieren que las inversiones estratégicas en energía renovable deben equilibrarse con esfuerzos para mejorar el acceso a tecnologías limpias para maximizar los beneficios económicos. Los responsables de las políticas deben centrarse en mejorar la electrificación rural e integrar los proyectos de energía renovable en el desarrollo más amplio de infraestructura. El estudio subraya la importancia de las políticas específicas y los avances tecnológicos para optimizar el impacto económico de las energías renovables. Las recomendaciones incluyen invertir en iniciativas de energía renovable con un enfoque en los resultados económicos a largo plazo, mejorar las políticas de electrificación rural e investigar más a fondo acerca de las innovaciones tecnológicas y sus impactos económicos. El estudio contribuye a la literatura existente al proporcionar un análisis detallado del papel de la energía renovable en el desempeño económico en el contexto de Zambia, destacando tanto su potencial como sus limitaciones. Su innovación radica en el uso de técnicas integrales de análisis de datos y triangulación para proporcionar información procesable que sea útil para el desarrollo de políticas y la investigación futura.

Palabras clave: energía renovable; desempeño económico; implicaciones de las políticas; historia económica.

Códigos JEL: Q42; Q43; Q48; O11; O33

Introduction

The relationship between renewable energy consumption and economic growth has been extensively studied, especially in developing countries. Renewable energy is increasingly recognized as an important factor in promoting sustainable economic development, reducing environmental degradation, and mitigating climate change (Ahmed & Shimada, 2019). In Zambia, a country heavily dependent on hydropower, the potential of other renewable energy sources such as solar, wind, and biomass remains underutilized despite their availability (Chishimba, 2022; Makai & Popoola, 2024). Zambia faces the dual challenge of ensuring continued economic growth while balancing energy consumption in a way that supports sustainability, particularly as energy demand increases in rural and off-grid areas (Munyeme & Jain, 1994; Nyoni et al., 2021).

Globally, the shift towards renewable energy is driven by the need to transition from fossil fuels to cleaner and more sustainable energy sources (Saidi & Omri, 2020; Zafar et al., 2019). Empirical studies have shown that renewable energy can contribute positively to economic growth, although the magnitude of its impact varies depending on a country's stage of development, resource endowment, and institutional quality (Azam, 2020; Bhattacharya et al., 2016). Economic growth can be disaggregated into factors such as capital, labor, and technological progress, which may further help to elucidate how renewable energy contributes to growth through technological progress. In sub-Saharan Africa, including Zambia, increased adoption of renewable energy technologies can significantly improve energy security and support broader development goals (Muazu et al., 2023).

However, Zambia faces several barriers to realizing the full potential of renewable energy in promoting economic growth. These barriers include governance challenges, inefficiencies within the energy sector, and the “resource curse” phenomenon, in which mismanagement of natural resources can hinder the effective use of renewable energy resources (Nyasha & Odhiambo, 2022; Atkinson & Hamilton, 2003). Addressing these challenges and optimizing the use of renewable energy could help Zambia align its energy policies with global sustainable development goals (Diallo & Ouo-ba, 2024).

Contribution to Literature

This study contributes to the existing literature on the subject by examining the specific dynamics of renewable energy consumption and economic growth within the Zambian context, with a particular focus on how renewable energy and access to clean cooking technologies affect economic performance. While previous studies have examined the broader relationship between renewable energy and economic growth, few have specifically examined the nuances within Zambia, where renewable energy consumption remains largely underdeveloped compared to its potential.

The study contributes by providing empirical insights into how different types of renewable energy sources, as well as the adoption of clean cooking technologies, affect Zambia’s GDP growth. By examining these factors, the study advances the understanding of the local challenges and opportunities for renewable energy adoption in a developing African context. It also adds to the growing body of research on how renewable energy can support sustainable development in sub-Saharan Africa, where renewable energy potential is high, but uptake remains low. The findings can inform energy policy decisions and strategies to accelerate the transition to a more sustainable and economically resilient energy system in Zambia.

Objective of the Study

This study aims to examine the relationship between renewable energy consumption and economic growth in Zambia, focusing on how renewable energy and access to clean cooking technologies affect economic performance. The main objective of the study is to analyze how these variables interact and influence Zambia's economic growth. Specifically, the study addresses the following objectives:

1. Assess the impact of renewable energy consumption on GDP growth.
2. Evaluate how access to clean cooking technologies affects economic development.
3. Determine the relative significance of renewable energy consumption and access to clean cooking technologies on GDP.

By addressing these objectives, the study aims to provide insights into the complex dynamics of energy consumption and economic growth, and to make recommendations for policies that could promote sustainable development in Zambia.

Literature Review

Theoretical Framework

The relationship between renewable energy and economic growth can be explained through several theoretical frameworks. The production function model views energy as a critical input, along with capital and labor, that increases productivity by reducing costs and ensuring a sustainable energy supply (Bhattacharya et al., 2016; Sharma, 2010). Endogenous growth theory supports this by emphasizing that technological innovation drives long-term economic growth (Lee & Chang, 2007; Zafar et al., 2019).

In Zambia, where traditional energy sources are strained, renewable energy is a viable solution, especially for rural areas. Solar and biomass energy can address off-grid energy challenges by providing cost-effective and cleaner alternatives (Kakoma-Bowa, 2020; Stritzke & Jain, 2021). Technological advances such as floating solar systems and off-grid renewable technologies are also emerging as promising solutions to improve energy access and economic productivity in rural Zambia (Nyoni et al., 2021).

Empirical Review

Empirical studies on renewable energy and economic growth provide mixed results. For example, Vlahinić and Zikovic (2010) found that in Croatia, economic growth primarily drives energy consumption due to the country’s low energy intensity. In contrast, Wolde-Rufael (2009), found that while energy consumption contributes to economic growth, its importance is often overshadowed by labor and capital in many African countries. Similarly, Zerbo (2017) found mixed relationships in sub-Saharan Africa, including Zambia, where the conservation hypothesis suggests that economic growth could lead to reduced energy consumption.

On the contrary, Bhattacharya et al. (2016) reported positive impacts of renewable energy on GDP growth in the top 38 renewable energy consuming countries, while Saidi and Omri (2020) observed significant economic benefits in large renewable energy consuming countries. These findings are not universal and depend on factors such as energy policies and institutional capacity (Azam, 2020). Omri (2014) reviewed the energy-growth nexus and found mixed results, particularly under the neutrality hypothesis, suggesting the need for further research in different contexts, including Zambia.

Research specific to sub-Saharan Africa suggests that renewable energy can drive economic growth, although its success is closely linked to governance and policy frameworks (Diallo & Ouoba, 2024). Muazu, Yu, and Liu (2023) emphasize the importance of institutional quality in maximizing the benefits of renewable energy. For Zambia, Nyasha and Odhiambo (2022) highlighted the understudied role of renewable energy despite its potential to alleviate power shortages and contribute to development goals (Chishimba, 2022; Mulenga, 2019). The findings of Papyrakis and Gerlagh (2004) also suggest that effective natural resource management could mitigate the negative impacts associated with resource abundance, which is relevant to Zambia's energy sector.

Gaps in the Literature

Despite the growing body of research, several gaps remain in the literature. This study addresses some of these gaps by providing valuable empirical evidence that focuses specifically on Zambia's renewable energy sector. While previous studies, such as those by Nyoni et al. (2021) and Mulenga (2019), have explored Zambia's renewable energy potential, comprehensive research on the long-term economic impacts of increased renewable energy adoption is limited. By examining the relationship between renewable energy consumption and economic growth in Zambia, this study contributes significantly to filling this gap, and further enhances the understanding of renewable energy consumption in developing countries. It responds to the call of Oliveira and Moutinho (2021) for further empirical studies in less developed countries and provides new insights into how renewable energy affects economic growth in Zambia. Addressing these areas will be critical for future research to provide a more comprehensive understanding of the interplay between renewable energy and economic growth in Zambia and similar contexts.

Methodology

Data Sources

This study used data from the World Bank and the International Renewable Energy Agency (IRENA) covering the period 2000 to 2022. These datasets provide a wide range of variables essential for understanding the dynamics of renewable energy and economic growth in Zambia. The World Bank provided detailed economic indicators, while IRENA provided data on renewable energy metrics, ensuring a comprehensive analysis of the variables involved.

Variables

The study examines several key variables. The dependent variables are GDP (current US$ million), which measures the total economic output of Zambia, and GDP Growth (annual %), which reflects the percentage change in GDP from year to year. The independent variables include Renewable Energy Share of Electricity Generation (%), which measures the percentage of electricity generated from renewable sources; Access to Electricity, Rural (% of Rural Population), which measures the percentage of the rural population with access to electricity; Renewable Energy Consumption (% of Total Final Energy Consumption), which shows the share of renewable energy in total energy consumption; Access to Electricity (% of Population), which shows the overall percentage of the population with access to electricity; and Access to Clean Fuels and Cooking Technologies (% of Population), which shows the percentage of the population using clean cooking technologies.

Data Analysis

Data analysis was conducted using the Jamovi software, which was selected due to its ability to perform descriptive statistics, correlation analysis, and regression analysis. Descriptive statistics were used to summarize the central tendencies, variabilities, and distributions of the variables, providing basic insights into the data set. Correlational analysis, including Pearson's correlation coefficients, was used to evaluate the relationships between independent and dependent variables and to identify significant associations and patterns. Multiple regression analyses were then conducted to assess the impact of the independent variables on GDP and GDP growth to determine their influence on Zambia's economic performance.

Triangulation

Triangulation was used to increase the reliability and validity of the findings. This method involved cross-referencing the results of descriptive statistics, correlation analysis, and regression analysis to ensure consistency and accuracy. By integrating these different analytical approaches, the study provided a robust examination of the interactions between renewable energy and economic growth in Zambia, providing a comprehensive understanding of how these variables influence each other.

Equations for Pearson's Correlation Coefficient and Spearman's Rho

The equation for Pearson's correlation coefficient (r) is:

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 \sum_{i=1}^{n}(Y_i - \bar{Y})^2} \qquad (1)$$

Where:

- r is Pearson's correlation coefficient.
- n is the number of data points.

- X_i and Y_i are the individual data points for variables X and Y, respectively
- $\bar{X}$ and $\bar{Y}$ are the means of X and Y, respectively.

The equation for Spearman's rho (ρ) is:

$$\rho = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)} \quad (2)$$

Where:

- ρ is Spearman's rank correlation coefficient.
- n is the number of data points
- d_i is the difference between the ranks of corresponding variables X and Y.

Specification of the Model

In this study, multiple linear regression models were used to analyze the relationship between the dependent variables (GDP and GDP growth) and several predictors, including renewable energy consumption, access to clean cooking technologies, access to electricity, and other related variables. The dependent variables in this model were GDP and GDP growth, while the independent variables included the share of renewable energy in electricity generation, rural access to electricity, renewable energy consumption, total access to electricity, and access to clean cooking fuels and technologies. Multiple linear regression is a statistical technique used to model the relationship between a dependent variable and multiple independent variables by fitting a linear equation to the observed data. This method allowed examining how each predictor affects GDP and GDP growth, both individually and in combination, thereby providing insights into the relative importance of renewable energy and related factors in driving economic development in Zambia.

Regression Equation

The general form of the multiple linear regression equation is:

$$Y=\beta_0+\beta_1X_1+\beta_2X_2+\cdots+\beta nX_n+\epsilon \quad (3)$$

In this study, the regression model is designed to examine the relationships between renewable energy variables and economic performance indicators in Zambia. Here is how the model components are defined in the context of this study:

- Y, in which GDP and GDP growth are the dependent variables. Specifically, GDP (current US$ Million) represents the total economic output of Zambia, and GDP Growth (annual %) measures the annual percentage change in GDP.
- β0 is the intercept of the regression model, representing the expected value of GDP and GDP Growth when all independent variables (i.e., renewable energy share of electricity generation, access to electricity in rural areas, renewable energy consumption, access to electricity, and access to clean cooking fuels and technologies) are equal to zero.
- β1, β2, ..., βn are the coefficients of the independent variables, indicating the expected change in GDP and GDP Growth for a one-unit change in each corresponding independent variable. These coefficients measure the impact of each predictor on the economic performance indicators.
- X1, X2, ..., Xn are the independent variables in the model. In this study, these include Renewable Energy Share of Electricity Generation (%), Access to Electricity, Rural (% of Rural Population), Renewable Energy Consumption (% of Total Final Energy Consumption), Access to Electricity (% of Population), and Access to Clean Fuels and Technologies for Cooking (% of Population).

- ϵ is the error term, capturing the variation in GDP and GDP Growth that is not explained by the independent variables in the model. This term accounts for the influence of factors not included in the model that might affect the economic performance indicators.

This regression model effectively quantifies the impact of various renewable energy-related predictors on Zambia's GDP and GDP growth. It highlights how different aspects of renewable energy and access to energy services contribute to economic outcomes, providing a comprehensive view of the factors influencing Zambia's economic performance. By incorporating both continuous variables (percentages and consumption rates) and examining their impact on economic indicators, the model provides valuable insights into the role of renewable energy in shaping Zambia's economic trajectory.

Results

Descriptive Statistics for Energy and Economic Variables

Table 1 presents descriptive statistics for the variables under study, providing a comprehensive overview of their central tendencies, dispersion and distribution characteristics.

Table 1. Descriptive Statistics for Energy and Economic Variables

	Renewable energy share of electricity generation (%)	Access to electricity, rural (% of rural population)	Renewable energy consumption (% of total final energy consumption)	Access to electricity (% of population)	Access to clean fuels and technologies for cooking (% of population)	GDP (current US$ Million)	GDP growth (annual %)
N	23	23	23	23	23	23	23
Mean	96.0	7.70	83.4	29.5	14.0	17518	5.47
Median	99.8	7.40	87.9	27.9	14.6	20266	5.32
Standard deviation	5.95	4.46	18.4	9.96	2.21	8622	2.81
Skewness	-1.23	0.263	-4.64	0.552	-1.06	-0.454	-0.956
Std. error skewness	0.481	0.481	0.481	0.481	0.481	0.481	0.481

The share of renewable energy in electricity generation has a mean of 96.0% and a median of 99.8%, indicating a high average share with a slight skew toward higher values. The standard deviation of 5.95% reflects moderate variability in the data. Access to electricity, rural has a mean of 7.70% and a median of 7.40%, with a standard deviation of 4.46%, indicating variability in rural access to electricity. Renewable energy consumption has a mean of 83.4% and a median of 87.9%, with a large standard deviation of 18.4%, reflecting considerable variation. Access to electricity has a mean of 29.5% and a median of 27.9%, with a standard deviation of 9.96%, indicating moderate variability. The minimum is 16.7% and the maximum is 47.8%. Access to clean cooking fuels and technologies has a mean of 14.0%, a median of 14.6%, and a standard deviation of 2.21%, indicating relatively low variability. GDP has a mean of 17,518 and a median of 20,266, with a standard deviation of 8,622, showing considerable dispersion in economic size. GDP growth has a mean of 5.47% and a median of 5.32%, with a standard deviation of 2.81%, reflecting variability in growth rates.

Correlation Matrix for Energy and Economic Variables

The correlation matrix in Table 2 provides insight into the relationships between various economic and energy-related variables.

Each correlation coefficient is accompanied by its statistical significance to indicate the strength and reliability of these relationships.

Table 2. Correlation Matrix for Energy and Economic Variables

		GDP (current US$ Million)	GDP growth (annual %)	Renewable energy share of electricity generation (%)	Access to electricity, rural (% of rural population)	Renewable energy consumption (% of total final energy consumption)	Access to electricity (% of population)	Access to clean fuels and technologies for cooking (% of population)
GDP (current US Million)	Pearson's r	—						
	df	—						
	p-value	—						
	Spearman's rho	—						
	df	—						
	p-value	—						
GDP growth (annual %)	Pearson's r	-0.183	—					
	df	21	—					
	p-value	0.404	—					
	Spearman's rho	-0.258	—					
	df	21	—					
	p-value	0.234	—					
Renewable energy share of electricity generation (%)	Pearson's r	-0.505 *	0.678 ***	—				
	df	21	21	—				
	p-value	0.014	< .001	—				
	Spearman's rho	-0.326	0.813 ***	—				
	df	21	21	—				
	p-value	0.129	< .001	—				
Renewable energy consumption (% of total final energy consumption)	Pearson's r	-0.395	0.090	0.344	-0.421 *	—		
	df	21	21	21	21	—		
	p-value	0.062	0.685	0.108	0.045	—		
	Spearman's rho	-0.816 ***	0.467 *	0.637 **	-0.724 ***	—		
	df	21	21	21	21	—		
	p-value	< .001	0.025	0.001	< .001	—		
Access to electricity (% of population)	Pearson's r	0.732 ***	-0.535 **	-0.859 ***	0.943 ***	-0.506 *	—	
	df	21	21	21	21	21	—	
	p-value	< .001	0.009	< .001	< .001	0.014	—	
	Spearman's rho	0.793 ***	-0.458 *	-0.609 **	0.916 ***	-0.873 ***	—	
	df	21	21	21	21	21	—	
	p-value	< .001	0.028	0.002	< .001	< .001	—	

Access to clean fuels and technologies for cooking (% of population)	Pearson's r	-0.381	0.648 ***	0.838 ***	-0.758 ***	0.571 **	-0.847 ***	—
	df	21	21	21	21	21	21	—
	p-value	0.073	< .001	< .001	< .001	0.004	< .001	—
	Spearman's rho	-0.343	0.807 ***	0.917 ***	-0.575 **	0.652 ***	-0.628 **	—
	df	21	21	21	21	21	21	—
	p-value	0.110	< .001	< .001	0.004	< .001	0.001	—

Note. * p < .05, ** p < .01, *** p < .001

GDP shows a negative, though insignificant, correlation with GDP growth (annual %), suggesting a possible weak inverse relationship between the size of the economy and its growth rate. This pattern is also evident in the Spearman's rho values, although both measures do not reach statistical significance.

GDP growth shows a moderate negative correlation with the share of renewable energy in electricity generation, suggesting that higher GDP growth is associated with a lower share of renewable energy in electricity generation. This correlation is statistically significant with a Pearson's r of -0.505 and a p-value of 0.014. Similarly, the Spearman's rho of -0.326, although not significant, supports this finding. The correlation with access to electricity, rural is negative and significant (Pearson's r = -0.464, p = 0.026), while its relationship with renewable energy consumption is also negative but only marginally significant (Pearson's r = -0.421, p = 0.045).

The share of renewable energy in electricity generation shows a significant positive correlation with access to electricity, rural (Pearson's r = -0.819, p < 0.001), indicating that increased renewable energy generation is associated with improved access to electricity in rural areas. This is further supported by a strong Spearman's rho of -0.518 with p = 0.011. The share of renewable energy is also positively correlated with renewable energy consumption (Pearson's r = 0.344, p = 0.108), although this result is not statistically significant.

Access to electricity, rural shows significant positive correlations with both access to electricity (Pearson's $r = 0.943$, $p < 0.001$) and access to clean cooking fuels and technologies (Pearson's $r = 0.571$, $p = 0.004$). This suggests that improvements in rural access to electricity are strongly associated with improved overall access to electricity and increased use of clean cooking technologies. The Spearman's rho for access to electricity, rural is also significant with access to electricity ($\rho = 0.916$, $p < 0.001$), reinforcing these findings.

Renewable energy consumption is negatively correlated with GDP (Pearson's $r = -0.395$, $p = 0.062$) and positively correlated with the share of renewable energy in electricity generation (%) (Pearson's $r = 0.344$, $p = 0.108$). It is significantly negatively correlated with access to electricity, rural (Pearson's $r = -0.421$, $p = 0.045$), suggesting that higher renewable energy consumption may be associated with lower access to electricity in rural areas.

Access to electricity shows a robust positive correlation with both the share of renewable energy in electricity generation (Pearson's $r = -0.859$, $p < 0.001$) and access to clean cooking fuels and technologies (Pearson's $r = -0.847$, $p < 0.001$). This indicates that broader access to electricity is strongly associated with higher use of renewable energy and better access to clean cooking technologies. The Spearman's rho values are also significant, reinforcing these relationships.

Finally, access to clean cooking fuels and technologies has a significant positive correlation with access to electricity (Pearson's $r = 0.571$, $p = 0.004$), suggesting that better access to clean cooking technologies is associated with better overall access to electricity. The Spearman's rho for this variable is also significant with access to clean cooking fuels and technologies ($\rho = -0.628$, $p = 0.001$).

Overall, these correlations provide a nuanced view of how economic and energy variables interact, revealing several significant associations that can inform further analysis and interpretation.

Table 3. Model Fit Measures

				Overall Model Test			
Model	R	R^2	Adjusted R^2	F	df1	df2	p
1	0.737	0.544	0.442	5.36	4	18	0.005

The omnibus ANOVA test shown in Table 4 evaluates the significance of each predictor in the model. For access to electricity, rural, the sum of squares is 1.168 with an F-value of 0.265 and a p-value of 0.613, indicating that this predictor is not statistically significant in explaining the variance in the dependent variable. Renewable energy consumption has a sum of squares of 21.133 with an F-value of 4.799 and a p-value of 0.042, indicating that it contributes significantly to the model. Access to electricity has a sum of squares of 0.762 with an F-value of 0.173 and a p-value of 0.682, indicating non-significance. Finally, access to clean fuels and technologies for cooking has a sum of squares of 32.529 with an F-value of 7.387 and a p-value of 0.014, which is significant.

Table 4. Omnibus ANOVA Test

	Sum of Squares	df	Mean Square	F	p
Access to electricity, rural (% of rural population)	1.168	1	1.168	0.265	0.613
Renewable energy consumption (% of total final energy consumption)	21.133	1	21.133	4.799	0.042
Access to electricity (% of population)	0.762	1	0.762	0.173	0.682
Access to clean fuels and technologies for cooking (% of population)	32.529	1	32.529	7.387	0.014
Residuals	79.266	18	4.404		

Note. Type 3 sum of squares

The model coefficients shown in Table 5 provide estimates of the impact of each predictor on GDP growth. The intercept has an estimate of -3.7430 with a standard error of 8.3380, yielding a t-value of -0.449 and a p-value of 0.659, indicating that the intercept is not significantly different from zero. Access to electricity, rural has an estimate of 0.1607 with a standard error of 0.3120, yielding a t-value of 0.515 and a p-value of 0.613, indicating non-significance. Renewable energy consumption has an estimate of -0.0657 with a standard error of 0.0300, a t-value of -2.191 and a p-value of 0.042, which is statistically significant and indicates a negative relationship with GDP growth. Access to electricity has an estimate of -0.0713 with a standard error of 0.1714, a t-value of -0.416 and a p-value of 0.682, which is not significant. Access to clean cooking fuels and technologies has an estimate of 1.1113 with a standard error of 0.4089, yielding a t-value of 2.718 and a p-value of 0.014, indicating a significant positive impact on GDP growth.

Table 5. Model Coefficients - GDP growth (annual %)

Predictor	Estimate	SE	t	p	Stand. Estimate
Intercept	-3.7430	8.3380	-0.449	0.659	
Access to electricity, rural (% of rural population)	0.1607	0.3120	0.515	0.613	0.255
Renewable energy consumption (% of total final energy consumption)	-0.0657	0.0300	-2.191	0.042	-0.429
Access to electricity (% of population)	-0.0713	0.1714	-0.416	0.682	-0.253
Access to clean fuels and technologies for cooking (% of population)	1.1113	0.4089	2.718	0.014	0.872

Assumption Checks

The Durbin-Watson autocorrelation statistic is 2.42 with a p-value of 0.706, indicating that there is no significant autocorrelation in the residuals. This suggests that the residuals are independent.

Table 6. Durbin–Watson Test for Autocorrelation

Autocorrelation	DW Statistic	p
-0.215	2.42	0.706

Normality Test (Shapiro-Wilk)

The Shapiro-Wilk test statistic is 0.914 with a p-value of 0.050, indicating that the residuals are approximately normally distributed with some variation.

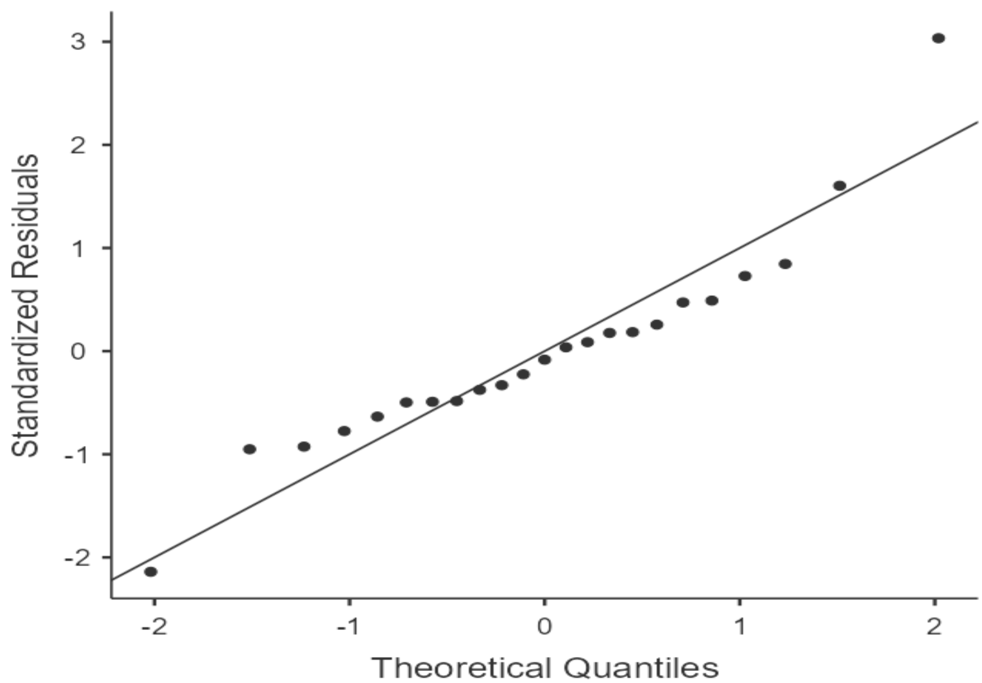
Table 7. Normality Test (Shapiro-Wilk)

Statistic	p
0.914	0.050

Q-Q Plot and Residuals Plots

The Q-Q plot and residuals plots are used to visually inspect the normality and homoscedasticity of the residuals. Figure 1 below shows that the assumptions of normality and constant variance are met in the regression analysis.

Figure 1. Q-Q Plot



Regression Analysis for GDP and Energy Variable

The regression analysis in Table 8 shows a strong model fit with an R value of 0.919. This high R value indicates a very strong correlation between the predictors and the dependent variable. The R^2 value of 0.844 indicates that approximately 84.4% of the variance in the dependent variable is explained by the model, which is a substantial proportion. The adjusted R^2 of 0.798, which takes into account the number of predictors in the model, reinforces this strong explanatory power. The F-statistic of 18.4, with degrees of freedom 5 and 17, and a p-value of less than 0.001, confirms that the overall model is statistically significant.

Table 8. Model Fit Measures

				Overall Model Test			
Model	**R**	**R^2**	**Adjusted R^2**	**F**	**df1**	**df2**	**p**
1	0.919	0.844	0.798	18.4	5	17	< .001

The omnibus ANOVA test, shown in Table 9, evaluates the significance of each predictor in the regression model. For the share of renewable energy in electricity generation, the F value is 0.139 and the p-value is 0.714, indicating that this predictor does not contribute significantly to the model. Access to electricity, rural has an F-value of 7.947 and a p-value of 0.012, indicating that it is a significant predictor. Renewable energy consumption has an F-value of 2.302 and a p-value of 0.148, indicating that it does not contribute significantly to the model. Access to electricity has an F-value of 37.387 and a p-value of less than 0.001, indicating a highly significant impact. Access to clean fuels and technologies for cooking has an F-value of 23.866 and a p-value of less than 0.001, indicating a significant contribution to the model.

Table 9. Omnibus ANOVA Test

	Sum of Squares	**df**	**Mean Square**	**F**	**p**
Renewable energy share of electricity generation (%)	2.08e+6	1	2.08e+6	0.139	0.714
Access to electricity, rural (% of rural population)	1.19e+8	1	1.19e+8	7.947	0.012
Renewable energy consumption (% of total final energy consumption)	3.45e+7	1	3.45e+7	2.302	0.148
Access to electricity (% of population)	5.61e+8	1	5.61e+8	37.387	< .001
Access to clean fuels and technologies for cooking (% of population)	3.58e+8	1	3.58e+8	23.866	< .001
Residuals	2.55e+8	17	1.50e+7		

Note. Type 3 sum of squares

The coefficients for the predictors in Table 10 provide insight into their impact on GDP. The intercept is estimated at -69,493.2 with a standard error of 33,019.8, yielding a t-value of -2.105 and a p-value of 0.051, indicating that the intercept is almost significant. The share of renewable energy in electricity generation has an estimate of -120.6 with a standard error of 323.9, yielding a t-value of -0.372 and a p-value of 0.714, indicating no significant effect. Access to electricity, rural shows an estimate of -1,635.7 with a standard error of 580.2, resulting in a t-value of -2.819 and a p-value of 0.012, indicating a significant negative impact on GDP. Renewable energy consumption has an estimate of -90.3 with a standard error of 59.5, yielding a t-value of -1.517 and a p-value of 0.148, indicating no significant impact. Access to electricity has an estimate of 1,984.0 with a standard error of 324.5, yielding a t-value of 6.114 and a p-value of less than 0.001, indicating a significant positive effect on GDP. Finally, access to clean cooking fuels and technologies has an estimate of 4,304.2 with a standard error of 881.1, yielding a t-value of 4,885 and a p-value of less than 0.001, indicating a significant positive impact.

Table 10. Model Coefficients - GDP (current US$ Million)

Predictor	Estimate	SE	t	p	Stand. Estimate
Intercept	-69493.2	33019.8	-2.105	0.051	
Renewable energy share of electricity generation (%)	-120.6	323.9	-0.372	0.714	-0.0832
Access to electricity, rural (% of rural population)	-1635.7	580.2	-2.819	0.012	-0.8453
Renewable energy consumption (% of total final energy consumption)	-90.3	59.5	-1.517	0.148	-0.1924
Access to electricity (% of population)	1984.0	324.5	6.114	< .001	2.2927
Access to clean fuels and technologies for cooking (% of population)	4304.2	881.1	4.885	< .001	1.1008

Normality Test (Shapiro-Wilk)

The Shapiro-Wilk test statistic is 0.968 with a p-value of 0.647, suggesting that the residuals are approximately normally distributed.

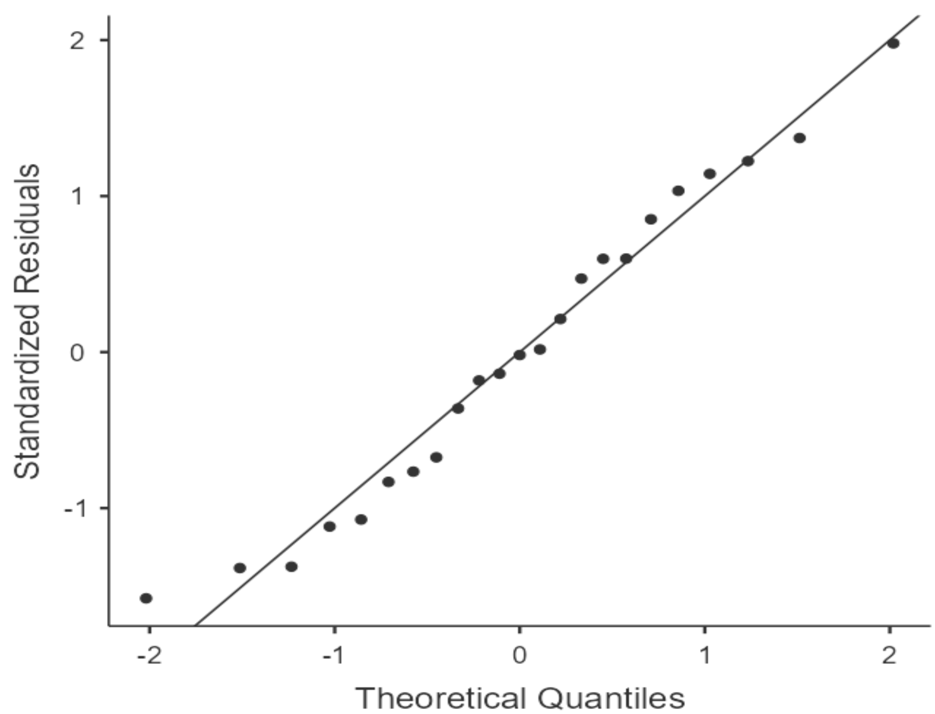
Table 11. Normality Test (Shapiro-Wilk)

Statistic	p
0.968	0.647

Q-Q Plot and Residuals Plots

The Q-Q plot and residuals plots are used to visually inspect the normality and homoscedasticity of the residuals. Figure 2 below shows that the assumptions of normality and constant variance are met in the regression analysis.

Figure 2. Q-Q Plot



Discussion

The descriptive statistics show significant variation in the energy and economic variables studied, consistent with findings from previous research. The mean share of renewable energy in electricity generation in Zambia is remarkably high at 96.0%, with a median of 99.8%. This high share is consistent with Bhattacharya et al. (2016), who found that top renewable energy consuming countries generally have high shares of renewable energy.

Access to electricity in rural areas, with a mean of 7.70% and a large standard deviation of 4.46%, highlights the significant challenges in extending electricity services to rural populations. This finding is in line with Chishimba (2022) who noted similar challenges in Zambia’s rural electrification efforts. Low access to clean cooking fuels and technologies, with a mean of 14.0% and minimal variability, reflects a consistent problem of limited availability across regions, echoing the findings of Nyoni and Odhiambo (2022) that rural areas face broad infrastructure challenges.

The correlation analysis reveals several noteworthy relationships between the variables, which are consistent with and contrary to the existing literature. The significant negative correlation between GDP growth and the share of renewable energy in electricity generation (Pearson’s $r = -0.505$, $p = 0.014$) suggests that higher GDP growth is associated with a lower share of renewable energy. This finding contrasts with studies such as Ahmed and Shimada (2019) and Bhattacharya et al. (2016), which highlight the positive impact of renewable energy on economic growth. The negative correlation may suggest that rapid economic development in Zambia may rely more on traditional energy sources, or that the benefits of renewable energy deployment are not yet fully reflected in growth metrics.

Similarly, the negative correlation between GDP growth and rural access to electricity (Pearson's r = -0.464, p = 0.026) suggests that areas with higher economic growth may see less improvement in rural electrification. This finding is consistent with literature indicating an uneven distribution of economic benefits (Muazu et al., 2023), suggesting that economic growth may not translate into equitable infrastructure development.

On the other hand, the strong positive correlation between the share of renewable energy in electricity generation and access to electricity in rural areas (Pearson's r = -0.819, p < 0.001) supports the idea that investment in renewable energy infrastructure can promote rural electrification, consistent with the findings of Stritzke and Jain (2021) that renewable energy can facilitate broader access to electricity. The positive correlation between rural electricity access and access to clean cooking fuels and technologies (Pearson's r = 0.571, p = 0.004) also supports the idea that improvements in electrification are associated with increased access to clean cooking solutions, consistent with Nyoni and Odhiambo (2022).

The regression analysis provides several key insights into the impact of energy variables on economic performance. The negative impact of renewable energy consumption on GDP growth (β = -0.0657, p = 0.042) suggests that while renewable energy is critical for sustainability, its short-term impact on economic growth may be limited. This result is consistent with the findings of Ocal and Aslan (2013), but somewhat at odds with studies such as Saidi and Omri (2020) and Zafar et al. (2019) which found positive effects of renewable energy on growth, suggesting potential transitional or investment-related challenges.

Conversely, the significant positive effect of access to clean cooking fuels and technologies on GDP growth (β = 1.1113, p = 0.014) is consistent with literature suggesting that improvements in health and productivity through clean cooking technologies can boost economic performance (Shahbaz et al., 2020). This underscores the importance of addressing health and productivity issues through improved access to clean technologies, which is supported by empirical studies.

The regression analysis for GDP (current US$ million) shows that both access to electricity (% of population) and access to clean cooking fuels and technologies have significant positive impacts on GDP (β = 1,984.0, $p < 0.001$; β = 4,304.2, $p < 0.001$, respectively). These results underscore the importance of improving access to these basic services, which are critical for improving economic performance, in line with the findings of Bhattacharya et al. (2016) and Muazu et al. (2023).

In contrast, the share of renewable energy in electricity generation does not show a significant impact on GDP (β = -120.6, $p = 0.714$), suggesting that while renewable energy is crucial for sustainable development, its direct impact on the size of GDP may be less pronounced in the short run. This finding contrasts with studies that indicate that renewable energy can significantly contribute to economic growth (Crafts & Woltjer, 2021; Vlahinić & Zikovic, 2010).

The study of energy and economic variables in Zambia reveals complex relationships that are both consistent with and challenge existing literature. While renewable energy and access to clean cooking technologies positively influence GDP, the role of renewable energy consumption on GDP growth appears less straightforward, possibly due to transitional challenges. These findings underscore the need for targeted policies that promote sustainable energy development while addressing infrastructural and economic disparities that affect rural electrification and access to clean technologies. Future research should explore the causal mechanisms behind these relationships in order to provide nuanced policy recommendations for improving both energy access and economic growth in Zambia.

Implications of the Study

This study provides important insights into the relationship between renewable energy variables and economic performance in Zambia. The analysis of data from 2000 to 2022 reveals a complex dynamic between renewable energy use and key economic indicators such as GDP and GDP growth. The findings suggest that while renewable energy consumption has a noticeable impact on Zambia's economic performance, the relationship is complex and multifaceted.

The study highlights that an increase in renewable energy consumption is associated with lower GDP growth in Zambia, which can be attributed to the economic costs associated with the transition to renewable energy sources. This finding suggests that while renewable energy is critical for sustainable development and environmental protection, its immediate economic benefits may not be as pronounced. This could be due to the transition period required for renewable energy investments to fully translate into economic growth, or to the higher initial costs associated with renewable technologies.

In addition, the positive impact of access to clean cooking fuels and technologies on GDP growth underscores the importance of improving energy access for economic development. Improved access to clean cooking technologies contributes to better health outcomes and increased productivity, which in turn can boost economic performance. This finding is consistent with the notion that improving energy infrastructure and access can have a direct positive impact on economic growth.

The study also shows a significant positive correlation between renewable energy generation and rural electricity access. This suggests that investments in renewable energy infrastructure can facilitate broader electrification efforts, which are critical to improving energy access in underserved regions. The positive relationship between rural electrification and access to clean cooking solutions further underscores the link between energy access and economic development.

Conclusion

This study has explored the intricate relationships between renewable energy variables and economic performance in Zambia, focusing on the period from 2000 to 2022. The findings reveal a complex interplay between renewable energy consumption, access to energy, and economic growth indicators such as GDP and GDP growth.

The analysis shows that while renewable energy consumption is critical for sustainable development, its impact on GDP growth in Zambia is nuanced. Increased renewable energy consumption is associated with lower GDP growth, possibly due to the higher initial costs and transitional challenges associated with the adoption of renewable technologies. This highlights the need for strategic investment and optimization of renewable energy projects to balance economic and environmental goals.

Conversely, improved access to clean cooking technologies was found to have a positive impact on GDP growth, demonstrating that better access to energy can improve productivity and economic performance. Similarly, the study highlights the important role of renewable energy in improving rural access to electricity, which is consistent with broader electrification goals and contributes to economic development.

These findings underscore the importance of a balanced approach to energy policy that considers both the immediate economic impact and the long-term benefits of renewable energy. The positive correlation between rural electrification and access to clean cooking solutions further supports the need for integrated energy policies that address multiple dimensions of energy access and economic development.

Recommendations

By implementing the recommendations outlined below, Zambia can better align its energy policies with its economic development goals and leverage renewable energy to drive sustainable growth while addressing the challenges it presents.

Optimize Investments in Renewable Energy

While renewable energy plays a critical role in sustainable development, policymakers should focus on optimizing investments in the sector to balance economic costs and benefits. This includes exploring cost-effective renewable technologies and improving efficiency to mitigate any negative impact on GDP growth.

Strengthen Rural Electrification Infrastructure

To address the significant challenges in rural energy access, there should be increased investment in renewable energy infrastructure specifically targeting off-grid and rural areas. Strengthening rural electrification can improve overall energy access and contribute positively to economic growth.

Promoting Access to Clean Cooking Technologies

Expanding access to clean cooking fuels and technologies should be a priority given its positive impact on GDP growth. Policies and programs that support the distribution and adoption of these technologies can lead to improved health outcomes and increased productivity.

Support Technological Progress

Investing in technological advancements in the renewable energy sector can drive economic growth. Encouraging innovation and the adoption of new technologies can help maximize the economic benefits of renewable energy while addressing potential transition challenges.

Address Governance and Policy Challenges

Effective governance and policy frameworks are essential to maximize the benefits of renewable energy. By addressing inefficiencies and improving institutional capacity, Zambia can better leverage its renewable energy resources for sustainable economic growth.

Limitations of the Study

While informative, this study has several limitations. The reliance on data from the World Bank and the International Renewable Energy Agency, though comprehensive, may not fully reflect the local variations and nuances of Zambia's energy and economic landscape. The temporal scope of the study, covering the period from 2000 to 2022, means that recent technological, policy and economic developments are not included in the analysis, which may affect the current relevance of the results. In addition, the regression models used, while providing valuable insights, may not capture all the variables that affect economic performance. The presence of unobserved factors or omitted variables could affect the results and limit their generalizability.

Future Recommended Studies

To address these limitations and extend the current findings, several areas for future research are recommended. First, incorporating more recent data and extending the time frame of the analysis could provide insights into how recent developments in technology and policy affect the relationship between renewable energy and economic performance. In addition, future studies should consider disaggregating the effects of different types of renewable energy, such as solar, wind, and biomass, to understand their individual contributions to economic development.

Examining local and regional variations within Zambia could also provide more detailed insights into how renewable energy impacts different areas, possibly through case studies or localized analyses. Exploring the role of technological advances in renewable energy and their impact on economic growth is another important area for future research, particularly in understanding how innovation drives productivity.

Finally, analyzing the impact of specific energy policies and international investments on Zambia's renewable energy sector could provide valuable information for designing more effective strategies for sustainable development. By addressing these areas, future research can provide deeper insights and more actionable recommendations for enhancing the role of renewable energy in promoting sustainable economic growth in Zambia and similar contexts.

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