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Finance-Renewable Energy Nexus: A Multidimensional Decomposition of Financial Development Approach

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This study uses the panel quantile regression (PQR) technique to examine the effects of different aspects of financial development (FD) on renewable energy consumption (REC) from 1995 to 2022 in selected SSA countries. The results indicate that various facets of FD influence REC across different quantiles. For example, institution-related variables have a more positive impact on REC compared to market indices.

I. Introduction

The transition to renewable energy is imperative for reducing global pollution and supporting sustained economic development (Akadiri et al., 2020; Shahbaz et al., 2022). This urgency is particularly critical for Sub-Saharan Africa (SSA), a region highly vulnerable to climate change effects such as droughts and extreme weather conditions (IMF, 2022). Although SSA contributes only a minor fraction of global CO₂ emissions, it remains among the most susceptible to climate change impacts due to several factors. These include limited adaptive capacity, reliance on climate-sensitive sectors such as agriculture, and socio-economic challenges like poverty and infrastructure deficits (Acheampong et al., 2019). These vulnerabilities heighten the region's susceptibility to adverse climate impacts, making the recent increase in emissions a pressing concern (Baye et al., 2021).

Despite growing interest in renewable energy sources, SSA faces numerous challenges in implementing renewable energy initiatives. Key obstacles include high initial capital investment, complex legal requirements, and gaps in local specialized skills specific to renewable energy technologies, notwithstanding the broader diaspora of skilled professionals (Alagidede et al., 2016; Shahbaz et al., 2021; Zhang & Da, 2015). In this context, financial development (FD) holds promise, with the potential to mitigate these challenges by enhancing access to capital. However, traditional measures of FD, such as credit availability and stock market capitalization, may not fully capture how FD influences renewable energy consumption (REC). These conventional metrics of-

ten overlook aspects such as the efficiency of green financing options, the role of financial depth, and the readiness of financial systems to support long-term investments in renewable energy. This gap suggests a need for more comprehensive measures of FD that account for its specific impact on REC (Habiba & Xinbang, 2023).

Unlike prior research that focuses on particular segments of FD and other less affected emerging economies, this study broadens the scope to include SSA and offers unique and valuable policy implications for policymakers. Therefore, this research significantly contributes to the existing literature and policy discussions on the finance-energy nexus by employing advanced statistical techniques and an extensive FD index. It provides policy recommendations for enhancing renewable energy initiatives in SSA, thus addressing a crucial gap in the current understanding of the subject (Dimnwobi et al., 2022; Yu et al., 2022).

The reminder of the paper is structured as follows. Section II discusses data and methodology used in this study. Empirical findings are discussed in Section III followed by concluding remarks in final section.

II. Data and Methodology

A. Data

The research, covering the period from 1995 to 2022, investigates the relationship between FD components and REC in four SSA countries: South Africa, Nigeria, Kenya, and Ghana. These countries were chosen due to their economic importance, renewable energy initiatives, and the

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availability of comprehensive data. South Africa and Nigeria are among the region's largest economies, while Kenya and Ghana have made significant advancements in renewable energy adoption.

In theory, the STIRPAT model, introduced by Dietz and Rosa (1997), is a stochastic regression extension of the IPAT model that looks like this:

$$I = \alpha P^{\beta_1} A^{\beta_2} T^{\beta_3} e \quad (1)$$

where α is a constant term, β_1 , β_2 , and β_3 are the exponential terms for P , A , and T , and e is the error term. Both sides of Equation (1) are then log-transformed as follows:

$$\ln I = \ln \alpha + \beta_1 \ln P + \beta_2 \ln A + \beta_3 \ln T + e \quad (2)$$

where $\ln \alpha$ is denoted as a constant term but is modified to β_0 in the log-transformed form presented in Equation (3). Subsequently, the model is adjusted to analyze Renewable Energy Consumption (REC) in Sub-Saharan Africa, utilizing financial development (OFDI) and its components, economic growth (GDP), ICT development, and population as explanatory variables:

$$REC_{it} = \beta_0 + \beta_1 OFDI_{it} + \beta_2 GDP_{it} + \beta_3 ICT_{it} + \beta_4 POP_{it} + \mu_{it} + \gamma_{it} + \varepsilon_{it} \quad (3)$$

where REC denotes renewable energy consumption, β_0 through β_4 represent parameters to be estimated for the constant and each of the explanatory variables. The $OFDI$ ¹ is an index of overall financial development. GDP depicts economic growth, ICT stands for information and communication technology, and POP represents the population. μ_{it} represents an unknown country-specific factor while γ_{it} is an unknown year specific. Finally, ε_{it} is the error term. Each model is constructed for every segment of financial development to avoid multicollinearity.

We initially estimated using the panel-correlated standard errors (PCSE) and feasible generalized least squares (FGLS). However, since PCSE and FGLS are limited to using only the dependent variable's conditional mean, we re-estimated the equations utilizing the panel quantile regression technique, known as panel quantile regression (PQR). Quantile analysis is a statistical tool that provides insightful information regarding the dispersion of the outcome variable. This method fits a regression line using the conditional quantiles of a distribution (Koenker & Bassett, 1978; Koenker & Hallock, 2001). Through this approach, it is possible to examine the conditional quantile function of the panel data concerning the specified econometric model.

$$Qy_{it}(\tau x_{it}) = i_{it}\beta(\tau) + \alpha_i + \varepsilon_{it} \quad (4)$$

where $Qy_{it}(\tau x_{it})$ indicates the τ th quantile of the outcome variable; i_{it} signifies the vector of independent variables; α_i is the individual effect; τ is the quantile; $\beta(\tau)$ refers to the regression parameter for the τ th quantile.²

III. Empirical Results

The dataset exhibits a range of characteristics across the variables as shown in Table 1. However, according to the Jarque-Bera test, the probability values indicate that all series follow normal distributions except for the financial institution efficiency index (FIEI) series.

Furthermore, results reported in Panel A of Table 2 provide sufficient evidence to reject the null hypothesis, indicating cross-sectional dependence among the cross-sectional units. The P-values are less than 0.05 at a 1% level of significance. Thus, the economic activities of one country can influence the economic conditions of other countries, indicating the presence of cross-dependence in the market. As a result, the second-generation unit root test was conducted. The results presented in Panel B demonstrate that all series achieved stationarity only at I (1). Consequently, the second-generation cointegration test results reported in Table 3 indicates that the null hypothesis of no cointegration among the models should be rejected.

Panel A of Table 2 shows enough evidence to reject the null hypothesis, indicating cross-sectional dependence among units.

The regression results of FD components and REC at the 20th, 50th, and 75th quantiles are reported in Panel A of Table 4. At the 20th quantile, $OFDI$ has a coefficient of 0.55, indicating a positive impact on REC , while overall financial institution index (OFII), financial institution depth index (FIDI), financial institution access index (FIAI), financial institution efficiency index (FIEI), and financial market depth index (FMDI) also show positive impacts. As the quantiles increase, these coefficients decrease, and at the 50th quantile, only overall financial development index (OFDI), overall financial market index (OFMI), overall financial institution index (OFII), and financial market depth index (FMDI) remain significant. At the 75th quantile, the coefficients for variables such as OFMI and FMDI are still statistically significant, whereas other variables like OFII, FIDI, FIAI, FIEI, and financial market access index (FMAI) are not. The PCSE and FGLS results reported in Panel B of Table 2 support the findings of the quantile regression, showing that the coefficients of financial institution indexes are larger than those of the financial market variables. These results are consistent with studies by Kim and Park (2016) and Habiba and Xinbang (2023), as well as the IPAT hypothesis, which highlights the role of technology and finance in mitigating environmental impact. The results suggest that financial development plays a significant role in explaining renewable energy consumption, particularly at lower consumption levels. However, the effects of financial components diminish as consumption increases, implying that other factors may become more important at higher levels of consumption. This aligns with the IPAT hypothesis, which posits that environmental impact equals population multi-

¹ Equation (3) was replicated for the other eight indexes of FD . Also, nine separate models are estimated to avoid multicollinearity.

² See Koenke and Bassett (1978) for details of the model.

Table 1. Descriptive Statistics

Statistic	REC	OFDI	FIAI	FIDI	FIEI	OFII	FMAI	FMDI	OFMI	FMEI	GDP	ICT	POP
Mean	57.27	0.24	0.13	0.21	0.52	0.28	0.22	0.19	0.19	0.15	2611.32	59.69	68553412.00
Median	72.23	0.18	0.10	0.12	0.50	0.22	0.18	0.07	0.17	0.10	1721.96	58.83	47445610.00
Max.	88.68	0.59	0.42	0.65	0.75	0.63	0.50	0.78	0.54	0.51	6263.10	168.92	0.00
Min.	7.720	0.09	0.03	0.02	0.30	0.13	0.00	0.01	0.53	0.00	931.19	0.01	17438874.00
Std. D.	29.43	0.15	0.11	0.21	0.09	0.15	0.18	0.24	0.86	0.12	1801.91	52.97	55509462.00
Skew.	-0.69	1.21	1.53	1.08	0.02	1.18	0.29	1.33	0.90	1.16	1.08	0.39	1.32
Kurt.	1.84	2.97	4.46	2.60	2.36	2.98	1.64	3.05	2.52	3.14	2.57	1.91	3.41
JB	15.29	27.27	53.48	22.66	1.91	26.0	10.23	33.15	16.30	25.59	22.92	8.49	33.77
Prob.	0.00	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00

Note: REC denotes renewable energy consumption, *OFDI* means overall financial development index, *FIAI* stands for financial institution access index, *FIDI* is for financial institution depth index, *FIEI* connotes financial institution efficiency index, *OFII* means overall financial institution index, *FMAI* is financial market access index, *FMDI* denotes financial market depth index, *OFMI* stands for overall financial market index, *FMEI* is financial market efficiency index, *GDP* is gross domestic product, *ICT* is information and communication technology, and *POP* means population.

Table 2. Cross-sectional dependence and stationarity tests

Panel A: Cross-sectional dependence		Panel B: Im-Pesaran-Shin unit root test	
Variable	Breusch-Pagan LM	Level	1 st Difference
REC	-1.06***	-0.2154	-3.4145***
OFDI	8.77***	-0.6008	-3.4365***
FIAI	10.82***	2.0321	-2.8495***
FIDI	12.44***	1.2556	-3.8727***
FIEI	12.71***	-1.3346	-3.7662***
OFII	11.26***	1.4323	-3.6157***
FMAI	10.37***	-1.7793	-3.5123***
FMDI	0.93***	-1.4699	-3.6582***
FMEI	9.97***	-2.4430	-3.6582***
OFMI	3.25***	-2.1891	-3.5023***
GDP	4.75***	-0.0778	-2.9543***
ICT	5.03***	0.3043	-2.9364***
POP	5.51***	3.4186	-2.6620***

Note: Panel A: Results of the Breusch-Pagan, Lagrange Multiplier (LM) test for cross-sectional dependence.

Panel B: Results of the Im-Pesaran-Shin (IPS) unit root test for stationarity.

*** signifiers p-value < 0.01

Table 3. Kao test for cointegration

AR parameter	Statistics (OFDI)	Statistics (FIAI)	Statistics (FIDI)	Statistics (FIEI)	Statistics (OFII)
MDF	-10.7264***	-8.7777***	-10.0581***	-8.6573***	-9.0402***
DF	-9.2584***	-7.3128***	-8.4905***	-7.0673***	-7.4260***
ADF	-4.5303***	-3.0547***	-4.1075***	-3.0802***	-3.3779***
UMDF	-15.1922***	-12.8050***	-14.3170***	-12.3280***	-12.8951***
UDF	-9.7064***	-7.8217***	-8.9510***	-7.5265***	-7.8900***
AR parameter	Statistics (FMAI)	Statistics (FIAI)	Statistics (FMEI)	Statistics (OFMI)	
MDF	-8.9385***	-10.7038***	-8.5121***	-10.7939***	
DF	-7.4300***	-9.2048***	-7.2854***	-9.4244***	
ADF	-3.3400***	-4.4642***	-2.9011***	-4.5033***	
UMDF	-12.8721***	-15.1217***	-12.7846***	-15.3502***	
UDF	-7.9124***	-9.6476***	-7.8539***	-9.8805***	

Note: MDF stands for Modified Dickey-Fuller, DF refers to Dickey-Fuller, ADF denotes Augmented Dickey-Fuller, UMDF signifies Unadjusted Modified Dickey-Fuller, and UDF is an acronym for Unadjusted Dickey-Fuller. The notation *** indicates significance at the 1% level.

plied by affluence multiplied by technology, with financial development facilitating technological advancements in renewable energy technologies.

IV. Conclusion

This paper investigates the influence of nine dimensions of financial development (FD) on renewable energy consumption (REC) in selected Sub-Saharan African (SSA) countries from 1995 to 2022. The findings indicate that institution-based indices within FD positively affect REC. The presence of well-developed financial institutions and a robust financial structure are among the factors that contribute to the utilization of renewable energy. Conversely, market-based indices yield mixed results and are not con-

sistently statistically significant. Although Financial Market Efficiency Index (FMEI) and Financial Market Access Index (FMAI) exhibit a very weak positive correlation with renewable energy consumption, they receive partial support within the SSA context.

Policymakers should aim to increase the stability of the financial sector to enhance the use of renewable energy. It is important to expand and improve the accessibility of financial institutions. Encouraging banks to offer loans for renewable energy projects and enhancing financial solutions for such initiatives are effective measures. While the development of the financial market remains relevant, institution-based solutions have proven to be more effective. Therefore, a balanced policy approach is recommended.

Table 4. Robust panel quantile regression and contemporaneous correlation models

Panel A: Robust Panel Quantile Regression					
Variable	LOW (.20)		MEDIUM (.50)	HIGH (.75)	
OFDI	0.55***		0.51***	0.46**	
OFII	0.42***		0.21**	0.12	
FIDI	0.25***		0.07	0.01	
FIAI	0.52***		0.24	0.24	
FIEI	0.13**		0.01	-0.05	
OFMI	0.07		0.22***	0.25**	
FMAI	-.15***		0.01	-0.02	
FMDI	0.34***		0.27***	0.20*	
FMEI	0.02		0.01	0.16*	
Panel B: Contemporaneous Correlation Models					
Panel-Corrected Standard Errors (PCSE)			Feasible Generalized Least Squares (FGLS)		Diagnostics
Variable	Coefficient	Standard Error	Coefficient	Standard Error	Wald Test
OFDI	65.8738***	14.8313	63.48***	12.60	39***
OFII	35.9817***	10.5875	31.62***	11.58	20***
FIDI	18.7811***	7.1268	18.67***	6.286	20***
FIAI	36.7166***	17.7558	4.928	5.494	17***
FIEI	7.9769*	4.3404*	31.37***	9.291	20***
OFMI	29.9880***	9.7025	-2.000	3.658	22***
FMAI	-4.9044	9.7025	36.13***	7.627	15***
FMDI	34.9013***	9.6548	17.54***	5.689	28***
FMEI	14.9719***	5.3226	23.20***	8.418	21***

Note: Panel A shows results from the robust panel quantile regression across low (0.20), medium (0.50), and high (0.75) quantiles of the dependent variable. Panel B highlights the results from the contemporaneous correlation models using Panel-Corrected Standard Errors (PCSE) and Feasible Generalized Least Squares (FGLS). Significance levels: ***p-value < 0.01, **p < 0.05, *p < 0.10.

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