




Quantile relationship between financial development, income, price, CO₂ emissions and renewable energy consumption: evidence from Nigeria

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Abstract

One of the solutions to climate change is the adoption and use of renewable energy sources. This understanding has driven Nigerian stakeholders to set a goal of achieving net-zero emissions by 2060. Capitalizing on the limitations of existing literature, this study employs a Quantile-on-Quantile (QQ) and quantile regression approach to investigate the impact of financial development on renewable energy consumption in Nigeria from 1960–2018. In addition, this research uses GDP per capita, energy price, and CO₂ emissions as moderating variables to eliminate omitted variable bias. The outcome of the QQ technique showed that financial development supplies mixed shocks (positive and negative) to renewable energy consumption. The negative shocks are highly negative. The quantile regression result also showed that financial development influences renewable energy consumption negatively at the lower quantile (0.10–0.20) and the upper quantile (0.80–0.90). The policy implications are discussed for Nigeria.

Keywords Financial development · Renewable energy consumption · Quantile-on-Quantile · Quantile regression · Nigeria

JEL Classification O13 · Q40

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1 Introduction

Greenhouse gases (GHGs) include carbon dioxide emissions (CO_2), methane emissions (CH_4), nitrous oxide emissions (N_2O), and fluorinated gases (EPA 2022). The largest contributor to GHGs is CO_2 emissions. According to Carbon Brief (2022), global CO_2 emissions increased by 0.8%, caused by land use and fossil fuel CO_2 emissions. This negatively affects the environment by increasing temperature, rising sea levels, and altering ecosystems.

Due to these negative impacts, discussions on the best strategy to achieve net-zero emissions are ongoing. One of the pathways being discussed is for economies to transit from fossil fuel to renewable energy consumption. For this to be achieved, financial commitments and investments are required, emphasizing the role of a well-developed financial system. Demirguc-Kunt (2006) remarked that stable economies are built on a well-functioning financial system. Abdulraheem et al. (2016) also mentioned that a developed financial system allows for an even distribution of economic opportunities amongst economic agents. The World Bank (2016) stated that financial development; (i) encourages capital accumulation and technological progress, (ii) contributes positively to long-term growth, (iii) can reduce poverty and inequality because it allows credit to be easily accessible to the poor and vulnerable and (iv) contributes to Small and Medium Size Enterprises (SMEs) growth by providing easy access to finance for business purposes.

Financial development allows for easy access to capital and loans, reduces borrowing costs, mitigates financial risks, facilitates transparency between creditors and debtors, encourages cross-border investments, and enables countries to adopt cutting-edge technology for environmentally friendly industries (Sadorsky 2010; Ulucak 2021; Abbasi et al. 2022; Awosusi et al. 2022). Each of these factors facilitates renewable energy consumption. On the other hand, due to easy access to capital and loans, financial development can also boost the use of fossil fuels, which increases CO_2 emissions. A rise in CO_2 emissions depicts that renewable energy use is declining.

Financial development can be divided into financial institutions and financial markets. Financial institutions include central banks, commercial banks, investment companies, insurance companies, brokerage companies, and mortgage companies. The financial market entails the stock market, bond market, and other commodities (Svirydzenka 2016). These components can be further split into depth, access, and efficiency. This study focuses on the depth of financial development.

In attaining the Sustainable Development Goals (SDG7&13), renewable energy consumption has always been deliberation (Antonakakis et al. 2017). This is because renewable energy can spur economic progress, lessen the damaging effect of fossil fuels, and give rise to sustainable development practices (Khare et al. 2016; Wang & Wang 2020). Li et al. (2021) opined that notable structural shifts in energy, trade, economy, and society have emerged due to renewable energy. In addition, Wang et al. (2022) stated that 68% of global GHGs come

from the energy sector, and fossil fuels contribute 44% to these emissions. Therefore, substituting fossil fuels for renewable energy sources can help solve climate change problems (Wang et al. 2023).

According to a report by IEA (2022), the global power mix will be transformed by using renewables, and it will become the biggest electricity source. In 2021, US\$366 billion was invested in renewables. More than 50% of climate mitigation finance is allotted to hydropower, solar PV, and wind power (REN21, 2022). Also, renewable energy increased by eight exajoules from 2019 to 2021 (BP 2022). This growth is attributed to policy support that is strong in China, European Union, and Latin America. Therefore, since funding is needed to combat climate change, it is paramount to continue investigating financial development's role in renewable energy consumption.

There needs to be more literature on how financial development impacts renewable energy consumption. More studies have focused on the financial development–energy consumption nexus. With this rationale, this research contributes to the existing literature in the following ways; (i) It uses a novel proxy for financial development, called domestic credit to the private sector by banks (% of GDP). This measures the financial depth and plays a major role in the stability of the Nigerian economy. Data from 1960–2020 showed that domestic credit to the private sector by banks in Nigeria averaged 12.31%, ranking the 121st position out of 131 countries. This is low compared to developed countries. The top countries are Hong Kong (258.45%), the USA (216.33%), and China (182.43%) (Global Economy 2020). (ii) It indirectly contributes to existing literature due to the inconclusive evidence of the financial development–renewable energy consumption nexus (Ozdeser et al. 2021; Shahbaz et al. 2021; Wang et al. 2021; Mukhtarov et al. 2022; Samour et al. 2022; Somoye et al. 2022; Jiakui et al. 2023). (iii) This paper incorporates some major determinants of renewable energy consumption, such as GDP per capita, energy price, and CO₂ emissions. (iv) Nigeria is used as a case study in this research because of its potential across different parameters. According to World Bank (2022), Nigeria has the highest GDP (US\$440.8 billion) and population size (211.4 million) among the Sub-Saharan African (SSA) countries. Nigeria has abundant renewable energy (solar, wind, biomass, and geothermal) and non-renewable energy sources (oil, gas, and coal). Nigeria is also one of the major oil players globally and is going through a series of energy crises in which renewable energy adoption can be a solution. (v) The quantile–on–quantile regression approach is employed in this study. Hung et al. (2022) explained that quantile–on–quantile regression has the advanced ability to combine quantile regression and non-parametric frameworks. It provides adequate information regarding the asymmetric impact of independent variables on the dependent variable across quantiles. In addition, it allows cross-dependence to be accessed between quantiles. This means that it is more policy informative than the mean–based estimation. (vi) The quantile regression approach is utilized as a robustness check for the quantile–on–quantile approach.

This study is organized as follows: The second section entails the literature review. The third section shows the theoretical framework, data, and methodology employed, while section four presents the empirical results. Section five concludes the study and recommends policies for implementation.

2 Literature review

This section examines the relationship between financial development, GDP per capita, energy price, CO₂ emissions, and renewable energy consumption.

2.1 Financial development (FDE) and renewable energy consumption

In 119 non-OECD countries, Brunnschweiler (2010) found a significant positive impact of financial intermediation (commercial banking activities) on renewable energy produced. Its impact can be seen in non-hydropower renewable energy sources such as wind, solar, geothermal, and biomass. The study also stated that the renewable energy sector has picked up significantly since adopting the Kyoto Protocol. In 55 global countries, Fangmin & Jun (2011) found that financial intermediation is necessary for renewable energy projects, especially hydropower projects. Kim & Park (2016) opined that the impact of financial development (FDE) on renewable energy (REN) is highly dependent on external financing. In the case of Russia, Burakov (2017) found no causality between FDE and REN. Steffen (2018) found that project finance is more viable for renewable energy projects than fossil fuel-based projects in the case of low investment risk situations. Shahbaz et al. (2018) found that FDE hinders REN.

In 22 OECD countries, Pham (2019) stated that FDE has a significant and positive impact on REN. The study further revealed that the effect of FDE on REN depends on carbon intensity and the growth rate of innovation. A more significant effect is seen in countries with higher carbon intensity and growth of innovation. In India, Eren et al. (2019) used a Principal Component Analysis (PCA) to group the FDE variables and found that FDE is essential for REN. In China, Ji & Zhang (2019) further explained that FDE is necessary for the country's renewable energy usage to increase. The study further stated that there is a need for effective policies for REN to grow while paying attention to the renewable energy development path of the European Union. In addition, the capital market variable contributes more to REN than other FDE variables.

Using stock market development (SMD), banking sector development (BSD), and bond market development (BMD) variables to proxy for financial development in 28 European Union (EU) countries, Anton and Nucu (2020) discovered that FDE is an essential condition for REN. Further results, however, showed that SMD does not affect REN in new member states of the EU. This is because the stock market is still developing in these new countries, which makes it lack the financial depth to contribute to REN. In 15 top renewable energy consumption countries, Raza et al. (2020) showed that FDE influences REN positively and negatively depending on the threshold. Mukhtarov et al. (2020) acknowledged that FDE is crucial for REN in Azerbaijan. Khan et al. (2020) discovered that FDE is necessary for developing renewable energy. The study further explained that a well-developed financial system provides the right incentives for renewable energy investments. Qamruzzaman & Jianguo (2020) also showed that FDE impacts REN positively.

Wang et al. (2021) found that FDE impacts REN positively in the short-run and negatively in the long-run. The factor contributing to the long-run negative effect is the higher financial costs that discourage investments in renewable energy. In the top 10 investment countries, Raghutla et al. (2021) discovered that SMD's impact on REN is negative. The study discovered that to promote and finance REN, FDI inflows and R&D are essential. In BRICS countries, Isiksal (2021) established that expanding the financial sector significantly contributes to renewable electricity production. Koksakal et al. (2021) found that FDE positively and significantly impacts REN. On the other hand, financial efficiency had no relationship with renewable energy demand. Saygin & Iskenderoglu (2021) found that the impact of FDE on REN depends on the FDE variable used. The banking sector variables have a negative impact, while the stock market variable has a positive impact. The research outcome of Shahbaz et al. (2021) also stated that FDE increases the demand for renewable.

2.2 GDP per capita (income) and renewable energy consumption

Omri and Nguyen (2014) studied 64 countries, dividing them into higher, middle, and lower-income countries. For higher and middle-income countries, income drives REN. However, for lower-income countries, income is statistically insignificant. Ergun et al. (2019) found a negative relationship between income and REN in African countries. Topcu & Tugcu (2020) explained that when there is a fair income distribution, REN will be impacted positively. The study further stated that when income inequality is reduced, it will increase people's ecological awareness, thereby increasing their economic concerns. This will contribute significantly to an increase in demand for a clean environment. The government can support or encourage this perspective through tax concessions and credit facilities for renewable energy investments.

Using a granger causality approach, Simionescu et al. (2020) found a positive relationship between income and REN. The study further stated that there is causality from income to REN, which implies that an increase in income enables people to consume more renewable energy sources. Iorember et al. (2020) revealed a unidirectional causality from GDP per capita to REN in Nigeria using the ARDL and VECM approach. Chen et al. (2021) explained that income increases REN in democratic countries, while in countries that are less democratic, there is a negative relationship between GDP per capita and REN. Shahbaz et al. (2021) argued that renewable energy consumption decreases as per capita income increases due to insufficient income.

2.3 Energy price (PRI) and renewable energy consumption

Asafu-Adjaye (2000) found a bidirectional causal relationship between PRI and energy consumption. Chang et al. (2009) found a positive relationship between PRI and REN in a higher economic growth regime. However, no relationship was found in a regime of lower economic growth. Using VAR and VECM methodologies,

Yuan et al. (2010) explained that an increase in PRI will reduce household energy consumption in the long-run and reduce energy consumption in the short-run in the Chinese industrial sector. Moreno et al. (2012) found a positive relationship between PRI and REN. Nayan et al. (2013) revealed that PRI is one of the major determinants of energy consumption. In Denmark, Munrad et al. (2019) stated that PRI impacts energy consumption negatively and significantly. PRI also granger causes energy consumption in Denmark. In high and lower-middle-income countries, Wang et al. (2019) opined that PRI impacts energy consumption negatively. For upper-middle-income countries, the impact is positive. Chen et al. (2021) used real oil prices to proxy for PRI and found that increasing oil prices increase renewable energy consumption in less democratic countries. However, there is no significant relationship in democratic countries. Shahbaz et al. (2021) found that PRI is insignificant in determining renewable energy consumption. Alsagr & Van-Hemmen (2021) found a positive relationship between PRI and REN.

2.4 CO₂ emissions and renewable energy consumption

Sardosky (2009) opined that CO₂ emissions increase REN in France & UK and decrease REN in Japan in the long-run. However, in the short-run, the interactions among the variables are statistically insignificant, which could be a result of a relatively short sample period. In 19 developed and developing countries, Apergis et al. (2010) showed that CO₂ emissions positively correlate with REN. Dogan & Ozturk (2017) explained that CO₂ emissions contribute to the degradation of the environment in the USA. Shafiei & Salim (2014) revealed that REN reduces CO₂ emissions in OECD countries. Using the Toda-Yamamoto causality approach, Menyah & Wolde-Rufae (2010) found a unidirectional causality moving from CO₂ emissions to REN. Jaforullah & King (2015) explained that an increase in REN mitigates CO₂ emissions. Using a VAR model, Kahia et al. (2016) found that the relationship between CO₂ emissions and REN is negative in both causal directions. Sharif et al. (2020) found mixed results (positive and negative) among the top 10 polluting emission countries. Chen et al. (2019) found unidirectional causality from CO₂ emissions to REN in the short-run. Using the Toda-Yamamoto causality approach, Kang et al. (2019) found no causality between CO₂ emissions and REN in India. Using the NARDL methodology, Toumi and Toumi (2019) found that positive and negative shocks of CO₂ emissions increase REN in the long-run, while in the short-run, a positive shock of CO₂ emissions decreases REN. Alola et al. (2019) also found a feedback relationship between CO₂ emissions and REN.

In summary, various studies have explored the connection among the chosen economic variables. However, they provide mixed evidence using diverse techniques, data, study periods, and countries. Also, limited literature dissects the role of financial development in renewable energy consumption. Therefore, this research unlocks a new discussion into the link among these economic variables. In addition, the literature reviewed has not incorporated the economic indicators for the case of Nigeria. Thus, this study fills the gap by utilizing the Quantile-on-Quantile and quantile regression approach for the Nigerian economy. The

findings of this study provide fresh insights, enhancing theoretical and empirical research in this area. Figure 1 and Table 1 show the graphical relationship between the variables and the literature review summary, respectively.

3 Theoretical framework, data, and methods

In line with Qamruzzaman & Jianguo (2020), the theoretical framework of this study is based on four major assumptions: the supply-leading hypothesis, the demand-following hypothesis, the feedback hypothesis, and the neutrality hypothesis. The supply-leading hypothesis states that a causal flow moves from FDE to REN. The demand-following hypothesis shows a movement from REN to FDE. The feedback hypothesis demonstrates a bidirectional relationship between FDE and REN. Lastly, the neutrality hypothesis shows no causal relationship between FDE and REN.

Sardosky (2010) expressed that income and price are major determinants of energy consumption. Mukhtarov et al. (2022) stated that market uncertainties occur when there is high inflation. This study proxy's energy prices with the consumer price index, a well-known indicator of inflation. All things being equal, a higher inflation rate leads to a decline in the purchasing power of consumers. Therefore, countries with high inflation rates will find it difficult to increase renewable energy consumption (Selmi et al. 2020).

Based on the Keynesian consumption function, there is a positive relationship between disposable income and consumption, with all other factors remaining constant. This means that as income increases, consumption also increases. Energy consumers will have more choices and capacity to use renewable energy as income increases. Based on the established theoretical viewpoint, the functional specification of this study is expressed as follows:

$$\text{REN} = f(\text{FDE}, \text{GDP}, \text{PRI}, \text{COE}) \quad (1)$$

where REN is renewable energy consumption; FDE is financial development; GDP is Gross Domestic Product per capita; PRI is energy prices proxied by the consumer price index and; COE is CO₂ emissions.

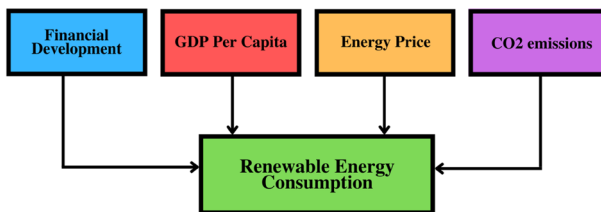


Fig. 1 Conceptual framework

Table 1 Summary of literature review

Author	Year	Countries	Methods	Outcome
Brunnschweiler (2010)	1980–2006	119 non-OECD	Generalized Least Square	FDE (+)
Fangmin & Jun (2011)	1980–2008	55 Global Financial	Fixed Effect	FDE (+)
Kim & Park (2016)	2000–2015	15 Developing & 15 Developed	Fixed Effect Model	FDE (+)
Burakov (2017)	1990–2014	Russia	VECM & Wald-Test	FDE (≠)
Shahbaz et al. (2018)	1992–2016	BRICS & Next-11	Panel Causality Analysis & CCEMG	FDE (-)
Pham (2019)	1990–2014	22 OECD	Wald-Test	FDE (+)
Eren et al. (2019)	1971–2015	India	DOLS & VECM Granger Causality	FDE (+)
Ji & Zhang (2019)	1992–2013	China	VAR	FDE (+)
Anton & Nucu (2020)	1990–2015	28 EU	Fixed Effect Model	FDE (+)
Raza et al. (2020)	1997–2017	15 Top Renewable Energy	PSTR	PRI (+)
Mukhtarov et al. (2020)	1993–2015	Azerbaijan	ARDL	FDE (+)
Khan et al. (2020)	1980–2015	192	Panel Quantile Regression	FDE (+)
Qamruzzaman & Jianguo (2020)	1990–2017	113	NARDL & System GMM	FDE (+)
Wang et al. (2021)	1997–2017	China	ARDL-PMG & Granger Causality	FDE (+)
Raghutla et al. (2021)	1996–2017	Top 10 Investment	FMOLS	FDE (-)
Isiksal (2021)	1995–2015	BRICS	MG, AMG, and CCEMG	FDE (+)
Koksal et al. (2021)	1990–2017	36 OECD	Systems GMM	FDE (+)
Saygin & Iskenderoglu (2021)	1990–2016	20 Emerging	Systems GMM	FDE (+)
Shahbaz et al. (2021)	1994–2015	34 Upper Middle Income Developing	FMOLS	FDE (+)
				PRI (≠)
				Income (-)

Table 1 (continued)

Author	Year	Countries	Methods	Outcome
Omri & Nguyen (2014)	1990–2011	64	GMM	Income (+) CO ₂ (+) PRI (-)
Ergun et al. (2019)	1990–2017	21 African	Fixed Effects	Income (-)
Topcu & Tugcu (2020)	2000–2015	43 Developed and Developing	ARDL–PMG	Income (+)
Simionescu et al. (2020)	2000–2017	EU 28	Granger Causality	Income (→)
Ioreंबर et al. (2020)	1990–2016	Nigeria	ARDL and VECM	Income (→)
Chen et al. (2021)	1995–2015	97	GMM	Income (+, -) PRI (+, ≠)
Alsagr & Van-Hemmen (2021)	1996–2015	19 Emerging	Two-Step System GMM	FDE (+) Income (-) PRI (+)
Asafu-Adjaye (2000)	1971–1995	Asian Developing	Granger Causality	PRI (↔)
Chang et al. (2009)	1997–2006	OECD	Panel Threshold Regression	PRI (+)
Yuan et al. (2010)	1993–2007	China	VAR and VECM	PRI (+, -)
Moreno et al. (2012)	1998–2015	27 EU	Fixed Effects	PRI (+)
Nayan et al. (2013)	2000–2011	23	GMM	PRI (+)
Murad et al. (2019)	1970–2012	Denmark	ARDL and VAR	PRI (-)
Wang et al. (2019)	1980–2015	186	Johansen Cointegration, Granger Causality, Impulse Response, & Variance Decomposition	PRI (-, +)
Sardosky (2009)	1980–2005	G7	FMOLS & DOLS	CO ₂ (+, ≠)
Apergis et al. (2010)	1984–2007	19 Developed and Developing	VECM	CO ₂ (+)
Dogan & Ozturk (2017)	1980–2014	USA	ARDL	CO ₂ (-)
Shaifei & Salim (2014)	1980–2011	OECD	AMG Estimator & Panel Causality	CO ₂ (-)
Menyah & Wolde-Rufae (2010)	1960–2007	USA	Toda–Yamamoto	CO ₂ (→)
Jaforullah & King (2015)	1960–2007	USA	VECM	CO ₂ (-)

Table 1 (continued)

Author	Year	Countries	Methods	Outcome
Kahia et al. (2016)	1980–2012	24 MENA	PVAR	CO ₂ (–)
Sharif et al. (2020)	1990–2017	Top 10 Polluted	Quantile on Quantile	CO ₂ (+, –)
Chen et al. (2019)	1980–2014	China	ARDL & VECM Granger Causality	CO ₂ (↔)
Kang et al. (2019)	1965Q1–2015Q4	India	Bayesian VAR & Toda–Yamamoto	CO ₂ (≠)
Toumi and Toumi (2019)	1990–2014	Kingdom of Saudi Arabia	NARDL	CO ₂ (+, –)
Alola et al. (2019)	1990–2016	Europe Largest States	FMOLS and DOLS	CO ₂ (↔)

(+) means positive relationship; (–) means negative relationship; (≠) means no relationship; (→) means unidirectional relationship; (↔) means bidirectional relationship; OECD means Organization for Economic Cooperation and Development; FDE means Financial Development; CO₂ means Carbon dioxide Emissions; VECM means Vector Error Correction Method; BRICS means Brazil, Russia, India, China, Russia; CCEMG means Common Correlated Effects Mean Group; DOLS means Dynamic Ordinary Least Square; VAR means Vector Autoregressive; PRI means Energy Price; EU means European Union; PSTR means Panel Smooth Transition Regression; ARDL means Autoregressive Distributed Lag; NARDL means Non-linear Autoregressive Distributed Lag; GMM means General method of moments; PMG means Pooled Mean Group; FMOLS means Fully Modified Ordinary Least Square; MG means Mean Group; AMG means Augmented Mean Group

3.1 Data

The Data used in this study is annual data from 1960–2018. The variables employed are renewable energy consumption (REN), domestic credit to the private sector by banks (FDE), GDP Per Capita (GDP), Consumer Price Index (PRI), and CO₂ Emissions (COE). FDE is a proxy for financial development, GDP is the proxy for income, and PRI is the proxy for energy prices. The dependent variable is REN, while the other variables are independent. In addition, the R software is used to obtain the QQ regression estimation results, while the Eviews software is used to obtain the Quantile regression estimation results. The variables description is presented in Table 2.

3.2 Method

3.2.1 Quantile–on–Quantile (QQ) approach

The QQ regression method is a modification of the traditional quantile regression approach (Adebayo et al. 2022). On the other hand, quantile regression is an extension of the classical regression technique. According to Yu et al. (2022), the QQ regression approach is an innovative technique for bivariate analysis, which provides richer and additional information than other estimation methods. In addition, this approach fills the deficit gap in other techniques; it performs well in an asymmetric environment, provides a more realistic picture of analysis, accounts for structural breaks, and can investigate an all-inclusive link between data series upper and low quantiles. From a policy perspective, the QQ regression technique contributes to policy development and supports contextual development from a methodological viewpoint (Adebayo 2022).

This paper used the QQ approach to analyze the impact of FDE, GDP, PRI, and COE on REN. This method was proposed by Sim & Zhou (2015) and adopted from the studies of (Seraj et al. 2020; Jiang et al. 2020). The regression model can be seen in Eq. 2.

$$Y_t = \beta^\theta + (X_t) + \mu_t^\theta \quad (2)$$

Y_t denotes the dependent variable at time t ; X_t shows the independent variables shocks at time t , θ represents θ^{th} quantile, and μ_t^θ denotes quantile residue. β^θ can be

Table 2 Variables description

Variables	Abbreviation	Source
Renewable energy consumption (% of total final energy consumption)	REN	World Bank (2022)
Domestic credit to the private sector by banks (% of GDP)	FDE	World Bank (2022)
GDP Per Capita (Constant 2015 US\$)	GDP	World Bank (2022)
Consumer Price Index (2010 = 100)	PRI	World Bank (2022)
Carbon dioxide Emissions (kt)	COE	World Bank (2022)

said to be an unknown factor in which the prior information is lacking. When a factor is unknown, β^θ a first-order Taylor expansion is employed which will therefore be:

$$\beta^\theta(X_t) \approx \beta^\theta(X^\tau) + \beta^\theta(X^\tau)(X^\tau - X_t) \tag{3}$$

$\beta^\theta(X^\tau)$ is a partial derivative of $\beta^\theta(X_t)$ with respect to independent variable shocks. Equation (3) can therefore be rewritten as:

$$\beta^\theta(X_t) \approx \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(X^\tau - X_t) \tag{4}$$

A new equation can be derived by substituting Eq. (4) into Eq. (2). The equation therefore can be written as:

$$Y_t = \beta_0(\theta, \tau) + \beta_1(\theta, \tau)(X^\tau - X_t) + \mu_t^\theta \tag{5}$$

At the end, b_0 and b_1 which are the linear regression estimates replaces β_0 and β_1 . The minimization problem can therefore be estimated as:

$$\min_{b_0, b_1} \sum_i^n \rho^\theta \left[Y_t - b_0 - b_1(\widehat{X}_t - \widehat{X}^\tau) K \frac{(F_n(\widehat{X}_t - \tau))}{h} \right] \tag{6}$$

The quantile loss function is (u) which can be written as $\rho^\theta(u) = (\theta - (u < 0))$. The indicator function is I and the kernel function is K . In weighing the neighborhood observations of X_t , the Gaussian Kernel is applied. In addition, as regards the distance observations of the distribution function, the weights have inverse linkage and can be written as:

$$\widehat{X}_t(F_n(\widehat{X}_t)) = \frac{1}{n} \sum_{K=1}^n I(\widehat{X}_K < \widehat{X}_t) \tag{7}$$

The distribution functions can therefore be obtained that correspond with the quantile X^τ .

4 Empirical results and discussions

This section shows the descriptive statistics, BDS test, QQ result, and quantile regression result.

4.1 Descriptive statistics

Table 3 shows the descriptive statistics. On the measures of central tendency, COE has the highest mean and median values. In addition, COE has the highest maximum value, while FDE has the lowest minimum value. REN, FDE, GDP, and PRI are positively and normally skewed, while COE is negatively skewed. For kurtosis,

Table 3 Descriptive statistics

	REN	FDE	GDP	PRI	COE
Mean	97.02754	8.176085	1820.366	36.13107	65,335.15
Median	89.04838	7.208665	1658.280	2.248333	70,747.43
Maximum	125.9481	19.60353	2688.267	240.1429	130,670.0
Minimum	82.95602	3.696699	1201.402	0.065887	3406.643
Std. Dev	13.38228	3.408458	424.4135	58.88770	33,282.86
Skewness	0.798275	1.328719	0.565968	1.841706	-0.476216
Kurtosis	2.180819	4.740741	2.011139	5.626071	2.363534
Jarque–Bera	7.915909	24.80989	5.553680	50.30676	3.225865
Probability	0.019102	0.000004	0.062235	0.000000	0.199302
Observations	59	59	59	59	59

REN is platykurtic ($2.18 < 3$), GDP is platykurtic ($2.01 < 3$) and COE is platykurtic ($2.36 < 3$). On the other hand, FDE is leptokurtic ($4.74 > 3$), and PRI is leptokurtic ($5.62 > 3$). Lastly, REN, FDE, and PRI are not normally distributed, while GDP and COE are normally distributed. Also, based on the selected data, the variable plots can be seen in Fig. 2.

4.2 BDS test

The BDS test developed by Broock et al. (1996) indicates if variables have a non-linear relationship. The result in Table 4 shows a non-linear relationship among the variables since the p-value is significant at the 1% level. This makes it appropriate for the QQ approach to be employed.

4.3 QQ empirical results and discussions

4.3.1 Financial development supply shocks to renewable energy consumption

The diagram in Fig. 3 shows the 3-axis (3D plots) for domestic credit to the private sector by bank supply shocks on renewable energy consumption. The z-axis shows the value of the slope coefficient. $b1(\theta, \tau)$ measures the effect of the τ th quantile of domestic credit to the private sector by banks supply shock movements (x-axis) on the quantile of the renewable energy consumption θ th in each state (y-axis). From the empirical results, it is observed that FDE supplies mixed shock to REN. For example, the quantiles of FDE (0.05 to 0.45) supply negative shocks to the 0.05 REN quantile. These shocks to REN are highly negative. Its value reaches -2.30 on the z-axis, while the FDE (0.05 to 0.95) quantiles supply positive shocks to the 0.95 REN Quantile. This positive shock is 0.52 on the z-axis.

The negative shock of FDE on REN is because of the low financial development regime. Some of the attributes of a low financial development regime are uneasy access to credit and high lending rates. Access to credit and low lending rates will

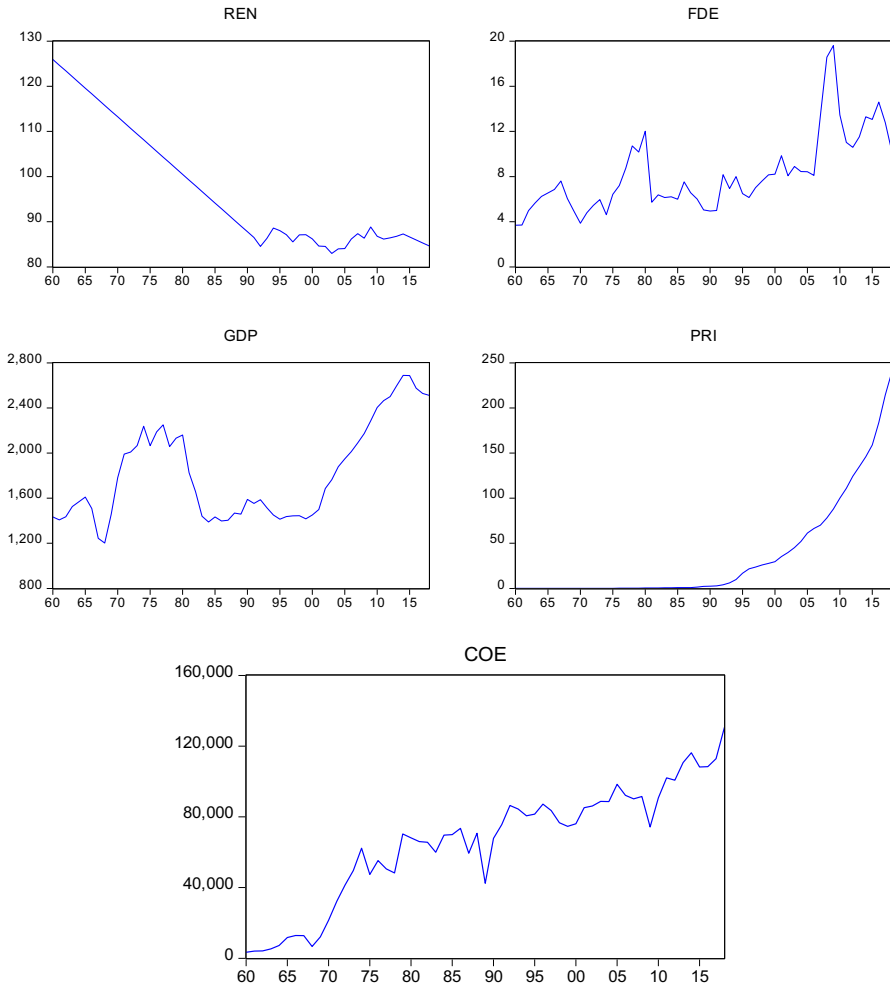


Fig. 2 Variable plots

Table 4 The BDS test

Dimension	m=2	m=3	m=4	m=5	m=6
REN	0.211936*	0.359918*	0.462622*	0.533565*	0.581970*
FDE	0.127750*	0.198887*	0.229412*	0.239870*	0.230543*
GDP	0.134696*	0.219271*	0.264295*	0.278521*	0.273674*
PRI	0.170623*	0.271250*	0.328506*	0.356329*	0.361441*
COE	0.164425*	0.290812*	0.378470*	0.440082*	0.484219*

* denotes significance level at 1%

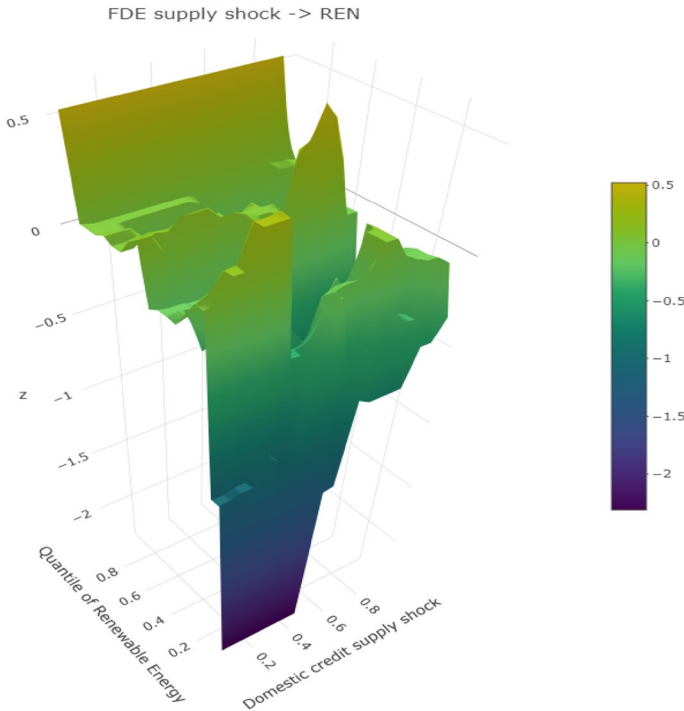


Fig. 3 FDE supply shocks to REN

enable energy consumers to buy/invest in renewable energy products. As Nigeria moves to a high financial development regime, the impact of FDE on REN becomes positive and significant. In 15 top renewable energy countries, Raza et al. (2020) used three financial development variables to proxy for financial development and found a negative impact at low levels of financial development and a positive impact at high levels of financial development. Zeren and Koç (2014) also stated that the negative impact of financial development on energy consumption could result from financial exclusion. In China, Wang et al. (2021) found that FDE impacts REN positively in the short-run and negatively in the long-run. The negative impact is due to an underdeveloped financial sector. For example, when financial institutions are weak in structures, higher financial costs prevent renewable energy investments from occurring.

In 28 EU countries, Anton and Nucu (2020) found a positive impact between FDE and REN because of the efficient operation of the banking system. This enables the bank to finance renewable energy investments at a lower cost, enabling liquidity, capital accumulation, and technological innovation. Pham (2019) stated that increasing innovation is essential for developing renewable energy in 22 OECD countries. Other studies that showed a positive relationship between FDE and REN are (Mukhtarov et al. 2020; Khan et al. 2020; Brunnschweiler 2010). This study differs from other studies such as Burakov (2017), who found no causality between FDE and REN in Russia. The absence of causality between FDE and REN is due to the

lack of significant incentives in the financial market of Russia to promote massive investment in green energy. Anton & Nucu (2020) also discovered that capital market development does not influence REN, while Assi et al. (2021) argued that FDE does not play a major role in REN in ASEAN economies.

4.3.2 GDP per capita supply shocks to renewable energy consumption

Figure 4 shows GDP per capita supply shocks to REN. The negative shocks to REN go from 0.05–0.7 quantiles of GDP to REN. Its slope in the extreme cases reaches -1.72 on Z-axis. Another significant negative shock goes from 0.55 GDP quantile to 0.75 quantiles of REN; its slope is -1.02 . Regarding the positive shocks, three major shocks to REN are observed. The most positive shocks go from the 0.7 quantiles of GDP to 0.3 quantiles of the REN; its value is about 0.68. The second one goes from 0.95 quantiles of GDP to 0.05–0.15 quantiles of REN. Their value is about 0.47. The third positive shock goes from 0.5 quantiles of GDP to 0.5 quantiles of REN; its value is 0.42.

Previous studies show that GDP per capita can have a positive, negative, or no impact on REN. The positive relationship is based on the premise that energy users will have better choices and additional income to spend on renewable energy sources as income grows. The studies that support a positive relationship include (Sardosky 2009; Omri & Nguyen 2014; Simionescu et al. 2020; Iorember et al. 2020). On the other hand, a negative relationship between GDP per capita and REN exists because African countries, including Nigeria, are still developing and characterized by low-income levels. With a low-income level, individuals will spend their limited income on maintaining their daily living. Also, low income will enable people to consume

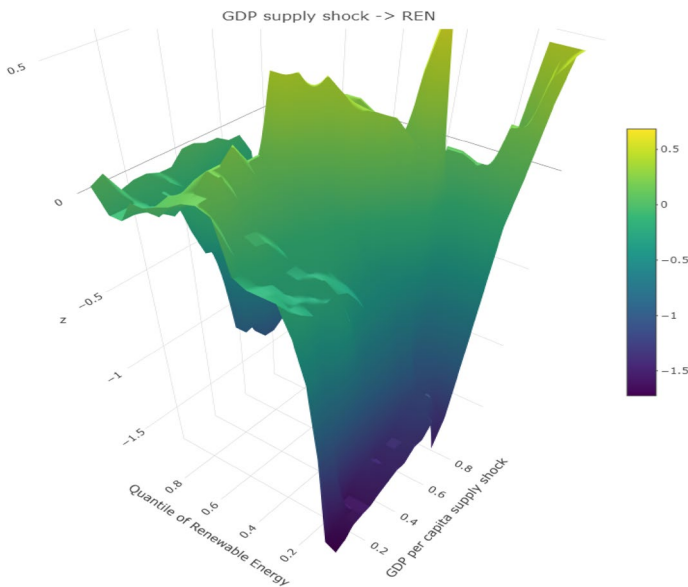


Fig. 4 GDP supply shocks to REN

non-renewable energy sources due to affordability and accessibility. The result corresponds to the studies of (Ergun et al. 2019; Anton & Nucu 2020). Shahbaz et al. (2021) explained that insufficient income causes a negative relationship between GDP per capita and REN in 34 upper-middle-income countries. This study's outcome contradicts the studies of (Al-mulali et al., 2013; Topcu & Togcu, 2020). These studies found no significant link between income and REN.

4.3.3 Energy price supply shocks to renewable energy consumption

Regarding the consumer price index (PRI), two significant shocks appear in Fig. 5. It shows that all PRI quantiles supply negative shocks to the 0.05 quantile of REN. The extreme shock runs from 0.05 quantile of PRI to 0.05 quantile of REN; its value is -0.45 , while the quantiles 0.2–0.5 of PRI supply positive shocks to 0.8 quantile of REN; its slope is 0.29.

For Asian developing economies, Asafu-Adjaye (2000) found bidirectional causality between PRI and REN. Chang et al. (2009) for OECD countries found a positive relationship between PRI and REN. Yuan et al. (2010) explained that as energy price increases, household energy consumption will increase in the short-run and decrease in the long-run. Nayan et al. (2013) explained that energy price is a major determinant of REN. Using oil prices to proxy for the price, Wang et al. (2019) stated that energy impacted energy consumption negatively both in high and lower-middle-income countries, but it has a positive impact on energy consumption in upper-middle-income countries. On the contrary, the studies that found no relationship between PRI and REN include (Chen et al. 2021; Shahbaz et al. 2021).

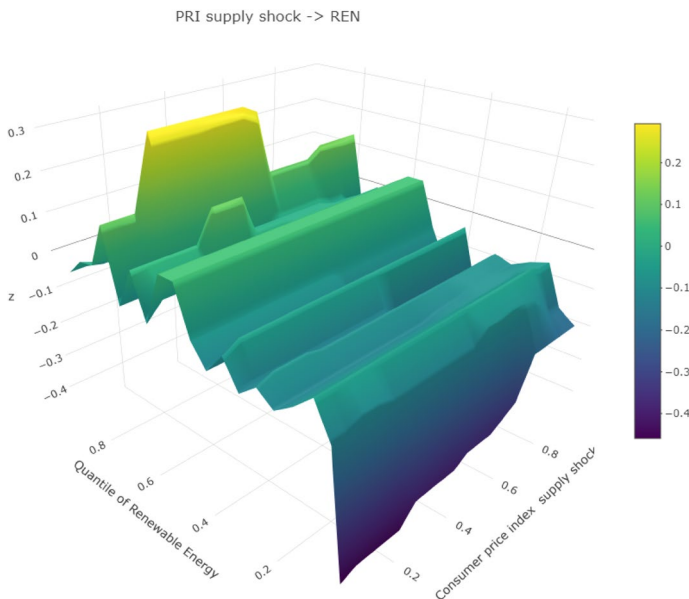


Fig. 5 PRI supply shocks to REN

4.3.4 CO₂ emission supply shocks to renewable energy consumption

Figure 6 shows many positive shocks supplied by COE to REN. The most important shock runs from 0.15 quantile of COE to 0.7 quantiles of REN; its value is about 0.64. Other positive shocks arise from all quantiles of COE to 0.7 quantiles of REN; its value is about 0.46. Regarding the negative shocks, it can be noticed that the quantiles of COE 0.25 to 0.3 provide negative shocks to the 0.6 quantiles of REN; its value is -0.83 .

There are different reasons why COE supplies mixed shock to REN. Positive shocks can be explained as energy stakeholders wanting to increase the share of renewable energy because of the adverse effect of CO₂ emissions on the environment. This view is similar to the studies of Chen et al. (2019) for the Chinese economy, Toumi and Toumi (2019) for the KSA economy, and Apergis et al. (2010) for 19 developed and developing countries. On the other hand, a negative relationship shows that an increase in CO₂ leads to the degradation of the environment. This finding is supported by the studies of (Shafiei & Salim 2014; Jaforullah & King 2015; Kahia et al. 2016). The study by Sardosky (2019) found no relationship between COE and REN.

In summary, it is observed that all independent variables asymmetrically impact the dependent variable. It supplies mixed shocks run to the dependent variable. Also, the study outcome shows that the negative shocks on the dependent variable are more extreme than the positive shocks.

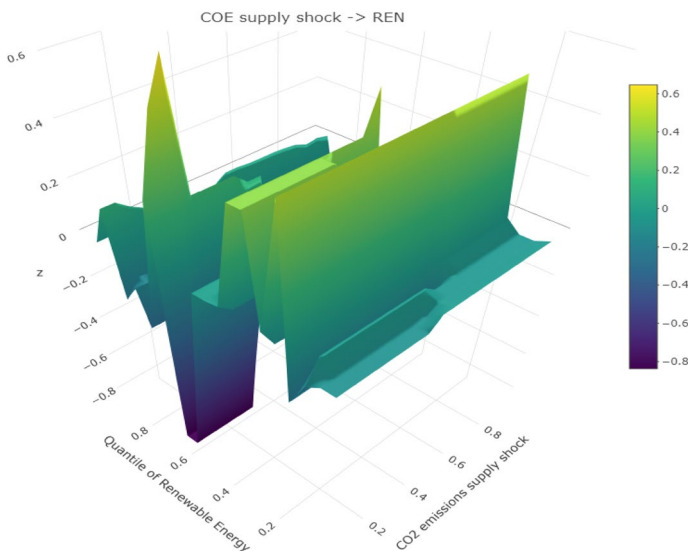


Fig. 6 COE supply shocks to REN

4.4 Quantile regression results

The proponent of the quantile regression method is (Koenker & Bassett 1978). To use the quantile regression technique, the conditions of heteroskedasticity, serial correlation, and non-normality have to be satisfied. The model of this study satisfies each of the conditions. The quantile result is presented in Table 5. The result shows that GDP impacts REN positively across all quantiles. FDE impacts REN negatively at the lower quantile (0.10–0.20) and the upper quantile (0.80–0.90). In addition, the impact of COE on REN is negative across all quantiles. However, the impact is very small.

5 Conclusion and policy recommendations

This research examined the quantile relationship between financial development and renewable energy consumption in Nigeria from 1960–2018. Capitalizing on the limitations of existing literature, this study employs a Quantile-on-Quantile (QQ) and quantile regression approach. These methods are capable of providing information that is richer and sufficient as compared to other methods of estimation. In addition, this research uses GDP per capita, energy price, and CO₂ emissions as moderating variables to eliminate omitted variable bias. The outcome of the QQ approach showed that financial development, GDP per capita, energy price, and CO₂ emissions supply mixed shocks (positive and negative) to renewable energy consumption. The negative shocks for financial development are highly negative. In addition, the result for the quantile regression method showed that financial development impacts renewable energy consumption negatively at the lower Quantile (0.10–0.20) and the upper Quantile (0.80–0.90). The impact of COE on REN is negative across all quantiles. However, the effect is very small. The outcome of this study differs from other studies, which found no association among the economic indicators. This research, therefore, provides further recommendations.

Firstly, to boost renewable energy consumption/investments, policymakers must understand how financial development affects clean energy usage. Financial

Table 5 Quantile regression

Quantile	FDE	GDP	PRI	COE
0.100	-0.627171**	0.007694**	0.061751**	-0.000452*
0.200	-0.664388**	0.010345*	0.015663	-0.000422*
0.300	-0.449324	0.009133*	0.037996	-0.000451*
0.400	-0.778365*	0.010011*	0.044294***	-0.000469*
0.500	-0.541654	0.010122*	0.027516	-0.000456*
0.600	-0.550944	0.009798*	0.023643	-0.000444*
0.700	-0.517582	0.010944*	0.011175	-0.000443*
0.800	-0.649856**	0.009827*	0.035864**	-0.000446*
0.900	-0.583348**	0.010480*	0.025084***	-0.000426*

* means significant at 1%; ** means significant at 5%; *** means significant at 10% probability level

development can affect clean energy in different ways, such as direct, business, and wealth effects. The direct effect can be seen in the area of financial intermediation. The business effect can be seen in firms' easy and better access to financial capital, and the wealth effect can be seen through the stock market development. Understanding these channels will pave the way for a competitive & sustainable energy industry and provide an immediate solution to Nigeria's low level of financial development. Secondly, local financial and economic development levels should be considered when formulating policies. Thirdly, policymakers should strengthen bank-based financial institutions. This will protect renewable energy investors, particularly private firms, from the volatility of the market. It will also encourage private businesses to take loans for renewable energy investments, which can make them achieve economies of scale. This can have a multiplier effect on the economy. Fourthly, necessary incentives should be created because they will increase the demand for loans for renewable energy investments. Incentives include reducing the lending rate, creating a renewable energy investment fund, and implementing favorable tax policies. This will reduce the financial burden or cost needed for renewable energy investment.

Finally, although this research used a novel QQ technique, it still has some suggestions for future research. Firstly, this study is based on a single-country analysis and utilizes a single financial development variable. Further studies should employ a panel framework and include additional financial development indicators, such as stock and bond market development. Secondly, the variables in this analysis were confined to REN, FDE, GDP per capita, PRI, and COE. Researchers should include other variables in their model to see how REN reacts to them. Thirdly, other studies should determine the impact of financial development on various renewable energy resources, especially for countries with diverse renewable energy sources. Finally, different and novel econometric techniques should be employed.

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Availability of data and material Data used in this study is annual data from 1960 – 2018. The variables used are renewable energy consumption (% of total final energy consumption) (REN), GDP Per Capita (Constant 2015 US\$) (GDP), Consumer Price Index (2010=100) (PRI), and CO₂ Emissions (kt) (COE). The dependent variable is REN while the other variables are independent variables. REN is the proxy for renewable energy consumption. GDP is the proxy for income. PRI is the proxy for energy price, while COE is the proxy for CO₂ emissions. In addition, all data are sourced from World Bank (2018).

Declarations

Conflicts of interest All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version. This manuscript has not been submitted to, nor is under review at, another journal or other publishing venue. The authors have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript.

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