Sustainable Social Development 2024, 2(6), 2891.
https://doi.org/10.54517/ssd2891

Article

Neutralizing the surging environmental pollution amidst renewable energy consumption and economic growth in Ghana: Insights from ARDL and quantile regression analysis

Michael Provide Fumey[1], Gabriel Mordzifa Sackitey[1], John Wiredu[2*], Clause Akrong-Nartey[3], Daniel Ewusi Arthur[4], Naftaly Mose[5]

[1] School of Public Policy and Administration, Northwestern Polytechnical University, Xi'an 7101, China
[2] School of Management, Northwestern Polytechnical University, Xi'an 7101, China
[3] Department of Accounting, Finance, Economics Decision Sciences, Western Illinois University, Macomb, IL 61455, U.S.A
[4] Department of Accounting, Robert H. Smith School of Business, University of Maryland, College Park, Washington, D.C. 20742, U.S.A
[5] Department of Economics, University of Eldoret, Eldoret 30100, Kenya
*** Corresponding author:** John Wiredu, johnwiredu50@gmail.com

CITATION

Fumey MP, Sackitey GM, Wiredu J, et al. Neutralizing the surging environmental pollution amidst renewable energy consumption and economic growth in Ghana: Insights from ARDL and quantile regression analysis. Sustainable Social Development. 2024; 2(6): 2891. https://doi.org/10.54517/ssd2891

ARTICLE INFO

Received: 19 September 2024
Accepted: 31 October 2024
Available online: 20 November 2024

Abstract: This research explores the link between renewable energy consumption, economic growth, electricity accessibility, greenhouse gas emissions, and environmental degradation in Ghana from 1993 to 2020. Utilizing the autoregressive distributed lag (ARDL) model and quantile regression, it analyzes the validity of the Environmental Kuznets Curve (EKC) hypothesis. ARDL findings imply that renewable energy consumption (REC), greenhouse gas emissions (GHG), and power accessibility (ATE) have positive but statistically negligible long-term associations with CO_2 emissions. In contrast, economic growth (ECG) shows a slight negative link. This suggests that current attempts to promote renewable energy and minimize emissions may only partially lower CO_2 levels. Quantile regression demonstrates a positive correlation between REC and CO_2 emissions, counter to the idea that more renewable energy consumption decreases emissions. GHG strongly affects environmental pollution (EVP) at all levels, whereas power accessibility (ATE) has a favorable effect at lower levels but becomes negative at higher ones. Economic growth's impact on pollution is detrimental at lower and median values but needs more relevance at more significant levels. These results imply the need for stricter laws, technical breakthroughs, emission limitations, and carbon pricing to mitigate pollution coming from economic expansion.

Keywords: renewable energy; economic growth; ARDL; quantile regression; EKC theory; Ghana

1. Introduction

Environmental pollution is becoming an increasingly pressing problem globally as numerous compounds are discharged into the environment, causing threats to both ecosystems and human health [1]. Pollution may emerge in various ways, spanning chemicals, organisms, biological materials, energy, noise, radiation, and heat [2]. The worldwide concern about environmental pollution and deterioration is severe, influencing the globe. Injudicious exploitation of natural resources, such as uncontrolled burning of fossil fuels, pollution, inadequate waste management, deforestation, and overpopulation, has resulted in environmental deterioration and resource depletion [3–5]. Individuals stricken by environmental pollution and environmental harm, particularly in poor countries, have significant barriers to obtaining equitable treatment and justice within the legal framework. The cause of this issue may be attributed to insufficient environmental laws and regulations and the need for robust and competent institutions responsible for enforcing environmental safeguards [6–8]. Environmental pollution, defined as toxic substances damaging the environment and human health, has reached worrisome levels worldwide, driven by urbanization, industrialization, and economic development [9]. Addressing global environmental pollution demands multiple solutions requiring the involvement of all countries and addressing political, social, and economic factors [10–12]. Urbanization, industrialization, and incorrect chemical use have also contributed to increasing environmental pollution and deterioration, resulting in detrimental health influences on living creatures [13–15]. The peculiar effects include greenhouse gas emissions, temperature variations, ozone depletion, loss of biodiversity, and ecosystem destruction [5]. These concerns need aggressive actions to minimize global difficulties, manage the continuing climate change disaster, and adopt conservation legislation globally.

Africa presents substantial environmental pollution and degradation issues, driven by industrialization, urbanization, and population increase, resulting in pollution from resource overexploitation and industrial waste discharge [16]. Contaminants of increasing concern (CECs), such as plastics, medicines, insecticides, and personal care items, have been detected in African terrestrial and aquatic habitats [17]. Traditional wastewater treatment systems in Africa generally fail to properly remove/degrade numerous CECs, resulting in their worrying prevalence in particular countries [18]. Climate change, pollution, and biodegradation are additional problems in Africa, especially with corporations reporting environmental consequences [19–22]. Industries in Ghana, including mining, agriculture, manufacturing, and construction, have contributed to environmental deterioration via air, water, and land pollution [23]. Mining has severe implications, including land degradation, environmental pollution, and socioeconomic concerns in communities involved in small-scale mining [24]. Nevertheless, traditional and cultural techniques have been shown to help environmental conservation in particular communities, demonstrating their potential for minimizing illicit mining and controlling environmental deterioration [25]. Amid requests for environmental policy reforms, notably within the mining industry, changes towards environmental governance and increasing laws are needed to maintain the environment [26,27]. Environmental challenges in Africa bear worldwide repercussions owing to the utilization of global resources, with environmental degradation in one nation possibly influencing others [28]. Despite attempts to monitor and manage pollutants, emerging environmental contaminants offer new issues [29,30]. Additionally, pollution damages animal and wildlife health and raises public health risks via contamination of the human food chain. Addressing pollution challenges is vital for ecosystems and human populations’ long-term health and sustainability.

This study analyzes how renewable energy consumption, economic growth, access to electricity, and greenhouse gas emissions affect environmental pollution reduction in Africa, emphasizing Ghana. Renewable energy plays a vital part in avoiding pollution. This study provides a novel empirical analysis by applying both ARDL and quantile regression approaches to assess the Environmental Kuznets Curve

(EKC) hypothesis in the context of Ghana. Unlike previous research that often treats renewable energy consumption and environmental pollution in isolation, this paper integrates multiple factors within a unified framework, such as access to electricity, greenhouse gas emissions, and economic growth covering the period. Furthermore, the inclusion of quantile regression offers a nuanced understanding of the varying effects of these factors across different levels of environmental pollution, thus filling existing gaps in the literature. While initially raising CO_2 emissions, research suggests renewable energy offers long-term advantages in lowering emissions and environmental deterioration [31,32]. Access to energy also greatly assists pollution management via technology that may purify waste and minimize emissions [2,25]. Economic expansion initially increases pollution levels, but the Environmental Kuznets Curve theory implies an inverted U-shaped connection ultimately arises between growth and pollution [33]. Promoting renewable energy, balanced urban-rural development, and clean production may decrease pollution while preserving economic growth. The food system is a substantial greenhouse gas emitter needing extensive reduction throughout the supply chain [4]. Efforts are ongoing to transition to a sustainable, carbon-neutral economy via emission reduction and offsetting [5]. By investigating the connection between Ghana's renewable energy consumption, economic development, and environmental pollution, this research informs policies and initiatives for environmental conservation, particularly in African countries. Employing ARDL and quantile regression models, it explores the Environmental Kuznets Curve hypothesis in the Ghanaian setting and analyzes the temporal dynamics using robust econometric approaches. The work comprises a literature review, methodology, data, empirical model, results, and discussion with policy implications.

2. Literature review

This portion of the study looks at the body of research that has already been done on the subject. More so, this section looks at earlier studies that looked at the connections between several essential variables, including the use of renewable energy consumption (REC), Economic growth (ECG), access to electricity (ATE), greenhouse gas emissions (GHG), and the effects these have on environmental pollution (EVP).

2.1. Nexus between renewable energy consumption and environmental pollution

Research has demonstrated that increasing renewable energy consumption may decrease carbon emissions and environmental pollution [34–36]. While renewable energy initially raises CO_2 emissions in the short term, it has a favorable influence on lowering emissions over the long run [37]. Renewable energy is crucial for closing the gap between production and consumption-based carbon emissions, especially in net emission-exporting countries [38]. The carbon reduction advantages of renewable energy are most evident in low-income countries, followed by lower-middle and upper-middle-income nations. In contrast, higher-income countries get the most minor benefits [39]. Trade openness, innovation, and technical advancement promote emission reductions, but tourism causes environmental damage. However, the ecological implications of renewable energy in Africa exhibit diverse outcomes across socioeconomic classes and geographies [40]. In rising Asian nations, renewable energy considerably cuts long-term carbon emissions [41]. For OECD nations, economic development adversely affects the environment when renewable consumption is below a threshold but favorably when above it [42]. A nonlinear connection exists between renewable consumption and CO_2, with larger renewable shares permitting more accurate emission estimates [43]. These studies underscore the need to increase renewable energy usage and sustainable practices to minimize pollution and meet long-term environmental and development objectives.

2.2. Nexus between ATE and EVP

Access to electricity is a crucial development aspect and impacts environmental pollution. In Nigeria, the reliance on generators due to poor electricity generation and distribution has led to high levels of environmental pollution and adverse health impacts [44]. In developing countries, increasing access to grid connections and reliable electricity can alleviate poverty and promote economic growth, while transitioning to low-carbon energy sources can have positive health and social benefits and reduce environmental damage [45]. In India, the evolution from dirty to unpolluted energy is hindered by the country's energy-intensive and carbon-intensive industrialized economy and the socio-cultural tradition of using multiple fuels, filthy fuels, at the household level [46]. Studies have revealed that airborne particle pollution tends to increase power consumption levels while reducing the electricity generated from distributed solar panel installations. This issue disproportionately affects disadvantaged people since lower-income neighborhoods and ethnic minority groups incur a higher cost from the consequences of particle air pollution on both increased energy consumption and decreased solar power production capabilities [47]. Limited access to electricity in Sub-Saharan Africa is influenced by income per capita, transmission and distribution losses, rural population proportion, population density, dependency ratio, savings, and government effectiveness [48–50]. Access to electricity and environmental pollution are interconnected. Electricity access has numerous benefits, including reducing reliance on unsustainable wood fuels and promoting low-carbon energy sources [51]. However, the transition to cleaner energy is hindered by the link between economic development and energy-related greenhouse gas emissions [52,53]. Poor electricity generation and distribution lead to high reliance on generators, resulting in environmental pollution and adverse health impacts. Additionally, particulate air pollution has indirect co-damages on human behaviors and technologies, such as increasing electricity consumption and reducing the efficiency of distributed solar panels [54]. While the impact of pollutants on avian influenza virus infection risk is poorly understood, anthropogenic pollution may disrupt wildlife immune function and increase susceptibility to infection [55]. The interplay between access to electricity and environmental pollution highlights the need for sustainable energy solutions that minimize negative environmental and health impacts.

2.3. Nexus between ECG and EVP

There is an unambiguous connection between economic expansion and pollution of the environment, as examined by several research across different nations. According to research on African countries, economic expansion is a significant factor in rising pollution levels [56]. Factors like food costs, money, and foreign direct investment encourage pollution, whereas agricultural output and labor diminish it. For Brazil, [57] gives data supporting the Environmental Kuznets Curve hypothesis, demonstrating that pollution initially increases with economic expansion but falls beyond a certain point. Examining China, it was discovered that economic expansion may accelerate and limit pollution emissions depending on the area's development state [58]. Much research has been done on the connection between economic expansion and carbon emissions. In nations like Uruguay, a positive statistically significant correlation exists between the two [59]. However, this connection is variable between areas and countries. Some research implies a bi-directional connection in economies in transition, a uni-directional link in emerging nations, and no relevant association in developed and least developed countries [60]. Additionally, the impact of financial development on carbon emissions is inconclusive, with some studies finding a negative effect [61]. Recommend reevaluating international trade regulations and strengthening export limitations for goods with high pollution levels [62]. Policymakers should also design appropriate policies to decarbonize energy consumption and promote renewable energy use without affecting economic growth [63]. Therefore, these studies highlight the need for sustainable development and environmental governance to control pollution while promoting economic growth.

2.4. Nexus between total greenhouse gas emissions and environmental pollution

Total greenhouse gas emissions have been proven to have a substantial connection with environmental contamination [64]. Numerous studies across areas and nations continuously reveal that pollution, particularly in CO_2 emissions, substantially contributes to environmental deterioration [65–68]. Economic expansion, energy usage, and urban agglomerations are fundamental causes of increased greenhouse gas emissions and accompanying environmental deterioration [69]. Bidirectional causation occurs between greenhouse gas emissions, energy consumption, and pollution, where increased energy usage leads to more emissions, further worsening pollution. These results underline the necessity for sustainable development plans, strong environmental laws, and adopting eco-friendly technology to alleviate pollution and limit emissions. In Canada, an inverted U-shaped connection was identified between carbon intensity (GHGs/Energy) and emissions, showing emissions first increase but gradually drop over time [70]. For South Africa, improved energy intensity and cumulative energy savings were connected to energy efficiency and low-carbon goods [71]. In Central and Eastern Europe, CO_2 emissions and energy usage showed no long-term influence on economic growth, while financial development displayed bidirectional causation with emissions [72]. Asian countries exhibited cointegration between carbon emissions, urbanization, energy usage, and economic development, with comparatively high short-term emission levels [73]. The causal relationship between total greenhouse gases and carbon emissions is complicated and impacted by variables including energy efficiency, economic growth, and financial development.

2.5. Research gap and contributions

The previous sections have evaluated current research on environmental pollution (EVP) factors. Despite the quantity of material analyzed, it is evident that there are distinct gaps and shortcomings in this domain. Therefore, more empirical research is essential to uncover the characteristics that minimize EVP successfully. The literature review also shows that no previous studies, especially those that focused on African economies like Ghana, have thoroughly investigated the relationship between access to electricity (ATE), greenhouse gas emissions (GHG), economic growth (ENG), renewable energy consumption (REC), and EVP within a single research framework. This research consequently fills a significant hole by being the first to analyze these factors together in the context of developing economies. Additionally, there is a distinct lack of contemporary research exploring the drivers of EVP, especially within African countries, in the environmental literature. Therefore, the duration of this research, stretching from 1993 to 2020, gives a new and original viewpoint on this problem. Furthermore, there remains a considerable methodological vacuum regarding quantile regression. This study intends to overcome this gap by applying the quantile regression and ARDL framework, offering a more contextually relevant and complete knowledge of the numerous elements driving the environmental pollution landscape in a growing African country.

3. Theoretical framework and empirical modeling

3.1. Theoretical framework—Environmental Kuznets Curve (EKC)

The EKC theory was established by [36] to highlight the link between economic development and environmental degradation. It suggests a curved link where environmental damage first increases throughout early economic growth stages but diminishes after reaching a particular economic threshold [74]. Since the 1990s, substantial research has been undertaken on the EKC theory. Studies have highlighted significant EKC-related issues, including economic growth, CO_2 emissions, energy consumption, renewable energy, and financial development [75]. The theory has attracted substantial interest, leading to multiple study communities concentrating on different times and issues within the EKC literature [76]. The EKC phenomena have been noticed in the E-7 economies (Brazil, China, India, Indonesia, Russia, Mexico, and Turkey), with technology developments assisting in reducing pollution [77]. In selected growing Asian nations, the N-shaped EKC theory has been verified, with increasing renewable energy consumption considerably lowering long-term carbon emissions [78,79]. Furthermore, empirical studies suggest a bidirectional link between renewable energy use and economic development, indicating a feedback loop [80,81]; promoting renewable energy consumption is a realistic method to promote energy security, cut carbon emissions, and stimulate future economic development in these countries. In this paper, we claim that the transition to renewable energy consumption, increased energy access, and economic development via strategic planning may successfully affect the amount of environmental pollution (EVP) in Ghana. Thus, we predict a negative association between renewable energy consumption (REC) and EVP. Access to electricity (ATE) and economic development (ECG) may aggravate pollution via increasing mobility, production, energy consumption, housing, urbanization, and industrial activity, leading to environmental deterioration. Given their significant contributions to EVP, we predict ATE, ECG, and greenhouse gas emissions (GHG) processes to encompass crucial concerns such as industrial and agricultural waste, heightened energy use, emissions from transportation, and home waste.

3.2. Explanation of variables

3.2.1. Dependent variable

The outcome variable, EVP, refers to introducing harmful substances stuck on the environment through social activities, leading to carbon accumulation on Earth. This carbon can be found in various forms, such as (CO_2) emissions, urban garbage, aquatic weeds, agricultural refuse, and other wastes [25,27]. Using CO_2 emissions as a proxy allows for analyzing trends and patterns in environmental pollution over time and across different regions. It is a commonly used indicator to assess the impact of human activity on the environment, particularly on economic development and urbanization [82,83]. The emissions of CO_2 from road vehicles, for example, contribute significantly to overall CO_2 emissions and are highly concentrated in urban areas. The link between CO_2 emissions and various factors, such as population density and financial development, has been studied to understand the drivers of environmental pollution

3.2.2. Independent variables

The study analyzed four predictor variables: economic growth, renewable energy usage, access to electricity, and overall greenhouse gas emissions. Economic growth (ECG) was calculated using GDP per capita, which offers a monetary value for all final products and services generated. GDP per capita enables cross-country comparisons of living standards by accounting for cost of living and inflation disparities. Renewable energy consumption (REC) was proxied by the proportion of total final energy consumption from renewable sources. This comprehensive statistic assesses total energy use and the renewable share, allowing the study of renewable energy integration and energy mix adjustments. Access to electricity (ATE) measures dependable and inexpensive access to electricity and cooking facilities, which are vital for economic growth, industrialization, productivity, and UN Sustainable Growth Goals. While power supply may harm the environment, efficiency advances give the potential for further environmental regulations. Emissions of greenhouse gases (GHGs) include sulfur hexafluoride, hydrofluorocarbons, methane, nitrous oxide, and carbon dioxide. These gases contribute to global warming and climate change. CO_2 from fuel burning provides the bulk of anthropogenic GHG emissions; however, agricultural operations also create considerable methane and nitrous oxide emissions. Mitigating these emissions through better practices and moving to biofuels is vital for tackling climate change. Countries and organizations must measure and cut GHG emissions to effectively confront global warming. A summary description of the measurement for all the series has been presented in **Table 1.**

Table 1. Variable description.

Variable	Symbol	Details of Variables	Source
Carbon emission	EVP	CO_2 (metric tons per capita)	WDI
Economic Growth	ECG	Per Capita (constant 2015 US$)	WDI
Renewable energy consumption	REC	% of total final energy consumption	WDI
Access to electricity	ATE	% of population	WDI
Total greenhouse gas emissions	GHG	kt of CO_2 equivalent	WDI

3.3. Source of data and measurement unit

The World Bank indicator database included the time series data for greenhouse gas emissions (GHG), access to electricity (ATE), renewable energy consumption (REC), economic growth (ECG), and environmental pollution (EVP). **Table 1** includes information on the unit of measurement, signs, and data source for the chosen variables.

3.4. Quantile plots

See **Figure 1**. Quantile plots for the variables under consideration.

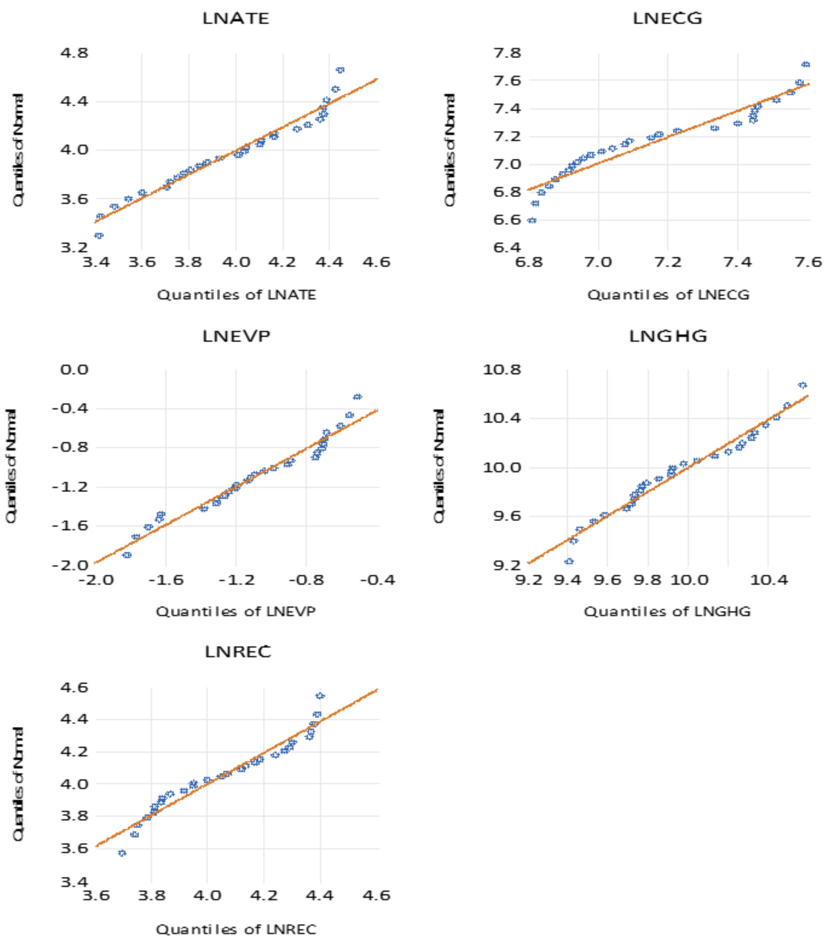


Figure 1. Quantile plots of variables.

3.5. Econometrics estimation approach

Drawing on the theoretical framework of the Environmental Kuznets Curve (EKC) hypothesis and the results of past academic research undertaken by [84–87]. This study adopts the ARDL and Quantile regression econometrics approach to examine the relationship between renewable energy consumption (REC), Economic growth (ECG), access to electricity (ATE), Greenhouse gas emissions (GHG), and Environmental pollution (EVP). ARDL (Autoregressive Distributed and Lag) is a method used in econometrics to analyze the relationship between variables over time, allowing both short-term and long-term dynamics to be captured. ARDL assumes stationarity and cointegration among the variables, making it suitable for modeling non-stationary time series data [88]. On the other hand, Quantile regression is a robust regression technique that estimates the conditional quantiles of the response variable, providing a more all-inclusive understanding of the relationship between interpreters and the reaction. Unlike traditional regression, Quantile regression does not rely on distributional assumptions and can handle heteroscedasticity effectively [84,86,89,90]. ARDL and Quantile Regression offer valuable insights into different aspects of data analysis, with ARDL focusing on time series dynamics and cointegration. In contrast, Quantile regression provides a robust alternative to traditional mean regression methods.

$$\mathrm{EVP_t} = f(\mathrm{ECG_t}, \mathrm{ATE_t}, \mathrm{GHG_t}, \mathrm{REC_t}) \quad (1)$$

To eliminate skewness problems, the data variables were transformed into natural logs.

Therefore, we may represent the equation above in the following form.

$$\mathrm{lnEVP}_t = \beta_0 + \beta_1 \mathrm{lnECG_t} + \beta_2 \mathrm{lnATE_t} + \beta_3 GHG_t + \beta_4 REC_t + \varepsilon_t \quad (2)$$

where ε_t—represents the error term, t represents time dimensions, β_0 shows the constant term, and β_1 *to* β_4—are coefficients variables.

ARDL estimation model was applied as shown mathematically in Equation (3).

$$\Delta\mathrm{lnEVP}_t = \alpha_{01} + \sum_{i=1}^{p} \alpha_{1\mathrm{i}} \Delta\mathrm{lnEVP}_{t-\mathrm{i}} + \sum_{i=0}^{w} \alpha_{2i} \Delta\mathrm{lnECG}_{t-i} + \sum_{i=0}^{w} \alpha_{3i} \Delta\mathrm{lnATE}_{t-i} + \sum_{i=0}^{w} \alpha_{4i} \Delta\mathrm{lnGHG}_{t-i} + \sum_{i=0}^{w} \alpha_{5i} \Delta\mathrm{lnREC}_{t-i} + \varepsilon_{1t} \quad (3)$$

To check for causality association error correction term Equation (4).

$$\Delta\mathrm{lnEVP}_t = \alpha_0 + \sum_{i=1}^{p} \alpha_{1i} \Delta\mathrm{lnEVP}_{t-i} + \sum_{i=0}^{w} \alpha_{2i} \Delta\mathrm{lnECG}_{t-i} + \sum_{i=0}^{w} \alpha_{3i} \Delta lnATE_{t-i} + \sum_{i=0}^{w} \alpha_{4i} \Delta\mathrm{lnGHG}_{t-i} + \sum_{i=0}^{w} \alpha_{5i} \Delta lnREC_{t-i} + \emptyset_1 ECT_{t-1} + \varepsilon_{1t} \quad (4)$$

In Equation (4), the delayed error correction term, abbreviated as ECT_{t-1}, assesses the pace at which the system adjusts towards long-term equilibrium. ECT_{t-1} Denotes the error correction component.

3.6. Causality test

The research evaluated the causation between the variables using the paired Granger causality analysis [35]. Causality is a statistical measure of causation based on prediction that this study uses because of its many advantages over other techniques of analyzing time-series data. Presume that the future behavior of a separate time series *X* can be predicted using a time series *Y*. We term it "Y Granger-causing *X*." Regular least squares (OLS) regression is used to estimate coefficients. Nonetheless, granger causality between components *X* and *Y* is found using F-tests. Representing their values at time t, the notations X_t and Y_t denote the temporal sequence of the two variables. X_t and Y_t bivariate autoregressive model representation follows.

$$X_t = \beta_1 + \sum_{i=1}^{w} \alpha_i Y_{t-i} + \sum_{i=1}^{w} \mu_i X_{t-i} + \varepsilon_t$$
$$Y_t = \beta_2 + \sum_{i=1}^{w} \Omega_i Y_{t-i} + \sum_{i=1}^{w} \infty_i X_{t-i} + \mu_t \qquad (5)$$

The assessment of "n" embodies the lag length, while the parameters β_2,β_1,α_i, Ω_i , μ_i and are active for estimation purposes. Likewise, the terms ε_t and μ_t exemplify the stochastic error terms or residuals.

3.7. Quantile regression estimation

Quantile regression offers numerous benefits over traditional mean regression methods. It provides a more all-inclusive understanding of how exposure affects the entire outcome distribution, making it valuable when outcomes have non-linear relationships [91]. Quantile regression outperforms linear regression owing to its greater robustness to outliers and poorly characterized error distributions, enabling a more complete statistical modeling method [92]. Unlike binary logistic regression, quantile regression does not require dichotomizing quantitative variables, thus retaining more information and providing trustworthy estimates. Additionally, applying deep learning to quantile regression allows for interpretable results and statistical inference, combining the flexibility of deep learning with the advantages of quantile regression [93]. These combined strengths make quantile regression a powerful tool in various fields, including economics, epidemiology, finance, and health psychology. Quantile regression can be defined as in Equation (5) [94]

$$y_i = x'\beta_q + e_i \qquad (6)$$

In Equation (6), βq signifies the collection of undetermined parameters associated with the *q*-th percentile. The OLS reduces the model prediction error's sum of squares. e_i ($\sum_i e_i^2$), whereas the most minor absolute deviation (LAD) regression, referred to as the median regression, minimizes $\sum_i | e_i |$. For a given total, the Quantile regression handles asymmetric penalties (1−*q*) $|e_i|$ for over-prediction and q$|e_i|$ for under-prediction (Baum et al., 2013). The goal function is minimized using the quantile regression estimator for quantile q. [95]

$$Q(\beta_q) = \sum_{i:yi \geq x_i'\beta}^{N} q\left|y_i - x_i'\beta_q\right| + \sum_{i:yi < x_i'\beta}^{N} (1-q)\left|y_i - x_i'\beta_q\right| \qquad (7)$$

where 0 < *q* < 1. The conditional quantile of y_i given x_i is as follows

$$Q_q\left(\frac{y_i}{e_i}\right) = x_i'\beta_q \qquad (8)$$

According to [28] there is often a significant disparity between the median and mean values of variables such as carbon dioxide emissions, gross domestic product, and energy usage. According to [33] quantile regression, which utilizes the absolute values of regression residuals, produces more resilient outcomes than the conventional ordinary least squares (OLS) model when the error terms deviate from a normal distribution and encompass outlier values. The sentence essentially emphasizes that there might be substantial divergence between the median and the mean for specific variables. Additionally, it is shown that quantile regression exhibits more excellent reliability compared to ordinary least squares (OLS) regression in cases where the data deviates from the assumption of normality and includes outliers that may disproportionately affect the outcomes.

4. Empirical findings and discussion

Table 2 offers a statistical descriptive overview of Ghana from 1993 to 2020. The table covers numerous statistical measurements such as the mean, median, standard deviation, etc. The five variables under analysis in this study are as follows: access to electricity (percentage of the population), total greenhouse gas emissions (metric tons of CO_2 equivalent), GDP per capita (constant US$), and renewable energy consumption (percentage of total final energy consumption). The dependent variable is carbon dioxide emissions (metric tons per capita). The four independent variables are renewable energy consumption and total greenhouse gas emissions. Data is accessible for each variable for the full-time without any missing values. All five variables indicate positive mean values. In contrast to the independent variable (CO_2 emissions), which has a relatively small standard deviation and values closely clustered around the average, the other independent variables (total greenhouse gas emissions and GDP per capita) show relatively extreme dispersions from their mean values. The distribution of all five variables is symmetric around the mean, indicating a normal distribution. The positive kurtosis values for all variables are less than three, suggesting a platykurtic character, meaning fewer extreme values are below the sample mean.

Table 2. Descriptive and correlation matrix.

	LNATE	**LNECG**	**LNEVP**	**LNGHG**	**LNREC**
Mean	3.979078	7.154889	−1.090355	9.950875	4.059188
Median	4.021724	7.082838	−1.101047	9.91655	4.059525
Maximum	4.447821	7.591667	−0.506025	10.57312	4.398146
Minimum	3.413436	6.810359	−1.820073	9.403576	3.69511
Std. Dev.	0.324279	0.266925	0.385475	0.341993	0.231525
Skewness	−0.193872	0.309378	−0.318313	0.15407	0.040268
Kurtosis	1.870166	1.577266	2.072281	1.924554	1.595774
Jarque-Bera	1.664684	2.808201	1.476949	1.460122	2.30806
Probability	0.435029	0.245588	0.477842	0.48188	0.315363
Sum	111.4142	200.3369	−30.52994	278.6245	113.6573
Correlation					
Matrix	LNATE	LNECG	LNEVP	LNGHG	LNREC
LNATE	0.101401				
	1				

Table 2. (*Continued*).

	LNATE	LNECG	LNEVP	LNGHG	LNREC
LNECG	0.079151	0.068704			
	0.948292	1			
LNEVP	0.116299	0.093866	0.143284		
	0.964835	0.946061	1		
LNGHG	0.103193	0.086611	0.124257	0.112782	
LNREC	−0.069925	−0.05829	−0.083155	−0.074675	0.05169
	−0.965843	−0.978131	−0.966245	−0.978038	1

The correlation coefficient values are shown for each of the five examined variables. It is significant to notice that the Spearman and pairwise correlation values are equal owing to the lack of missing data in the sample. Furthermore, all associations are statistically significant at varying degrees of significance. Except for renewable energy use, all variables indicate a substantial positive association with each other. There is a substantial negative connotation between CO_2 emanations and renewable energy use, which accords with economic and theoretical assumptions. It is natural to predict that as society shifts towards higher usage of renewable energy, CO_2 emissions will decrease. Conversely, total greenhouse emissions, access to power, and economic development indicate a highly positive connotation with CO_2 releases, suggesting that a rise in any of these factors would lead to a comparable increase in CO_2 emissions. This finding is compatible with economic theory.

4.1. Unit root test

The ADF (augmented Dickey-Fuller) and PP (Phillips Perron) tests were used to evaluate the degree of integration between the variables. The ADF test implies that error terms are statistically independent and homogenous, whereas the PP test assumes weak dependency and heterogeneity in the error terms. The data relating to stationarity are given in **Table 3**. Both tests demonstrate that all variables are stable on level, meaning they are integrated in order (0). As a result, it is appropriate to use the Johansen cointegration test to look for possible cointegration between the variables.

Table 3. Unit root test.

Augmented Dicky Fuller			**Phillips Perron**	
Variables	Constant-Trend	Without constant	Constant-Trend	Without constant
lnCO_2	−3.818***	−2.542***	−3.366***	−2.801***
lnREC	−2.425**	−5.324***	−4.065***	−5.371***
lnGHG	−2.096**	3.870***	−2.416**	4.840***
lnATE	−3.628***	2.905***	−4.5558***	2.672***
lnECG	−2.133**	2.196**	−1.966**	5.140***

** = significant at 5%, *** = significant at 1%.

The natural logarithmic form is applied to all variables, indicated by the letter "ln" before each variable name. GDP stands for gross domestic product per capita in constant 2015 US dollars, ATE stands for access to electricity as a percentage of the population, GHG stands for total greenhouse gas emissions measured in metric tons of CO_2 equivalent, CO_2 stands for CO_2 emissions per capita, and REC stands for renewable energy consumption as a percentage of total final energy consumption. The Augmented Dickey-Fuller and Phillips-Perron tests were run to check for unit roots in the data to avoid false regression. The findings from both tests indicated all variables are stationary at level, suggesting they are integrated of order zero (0). The Johansen cointegration test was applied to evaluate possible long-run correlations among the variables and test the Environmental Kuznets Curve hypothesis. The appropriate lag duration was set to a maximum of 4 lags. An unconstrained error correction model was then generated to test for long-run connections between the associated variables. The proper ARDL (3, 3, 1, 3, 2) model was chosen, and diagnostic tests shown in **Table 4** verified no concerns with autocorrelation or heteroscedasticity, and the error terms were usually distributed. Analysis of the ARDL model coefficients found that renewable energy consumption (lnREC) had a positive long-run connection with CO_2 emissions, with a coefficient of 2.183268. However, this was statistically insignificant (p-value = 0.421). Similarly, greenhouse gas emissions (lnGHG) revealed a positive coefficient of 2.682888, showing a positive long-run association with CO_2 emissions, but again statistically insignificant (p-value = 0.349). Access to electricity (lnATE) exhibited a positive correlation of 0.2964714, showing a positive long-run link with CO_2 emissions, while statistically insignificant (p-value = 0.819). Conversely, economic growth (lnECG) revealed a negative coefficient of −0.6738055, demonstrating a negative long-run association with CO_2 emissions, albeit statistically insignificant (p-value = 0.763). The negligible coefficients for renewable energy consumption (lnREC) and greenhouse gas emissions (lnGHG) show that present policies targeting these sectors may not successfully lower CO_2 emissions in the long term. Policymakers may need to examine and expand renewable energy policies, emissions laws, and investment strategies to achieve more substantial emission reductions. Similarly, the cheerful but small coefficient for access to electricity (lnATE) shows that initiatives oriented primarily at boosting electricity availability may not directly contribute to CO_2 emissions reduction in the long term. However, electrification may still be crucial in enabling the transition to renewable energy and boosting energy efficiency, indirectly affecting emissions. The opposing but negligible coefficient for economic growth (lnECG) contradicts the traditional notion of a positive link between economic growth and CO2 emissions in the long term. Policymakers should study measures to divorce economic development from environmental deterioration, stressing sustainable industrial practices, clean technology uptake, and circular economy concepts.

Table 4. Diagnostic test.

Dependent Variable	Model ARDL	B-G serial correlation LM test	ARCH LM test	Jarque-Bera normality test	Ramsey-Reset Test	CUSUM test	CUSUM of Squares test
$lnCO_2$	(3, 3, 1, 3, 2)	0.3085	0.4921	0.5567	0.1846	Stable	Stable

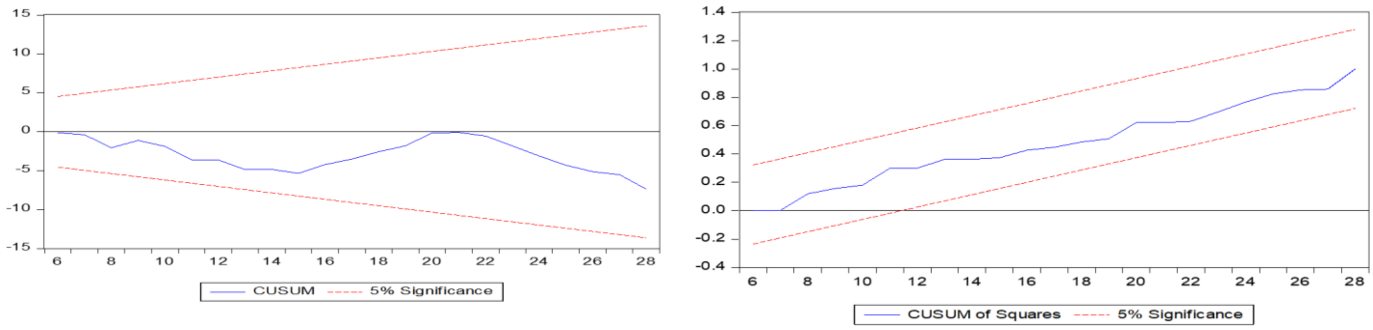
The derived F statistic value for the suitable ARDL model falls below the upper limit of the critical value table supplied by Pesaran et al. (2001). Consequently, the null hypothesis (H0) showing no long-term link between the series is accepted. This suggests that the existing data does not give sufficient evidence to reject the null hypothesis, showing a lack of persistent link among the variables in the model. The error correction model and long-term coefficients of the specified ARDL model are detailed in **Table 5**. Therefore, no statistically significant long-run association is identified between CO_2 emissions or environmental pollution, renewable energy use, access to power, and greenhouse gas emissions. Thus, it may be argued that the reverse U-shaped Environmental Kuznets Curve hypothesis holds from 1993 to 2020. These data show that the interactions between these characteristics and environmental contaminants may develop over time, needing lengthy observation and study to comprehend their implications thoroughly. Regular monitoring and continuing study of these elements are vital for guiding policy revisions and guaranteeing the success of adopted initiatives.

Table 5. ARDL estimation.

The dependent variable EVP				
Independent variable	Coefficients	Std. error	t statistics	Probability
lnREC	2.183268	2.571757	0.85	0.421
lnGHG	2.682888	2.697513	0.99	0.349
lnATE	0.2964714	1.250384	0.24	0.819
lnECG	−0.6738055	2.154979	−0.31	0.763

Upon evaluating the OLS and quantile regression findings reported in **Table 5**, it becomes evident that the OLS results closely reflect those obtained from the ARDL study. According to the OLS test findings, the effect of access to electricity (ATE), renewable energy consumption (REC), total greenhouse gas emissions (GHG), and economic development (ECG) on the environment in Ghana is judged statistically significant. However, quantile regression results give a more thorough view of the correlations between the independent variables and environmental contaminants. The effects of renewable energy consumption (REC), economic growth (ECG), and access to electricity (ATE) on environmental pollution (EVP) demonstrate variation throughout the range, with more apparent consequences reported at lower percentiles. In contrast, greenhouse gas emissions (GHG) consistently and substantially influence all quantiles' environmental pollution.

The CUSUM (Cumulative Sum of Recursive Residuals) and CUSUMSQ (CUSUM of Squares) tests at the 5% significance level are used to analyze the stability of the short-run and long-run coefficients in the model. Since the model's residuals stay within the critical limits, the model is stable and has no evident structural break. The CUSUM and CUSUMSQ test results imply that the regression model employed in this research is stable over the sample period under consideration. This stability suggests that the model's coefficients (parameters) and variance do not display substantial structural alterations or instability over time. In other words, the correlations between the independent factors (renewable energy consumption, greenhouse gas emissions, access to power, and economic development) and the dependent variable (environmental pollution) stay stable throughout the sample period. The steady CUSUM and CUSUMSQ charts offer confidence in the reliability and robustness of the regression results, including the quantile regression findings mentioned previously. The model's stability demonstrates that the relationships between the independent and dependent variables are stable and may be evaluated with a high degree of confidence. These tests reveal that the regression model adopted in the research is stable, with its coefficients and variance not demonstrating significant changes or instability across the sample period, which is a critical assumption for the validity of the regression analysis. This consistency strengthens trust in the regression findings and their inferences. (see **Figure 2a,b**)



(a) **(b)**

Figure 2. Model Stability Graph **(a)** CUSUM (Cumulative Sum of Recursive Residuals); **(b)** CUSUMSQ (CUSUM of Squares).

4.2. Causality test

The Granger causality test results reveal complex interconnections between environmental, economic, and energy variables, as shown in **Table 6**. Several crucial relationships emerge at a 5% significance: greenhouse gas emissions and renewable energy consumption. Both Granger causes access to electricity, suggesting these factors precede changes in electricity accessibility. Economic growth appears to be a significant driver, Granger causing both CO_2 and greenhouse gas emissions, highlighting the environmental challenges of development. Renewable energy consumption causes economic growth, indicating that sustainable energy adoption may support economic development. At a 10% significance level, additional relationships emerge, including a bidirectional relationship between economic growth and electricity access, suggesting a feedback loop between economic development and energy accessibility. Similarly, carbon emissions and electricity access are bidirectional, while renewable energy consumption shows a weak causal relationship with CO_2 emissions. These findings reveal where economic growth drives emissions, but renewable energy adoption could mitigate these environmental impacts while supporting economic development and electricity access. The relationships between greenhouse gas emissions and CO_2 per capita highlight the interconnected nature of different emission metrics.

Table 6. Causality test.

Pairwise Granger Causality Tests			
Null Hypothesis:	Obs	F-Statistic	Prob.
LNECG does not Granger Cause LNATE	26	2.688	0.0913
LNATE does not Granger Cause LNECG		2.66787	0.0928
LNEVP does not Granger Cause LNATE	26	2.62193	0.0963
LNATE does not Granger Cause LNEVP		3.4242	0.0516
LNGHG does not Granger Cause LNATE	26	5.41022	0.0127
LNATE does not Granger Cause LNGHG		0.7406	0.4889
LNREC does not Granger Cause LNATE	26	4.50222	0.0236
LNATE does not Granger Cause LNREC		1.01397	0.3799
LNEVP does not Granger Cause LNECG	26	0.34617	0.7114
LNECG does not Granger Cause LNEVP		4.83548	0.0187
LNGHG does not Granger Cause LNECG	26	0.13947	0.8706
LNECG does not Granger Cause LNGHG		4.05311	0.0325
LNREC does not Granger Cause LNECG	26	4.39926	0.0254
LNECG does not Granger Cause LNREC		2.65288	0.0939
LNGHG does not Granger Cause LNEVP	26	5.5193	0.0119
LNEVP does not Granger Cause LNGHG		2.49588	0.1065
LNREC does not Granger Cause LNEVP	26	2.87057	0.0791
LNEVP does not Granger Cause LNREC		0.06375	0.9384
LNREC does not Granger Cause LNGHG	26	0.97393	0.394
LNGHG does not Granger Cause LNREC		0.1659	0.8482

The quantile regression findings in **Figure 3** and **Table 7** give full and nuanced knowledge of the links between the independent variables and environmental contaminants, offering a more sophisticated viewpoint than the OLS regression study. To elucidate the connection between renewable energy consumption (RNE), economic growth (ECG), access to electricity (ATE), greenhouse gas emissions (GHG), and Environmental pollution (EVP). **Table 7** presents the quantile regression coefficient results with their respective *p*-values, and **Figure 3** provides the quantile regression diagram, which is duly discussed after that.

Table 7. OLS and quantile regression.

VARIABLES	**OLS**	**Q (0.05)**	**Q (0.10)**	**Q (0.20)**	**Q (0.25)**	**Q (0.50)**	**Q (0.75)**	**Q (0.90)**	**Q (0.95)**
lnREC	−0.657*	−0.567	−0.567	−0.789**	−0.740	−0.433	−0.665	−0.347	−0.347
	(0.334)	(0.421)	(0.425)	(0.379)	(0.444)	(0.525)	(0.533)	(0.520)	(0.581)
lnGHG	1.231***	0.679*	0.679*	0.943***	1.015**	0.879*	1.643**	2.381***	2.381***
	(0.259)	(0.342)	(0.340)	(0.302)	(0.386)	(0.466)	(0.650)	(0.635)	(0.536)
lnATE	0.210	0.460***	0.460***	0.362**	0.332	0.467	−0.089	−0.189	−0.189
	(0.171)	(0.130)	(0.095)	(0.139)	(0.252)	(0.352)	(0.453)	(0.388)	(0.287)
lnECG	−0.984***	−0.459	−0.459	−0.886***	−0.886***	−0.633	−1.032*	−1.634***	−1.634***
	(0.309)	(0.379)	(0.368)	(0.242)	(0.288)	(0.488)	(0.588)	(0.468)	(0.417)

Table 7. (*Continued*).

VARIABLES	OLS	Q (0.05)	Q (0.10)	Q (0.20)	Q (0.25)	Q (0.50)	Q (0.75)	Q (0.90)	Q (0.95)
Constant	−4.468	−4.166	−4.166	−2.421	−3.216	−5.428	−6.955	−10.845*	−10.845*
	(3.205)	(4.007)	(4.093)	(3.604)	(3.878)	(4.253)	(4.760)	(5.425)	(5.933)
Observations	28	28	28	28	28	28	28	28	28
R-squared	0.974								

Standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

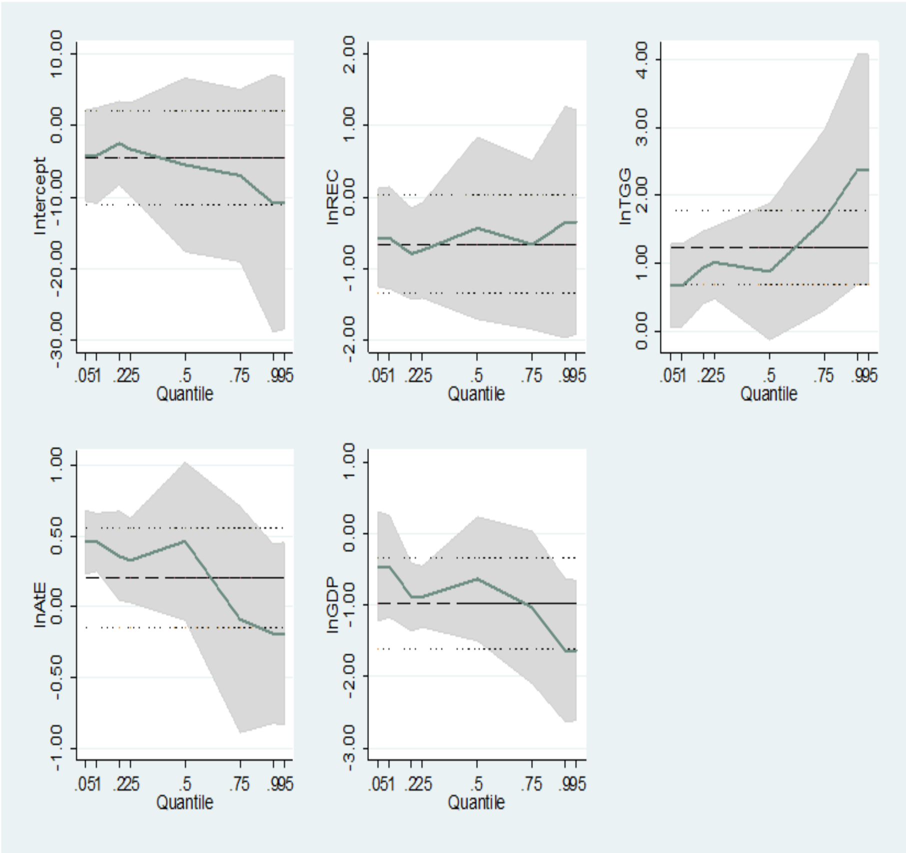


Figure 3. Quantile regression.

From the OLS and Quantile regression conclusions, renewable energy consumption (REC) has a statistically substantial deleterious bearing on EVP, as demonstrated by the OLS model aligning with the findings of [61–62,96–98]. The quantile regression results provide a more sophisticated view of this relationship. At the lower quantile (20th), REC shows a negative and statistically significant effect on EVP, indicating that in locations with lower levels of environmental pollution, increases in REC are associated with more significant decreases in pollution. The effect of REC on EVP is undesirable at the median (50th quantile) and higher quantiles. However, it is not statistically significant, indicating that the influence of REC on pollution reduction is less prominent in locations with greater environmental pollution levels. This shows that the influence of REC on lowering environmental pollution is more pronounced in places with lower pollution levels, as indicated by the lower quantiles. The OLS regression yields an average effect but does not adequately reflect this variability across the distribution. The OLS regression shows that ECG has a deleterious and statistically momentous effect on EVP [32,99–100]. The quantile regression results provide more insights. At the lower quantiles (20th and 25th), ECG shows a negative and statistically significant effect on EVP, indicating that in locations with lower levels of environmental pollution, increases in ECG are associated with higher decreases in pollution [30–33,101]. The upshot of ECG on EVP is statistically significant and negative at the median (50th quantile) and higher quantiles, indicating that the influence of ECG on pollution reduction is more pronounced in locations with higher levels of environmental pollution. The quantile regression results demonstrate that the influence of ECG on lowering environmental pollution is more pronounced in locations with higher pollution levels, as indicated by the higher quantiles. The OLS regression does not fully capture this nuance.

Economic growth gains are associated with pollution reductions at lower levels of environmental contamination (represented by the lower quantiles). This is compatible with the downward-sloping aspect of the EKC theory [75,78,102]. At more significant levels of environmental contamination (represented by the median and upper quantiles), the negative effect of economic expansion on pollution becomes more pronounced and statistically significant. This also coincides with the EKC theory, where increased economic development reduces environmental damage. The quantile regression approach provides a more detailed view of the ECG-EVP relationship than the OLS regression, which only displays the average effect. The quantile results indicate the diverse nature of this relationship over the distribution of environmental contamination levels, validating the EKC theory in Ghana. The quantile regression results in this study are primarily compatible with the expectations of the EKC hypothesis, as they reveal that the link between economic growth and environmental pollution changes over the spectrum of pollution levels. This shows that the EKC hypothesis may be a binding framework for analyzing the ECG-EVP link in Ghana.

Secondly, the OLS analysis demonstrates that access to electricity (ATE) has a positive but statistically negligible influence on environmental pollution (EVP). The quantile regression findings give more information than sophisticated ones. ATE has a positive and substantial effect on EVP at lower quantiles (5th, 10th, 20th), indicating that in locations with lower pollution levels, ATE increases relate to higher pollution increases [19]. At the median and higher quantiles, the effect of ATE on EVP is negative but negligible, suggesting ATE's impact on pollution is less evident in places with greater pollution levels [82]. Furthermore, the OLS demonstrates that greenhouse gas emissions (GHG) positively and statistically significantly influence EVP [47–50]. From the quantile regression, GHG demonstrates a positive and substantial influence on EVP across all quantiles, demonstrating that increases in GHG are related to immense pollution rises throughout the whole distribution [18–20,103–107]. The quantile regression provides complete knowledge of the interactions between the independent variables and environmental pollutants. The impacts of renewable energy consumption (REC), economic growth (ECG), and ATE on EVP vary throughout the distribution, with more apparent effects at lower quantiles. In contrast, GHG consistently has a favorable and substantial influence on EVP across all quantiles. Compared to OLS, quantile regression shows diverse effects that are not represented by the average impact reported in the OLS model. This method shows complex effects that change throughout the conditional distribution of the dependent variable.

5. Conclusions and policy implications

5.1. Conclusion

This study provides valuable insights into Ghana's intricate relationship between renewable energy consumption, economic growth, and environmental pollution. The findings from the ARDL and quantile regression analyses offer important policy implications for Ghana's pursuit of sustainable development and environmental sustainability. The primary driver of carbon emissions is energy usage, which leads to global ecological degradation and challenges that nations face. Firstly, the quantile regression results reveal that the influence of renewable energy consumption on environmental pollution varies across different pollution levels in Ghana. While increased renewable energy consumption effectively reduces pollution in lower pollution levels, its impact is less pronounced in areas with higher pollution intensities. This highlights the need for a targeted approach, where renewable energy policies and investments are strategically focused on sectors or regions contributing significantly to Ghana's overall pollution levels. Secondly, the positive and significant relationship between greenhouse gas emissions and environmental pollution across most quantiles underscores the urgency for Ghana to adopt comprehensive mitigation strategies. Reducing greenhouse gas emissions from various sectors, such as energy, transportation, and industry, should be a top priority to combat environmental degradation effectively. Furthermore, the study also reveals an interesting pattern regarding the role of economic growth in environmental pollution. While economic growth tends to reduce pollution in regions or sectors with lower pollution levels, it may exacerbate pollution in areas with already high pollution intensities. This finding emphasizes the importance of striking an elusive balance between Ghana's economic development and environmental sustainability. When viewed through the EKC framework, the quantile regression results suggest that economic growth's impression on Ghana's environmental pollution follows an inverted U-shaped pattern. Economic growth in regions or sectors with lower pollution levels initially increases pollution. However, beyond a particular turning point, further growth is associated with a decline in pollution levels. This pattern aligns with the EKC theory, which posits that environmental degradation increases in the early stages of economic development but decreases after a certain income level is attained as societies prioritize environmental quality and adopt cleaner technologies. Policymakers should prioritize the implementation of cleaner production technologies, stricter environmental regulations, and incentives for industries to adopt eco-friendly practices, particularly in areas with high pollution levels. Notably, the ARDL long-run coefficients indicate that none of the variables (renewable energy consumption, greenhouse gas releases, access to electricity, or economic growth) has a statistically significant impact on CO_2 emanations in the long run. This suggests that the relationships between these factors and environmental pollution may evolve, and more extended periods may be required to capture their full effects. Continuous monitoring and analysis of these variables are crucial to inform policy adjustments and ensure the effectiveness of implemented strategies. Lastly, this study accentuates the necessity for a multifaceted approach to address environmental pollution in Ghana. Policymakers should prioritize promoting renewable energy sources, particularly in sectors or regions with high pollution levels, while simultaneously implementing effective greenhouse gas emission reduction strategies. Sustainable economic growth should be pursued by balancing development and environmental protection, adopting cleaner technologies, and encouraging eco-friendly practices across all sectors.

5.2. Policy recommendations

Clear policy implications exist for Ghana to consider based on the analytical results given. Initially, it will be critical for the government to prioritize cooperative relationships with businesses in the private sector, offer enticing tax breaks and subsidies to support renewable energy initiatives and create a welcoming regulatory framework that stimulates investment in hydropower, solar, and wind energy solutions. These steps will be vital for boosting the acceptance and expansion of renewable energy in Ghana. Harnessing Ghana’s vast renewable energy potential can significantly reduce the region’s reliance on fossil fuels and mitigate greenhouse gas emissions, contributing to global efforts in combating climate change. Implement carbon pricing mechanisms and emissions trading systems tailored to the Ghanaian context. By introducing market-based instruments such as carbon taxes or emissions trading systems, industries and businesses across the continent will be incentivized to reduce their carbon footprint and adopt cleaner technologies. These mechanisms can generate revenue streams for the government, which can be reinvested in renewable energy projects, energy efficiency initiatives, and environmental protection programs, fostering a sustainable development pathway. Strengthen regional cooperation and knowledge sharing among African nations. Sub-Saharan countries like Rwanda have taken more aggressive steps with environmental regulations. Environmental challenges transcend national boundaries, and regional collaboration is crucial for effective mitigation and adaptation strategies. African countries should collaborate to set ambitious regional emissions targets, share best practices, and develop joint initiatives promoting sustainable development. Rwanda’s National Environment and Climate Change Policy emphasizes strict enforcement of emission standards and comprehensive urban planning, contributing to lower pollution levels. Ghana could benefit from strengthening enforcement mechanisms and integrating carbon pricing and emission trading systems to create more accountability in environmental governance. Establishing platforms for knowledge sharing and technology transfer can accelerate the adoption of clean energy solutions and drive progress toward a greener Africa. Invest in sustainable urbanization and green infrastructure to accommodate the rapid urban growth in Africa. This includes developing efficient public transportation systems, constructing energy-efficient buildings, implementing robust waste management facilities, and incorporating green spaces into urban planning. Sustainable urbanization can significantly reduce the environmental impact of cities and improve the quality of life for urban residents, aligning with global goals for sustainable development. Enhance ecological education and public awareness campaigns across African communities. Raising awareness about environmental protection and the benefits of renewable energy is crucial for driving behavioral changes and fostering societal support for sustainable policies. Governments should invest in environmental education programs, public awareness campaigns, and community engagement initiatives to promote eco-friendly practices and sustainable lifestyles, empowering citizens to be agents of change. Actively align African policies with global climate change mitigation efforts and international agreements. African countries should actively participate in global climate change negotiations and ensure their policies are aligned with international frameworks, such as the Paris Agreement and the United Nations Sustainable Development Goals (SDGs). This collaboration can facilitate access to global financing, technology transfer, and capacity-building support, accelerating Africa's transition towards a more sustainable future. Promote sustainable agriculture and forestry practices to address the significant contributions of these sectors to greenhouse gas emissions and environmental degradation in Africa. Governments should incentivize conservation agriculture, agroforestry, precision farming, forest conservation, reforestation efforts, and sustainable forest management practices. By prioritizing these sustainable practices, Africa can protect its natural resources, improve food security, and contribute to global efforts to mitigate climate change. By implementing these personalized strategic and practical policy recommendations, Ghana and African nations can leverage the potential of renewable energy and sustainable economic growth to address environmental pollution challenges while actively contributing to global efforts in combating climate change and achieving sustainable development goals for a greener and more prosperous future.

5.3. Limitations and suggestions for future research

This study has a few limitations. First, it focuses only on Ghana, which may limit the applicability of findings to other African nations. Future research should expand the analysis to multiple countries for broader insights. Second, using national-level data might overlook regional differences. Future studies could use more localized data to capture variations between rural and urban areas. Third, while ARDL and quantile regression were effective, other models, like non-linear or machine learning techniques, could better explore complex relationships. Finally, additional factors like industrialization and trade openness should be considered in future analyses.

Author contributions: Conceptualization, MPF and GMS; methodology, MPF; software, GMS; validation, MPF; formal analysis, MPF; investigation, JW and NM; resources, CAN; data curation, MPF; writing—original draft preparation, MPF and JW; writing—review and editing, MPF and DEA; visualization, GMS and CAN; supervision, NM. All authors have read and agreed to the published version of the manuscript.

Conflict of interest: The authors declare no conflict of interest.

References

1. Khadka A, Hebert J, Maria Glymour M, et al. Quantile regressions as a tool to evaluate how an exposure shifts and reshapes the outcome distribution: A primer for epidemiologists. MedRxiv (Cold Spring Harbor Laboratory); 2023. doi:

10.1101/2023.05.02.23289415
2. Acharya S, Shil A, Debbarma C, et al. Analysis of energy consumption, emission and saving opportunities in an educational institute in northeast India. International Journal of Energy and Water Resources. 2020; 4(4): 375-388. doi: 10.1007/s42108-020-00086-1
3. Achuo ED, Ojong N. Energy transition and pollution emissions in developing countries: are renewable energies guilty? International Journal of Development Issues. 2023; 22(3): 361-382. doi: 10.1108/ijdi-05-2023-0114
4. Adams S, Klobodu EKM, Apio A. Renewable and non-renewable energy, regime type and economic growth. Renewable Energy. 2018; 125: 755-767. doi: 10.1016/j.renene.2018.02.135
5. Adenuga OT, Mpofu K, Modise RK. Energy–Carbon Emissions Nexus Causal Model towards Low-Carbon Products in Future Transport-Manufacturing Industries. Energies. 2022; 15(17): 6322. doi: 10.3390/en15176322
6. Agbata AE, Egolum PU, Offia AC, et al. Corporate governance and firm sustainability in the emerging economy: A literature review. Corporate Governance and Sustainability Review. 2023; 6(4): 33-43. doi: 10.22495/cgsrv6i4p3
7. Sampene AK, Li C, Wiredu J. An outlook at the switch to renewable energy in emerging economies: The beneficial effect of technological innovation and green finance. Energy Policy. 2024; 187: 114025. doi: 10.1016/j.enpol.2024.114025
8. Al-Attar AM. Vitamin E. Attenuates liver injury induced by exposure to lead, mercury, cadmium and copper in albino mice. Saudi Journal of Biological Sciences. 2011; 18(4): 395-401. doi: 10.1016/j.sjbs.2011.07.004
9. Ali A, Radulescu M, Balsalobre-Lorente D. A dynamic relationship between renewable energy consumption, nonrenewable energy consumption, economic growth, and carbon dioxide emissions: Evidence from Asian emerging economies. Energy & Environment. 2023; 34(8): 3529-3552. doi: 10.1177/0958305x231151684
10. Asumadu-Sarkodie S, Yadav P. Achieving a cleaner environment via the environmental Kuznets curve hypothesis: determinants of electricity access and pollution in India. Clean Technologies and Environmental Policy. 2019; 21(9): 1883-1889. doi: 10.1007/s10098-019-01756-3
11. Aydin C, Cetintas Y. Does Renewable Energy Determine the Environmental Impacts of Economic Growth? New Evidence from PSTR Analysis. 2022. doi: 10.21203/rs.3.rs-1388826/v1
12. Aydin M, Koc P, Sahpaz KI. Investigating the EKC hypothesis with nanotechnology, renewable energy consumption, economic growth and ecological footprint in G7 countries: panel data analyses with structural breaks. Energy Sources, Part B: Economics, Planning, and Policy. 2023; 18(1). doi: 10.1080/15567249.2022.2163724
13. Izah SC, Ogwu MC. Sustainable Utilization and Conservation of Africa's Biological Resources and Environment. Springer Nature Singapore; 2023. doi: 10.1007/978-981-19-6974-4
14. Bahe AR, Staveley J, Classen J, et al. Emerging Environmental Contaminants: Current Science And Policy Concerns. Animal Agriculture and the Environment, National Center for Manure & Animal Waste Management White Papers; 2006. doi: 10.13031/2013.20253
15. Barış-Tüzemen Ö, Tüzemen S, Çelik AK. Does an N-shaped association exist between pollution and ICT in Turkey? ARDL and quantile regression approaches. Environmental Science and Pollution Research. 2020; 27(17): 20786-20799. doi: 10.1007/s11356-020-08513-w
16. Baum S, Ma J, Payea K. Education Pays, 2013: The Benefits of Higher Education for Individuals and Society. Trends in Higher Education Series. In ERIC. College Board; 2013.
17. Baxi U. Human Rights Responsibility of Multinational Corporations, Political Ecology of Injustice: Learning from Bhopal Thirty Plus? Business and Human Rights Journal. 2015; 1(1): 21-40. doi: 10.1017/bhj.2015.7
18. Ampomah Asiedu B. Economic Growth and Environmental Pollution; Testing the EKC Hypothesis in Brazil. The Toxicity of Environmental Pollutants; 2022. doi: 10.5772/intechopen.104388
19. C OO, O OO, R FA, et al. Environmental pollution as health depreciator: the case of household generator use in nigeria. Global Journal of Pure and Applied Sciences. 2023; 29(1): 11-17. doi: 10.4314/gjpas.v29i1.2
20. de Abreu MCS, Soares RA, Daniel-Vasconcelos V, et al. Does board diversity encourage an environmental policy focused on resource use, emission reduction and innovation? The case of companies in Latin America. Corporate Social Responsibility and Environmental Management. 2022; 30(3): 1161-1176. doi: 10.1002/csr.2411
21. Çelik D. The Share of Renewable Energy as a Factor Affecting Economic Growth and Foreign Trade Balance (Turkish). Kent Akademisi. 2022; 15(2): 781-797. doi: 10.35674/kent.1094116
22. Chakravorty U, Emerick K, Ravago ML. Lighting Up the Last Mile: The Benefits and Costs of Extending Electricity to the Rural Poor. SSRN Electronic Journal. 2016. doi: 10.2139/ssrn.2851907

23. Cloy JM, Smith KA. Greenhouse Gas Emissions☆. Reference Module in Earth Systems and Environmental Sciences; 2015. doi: 10.1016/b978-0-12-409548-9.05178-2
24. Asif M. Energy and Environmental Security in Developing Countries. Springer International Publishing; 2021. doi: 10.1007/978-3-030-63654-8
25. Dhillon DK, Kaur K. A nexus between sustainability, energy utilisation and economic growth at aggregate and disaggregate level: a case of India. International Journal of Energy Sector Management. 2023; 18(3): 433-456. doi: 10.1108/ijesm-09-2022-0013
26. Dion G. Green Debate. JEMS. 2021; 36(4): 16-16. doi: 10.1016/s0197-2510(11)70076-6
27. Eboe-Osuji C, Emeseh E. Nigerian Yearbook of International Law 2017. Springer International Publishing; 2018. doi: 10.1007/978-3-319-71476-9
28. Ali EB, Gyamfi BA, Bekun FV, et al. An empirical assessment of the tripartite nexus between environmental pollution, economic growth, and agricultural production in Sub-Saharan African countries. Environmental Science and Pollution Research. 2023; 30(27): 71007-71024. doi: 10.1007/s11356-023-27307-4
29. Felix D, Edmond D. Managing Environmental Degradation Using Traditional, Cultural and Spiritual Strategies the Tale of Dagaaba and Birifor People. Asian Journal of Education and Social Studies. 2023: 17-22. doi: 10.9734/ajess/2023/v38i4831
30. Field BG. GDP revisited. Journal of Mega Infrastructure & Sustainable Development. 2020; 2(3): 310-313. doi: 10.1080/24724718.2021.2087962
31. Fu Y, Yang C, Li T, et al. Study of renewable energy consumption under energy internet. Advances in Energy, Environment and Chemical Engineering Volume 1. 2022: 470-476. doi: 10.1201/9781003330165-69
32. Fumey MP, Wiredu J, Essuman AN. Evaluating taxation's dual impact on business and social development: A case study of the Cape Coast metropolis in Ghana. Financial Statistical Journal. 2024; 7(1). doi: 10.24294/fsj.v6i2.3833
33. Giles DE. Roger Koenker, Victor Chernozhukov, et al. Handbook of Quantile Regression. Statistical Papers; 2018. 59(2): 849-850. doi: 10.1007/s00362-018-1004-2
34. Greenstone M, Hanna R. Environmental Regulations, Air and Water Pollution, and Infant Mortality in India. National Bureau of Economic Research; 2011. doi: 10.3386/w17210
35. Granger CWJ. Investigating Causal Relations by Econometric Models and Cross-spectral Methods. Econometrica. 1969; 37(3): 424. doi: 10.2307/1912791
36. Grossman GM, Krueger AB. Economic Growth and the Environment. The Quarterly Journal of Economics. 1995; 110(2): 353-377. doi: 10.2307/2118443
37. Guo X, Huang K, Li L, et al. Renewable Energy for Balancing Carbon Emissions and Reducing Carbon Transfer under Global Value Chains: A Way Forward. Sustainability. 2022; 15(1): 234. doi: 10.3390/su15010234
38. Haider A, Rankaduwa W, Shaheen F, et al. The Nexus between GHGs Emissions and Clean Growth: Empirical Evidence from Canadian Provinces. Sustainability. 2023; 15(3): 2218. doi: 10.3390/su15032218
39. Dissanayake H, Perera N, Abeykoon S, et al. Nexus between carbon emissions, energy consumption, and economic growth: Evidence from global economies. PLOS ONE. 2023; 18(6): e0287579. doi: 10.1371/journal.pone.0287579
40. Hashmi SH, Fan H, Fareed Z, et al. Asymmetric nexus between urban agglomerations and environmental pollution in top ten urban agglomerated countries using quantile methods. Environmental Science and Pollution Research. 2020; 28(11): 13404-13424. doi: 10.1007/s11356-020-10669-4
41. He P, Liang J, Qiu Y, et al. Increase in domestic electricity consumption from particulate air pollution. Nature Energy. 2020; 5(12): 985-995. doi: 10.1038/s41560-020-00699-0
42. Hübler M. The inequality-emissions nexus in the context of trade and development: A quantile regression approach. Ecological Economics. 2017; 134: 174-185. doi: 10.1016/j.ecolecon.2016.12.015
43. Ibili F, Adams CA, Adebanji AO, et al. The state-of-the-art of practice of traffic noise regulations in Ghana. Noise & Vibration Worldwide. 2023; 54(4-5): 204-214. doi: 10.1177/09574565231161645
44. Gharbi I, Kammoun A, Kefi MK. To what extent does renewable energy deployment reduce pollution indicators? the moderating role of research and development expenditure: Evidence from the top three ranked countries. Frontiers in Environmental Science. 2023; 11. doi: 10.3389/fenvs.2023.1096885
45. Islam MdS. Influence of economic growth on environmental pollution in South Asia: a panel cointegration analysis. Asia-Pacific Journal of Regional Science. 2021; 5(3): 951-973. doi: 10.1007/s41685-021-00208-5
46. Ivanovski K, Hailemariam A. Is globalisation linked to CO2 emission? Evidence from OECD nations. Environmental and

Ecological Statistics. 2021; 29(2): 241-270. doi: 10.1007/s10651-021-00520-5

47. Jantre SR, Bhattacharya S, Maiti T. Quantile Regression Neural Networks: A Bayesian Approach. Journal of Statistical Theory and Practice. 2021; 15(3). doi: 10.1007/s42519-021-00189-w
48. Jena PR, Majhi B, Majhi R. Estimating Long-Run Relationship between Renewable Energy Use and CO2 Emissions: A Radial Basis Function Neural Network (RBFNN) Approach. Sustainability. 2022; 14(9): 5260. doi: 10.3390/su14095260
49. Kayani UN, Sadiq M, Rabbani MR, et al. Examining the Relationship between Economic Growth, Financial Development, and Carbon Emissions: A Review of the Literature and Scientometric Analysis. International Journal of Energy Economics and Policy. 2023; 13(2): 489-499. doi: 10.32479/ijeep.14278
50. Anmol KT. Learning for development: factors that lead to successful development projects for marginalised communities affected by climate change in Bangladesh. University of Canterbury; 2020. doi: 10.26021/10813
51. Lau LS, Yii KJ, Ng CF, et al. Environmental Kuznets curve (EKC) hypothesis: A bibliometric review of the last three decades. Energy & Environment. 2023: 0958305X2311777. doi: 10.1177/0958305x231177734
52. Li C, Sampene AK, Agyeman FO, et al. The role of green finance and energy innovation in neutralizing environmental pollution: Empirical evidence from the MINT economies. Journal of Environmental Management. 2022; 317: 115500. doi: 10.1016/j.jenvman.2022.115500
53. Li G, Koomson DA, Huang J, et al. A review from environmental management to environmental governance: paradigm shift for sustainable mining practice in Ghana. Environment, Development and Sustainability. 2020; 23(7): 9710-9724. doi: 10.1007/s10668-020-01050-z
54. Llácer-Iglesias RM, López-Jiménez PA, Pérez-Sánchez M. Energy Self-Sufficiency Aiming for Sustainable Wastewater Systems: Are All Options Being Explored? Sustainability. 2021; 13(10): 5537. doi: 10.3390/su13105537
55. López-González LM, López-Ochoa LM, Las-Heras-Casas J, et al. Final and primary energy consumption of the residential sector in Spain and La Rioja (1991–2013), verifying the degree of compliance with the European 2020 goals by means of energy indicators. Renewable and Sustainable Energy Reviews. 2018; 81: 2358-2370. doi: 10.1016/j.rser.2017.06.044
56. Manisalidis I, Stavropoulou E, Stavropoulos A, et al. Environmental and Health Impacts of Air Pollution: A Review. Frontiers in Public Health. 2020; 8. doi: 10.3389/fpubh.2020.00014
57. Manta AG, Florea NM, Bădîrcea RM, et al. The Nexus between Carbon Emissions, Energy Use, Economic Growth and Financial Development: Evidence from Central and Eastern European Countries. Sustainability. 2020; 12(18): 7747. doi: 10.3390/su12187747
58. Elbadri M, Bsikre S, Alamari O, et al. Nexus between renewable energy consumption, economic growth, and CO2 emissions in Algeria: New evidence from the Fourier-Bootstrap ARDL approach. Natural Resources Forum. 2023; 47(3): 393-412. doi: 10.1111/1477-8947.12292
59. Ayyat MS, Mahmoud HK, El-Hais AEAM, et al. The role of some feed additives in fish fed on diets contaminated with cadmium. Environmental Science and Pollution Research. 2017; 24(30): 23636-23645. doi: 10.1007/s11356-017-9986-1
60. Mose N, Fumey M, Kipchirchir E. Drivers of Carbon Emissions in Kenya: The Perspective of Technology. Asian Journal of Geographical Research. 2024; 7(2): 1-10. doi: 10.9734/ajgr/2024/v7i2226
61. Mukhtarov S, Aliyev F, Aliyev J, et al. Renewable Energy Consumption and Carbon Emissions: Evidence from an Oil-Rich Economy. Sustainability. 2022; 15(1): 134. doi: 10.3390/su15010134
62. Murshed M. Can regional trade integration facilitate renewable energy transition to ensure energy sustainability in South Asia? Energy Reports. 2021; 7: 808-821. doi: 10.1016/j.egyr.2021.01.038
63. Muszeros O, Zsult KG. Collaboration of Communities and Non-Profit Organizations in Addressing Environmental Problems with African Countries. International Journal Papier Public Review. 2021; 2(2): 15-20. doi: 10.47667/ijppr.v2i2.83
64. Necibi MC, Dhiba D, El Hajjaji S. Contaminants of Emerging Concern in African Wastewater Effluents: Occurrence, Impact and Removal Technologies. Sustainability. 2021; 13(3): 1125. doi: 10.3390/su13031125
65. Neumann R, Mehlkop G. Neutralization strategies account for the concern-behavior gap in renewable energy usage – Evidence from panel data from Germany. Energy Research & Social Science. 2023; 99: 103041. doi: 10.1016/j.erss.2023.103041
66. Muhammad T, Farah Z, Sania A, et al. Nexus between Carbon emission per capita and Urbanization. Journal of Economics, Management & Business Administration. 2023; 1(2): 15-26. doi: 10.59075/jemba.v1i2.116
67. Okereafor U, Makhatha M, Mekuto L, et al. Toxic Metal Implications on Agricultural Soils, Plants, Animals, Aquatic life and Human Health. International Journal of Environmental Research and Public Health. 2020; 17(7): 2204. doi:

10.3390/ijerph17072204
68. Osemene OF, Adinnu P, Fagbemi TO, et al. Corporate Governance and Environmental Accounting Reporting in Selected Quoted African Companies. Global Business Review. 2021; 25(4): 1096-1119. doi: 10.1177/09721509211010989
69. Paganelli MP. Population as a GDP Proxy in Adam Smith. Journal of Scottish Philosophy. 2021; 19(2): 115-123. doi: 10.3366/jsp.2021.0297
70. Mleczek P, Borowiak K, Budka A, et al. Possible sources of rare earth elements near different classes of road in Poland and their phytoextraction to herbaceous plant species. Environmental Research. 2021; 193: 110580. doi: 10.1016/j.envres.2020.110580
71. Pellagatti M, Masci C, Ieva F, et al. Generalized mixed‐effects random forest: A flexible approach to predict university student dropout. Statistical Analysis and Data Mining: The ASA Data Science Journal. 2021; 14(3): 241-257. doi: 10.1002/sam.11505
72. Pereira MG, Sena JA, Freitas MAV, et al. Evaluation of the impact of access to electricity: A comparative analysis of South Africa, China, India and Brazil. Renewable and Sustainable Energy Reviews. 2011; 15(3): 1427-1441. doi: 10.1016/j.rser.2010.11.005
73. Piacentini RD, Garro S. Carbon neutral industries and compensation for greenhouse gas emissions. Drying Technology. 2022; 40(16): 3371-3372. doi: 10.1080/07373937.2022.2149181
74. Proudlove R, Finch S, Thomas S. Factors influencing intention to invest in a community owned renewable energy initiative in Queensland, Australia. Energy Policy. 2020; 140: 111441. doi: 10.1016/j.enpol.2020.111441
75. Raihan A. Nexus between economic growth, natural resources rents, trade globalization, financial development, and carbon emissions toward environmental sustainability in Uruguay. Electronic Journal of Education, Social Economics and Technology. 2023; 4(2): 55-65. doi: 10.33122/ejeset.v4i2.102
76. Rezania S, Park J, Md Din MF, et al. Microplastics pollution in different aquatic environments and biota: A review of recent studies. Marine Pollution Bulletin. 2018; 133: 191-208. doi: 10.1016/j.marpolbul.2018.05.022
77. Nahrin R, Rahman MdH, Majumder SC, et al. Economic Growth and Pollution Nexus in Mexico, Colombia, and Venezuela (G-3 Countries): The Role of Renewable Energy in Carbon Dioxide Emissions. Energies. 2023; 16(3): 1076. doi: 10.3390/en16031076
78. Ross TA, Zhang J, Wille M, et al. Interplay between pollution and avian influenza virus in shorebirds and waterfowl. 2023. doi: 10.1101/2023.02.23.529812
79. Rykowska I, Wasiak W. Research trends on emerging environment pollutants – a review. Open Chemistry. 2015; 13(1). doi: 10.1515/chem-2015-0151
80. Sadhu SD, Garg M, Kumar A. Major environmental issues and new materials. New Polymer Nanocomposites for Environmental Remediation. 2018: 77-97. doi: 10.1016/b978-0-12-811033-1.00004-4
81. Saqib N, Usman M, Radulescu M, et al. Revisiting EKC hypothesis in context of renewable energy, human development and moderating role of technological innovations in E-7 countries? Frontiers in Environmental Science. 2022; 10. doi: 10.3389/fenvs.2022.1077658
82. Sarkar S. Mycoremediation—The promising thread between the present and future. International Journal of Chemical and Environmental Sciences. 2022; 3(4): 34-45. doi: 10.15864/ijcaes.3404
83. Saunois M, Bousquet P, Poulter B, et al. Variability and quasi-decadal changes in the methane budget over the period 2000–2012. Atmospheric Chemistry and Physics. 2017; 17(18): 11135-11161. doi: 10.5194/acp-17-11135-2017
84. Schneider N. Sustainable development or environmental Kuznets curve: some unresolved controversies. International Journal of Environmental Studies. 2022; 80(3): 531-534. doi: 10.1080/00207233.2022.2078109
85. Semenova G. Global environmental problems in the world. E3S Web of Conferences. 2020; 217: 11004. doi: 10.1051/e3sconf/202021711004
86. Singh VP, Yadav S, Yadav KK, et al. Environmental Degradation: Challenges and Strategies for Mitigation. Springer International Publishing; 2022. doi: 10.1007/978-3-030-95542-7
87. Ssali MW, Du J, Mensah IA, et al. RETRACTED ARTICLE: Investigating the nexus among environmental pollution, economic growth, energy use, and foreign direct investment in 6 selected sub-Saharan African countries. Environmental Science and Pollution Research. 2019; 26(11): 11245-11260. doi: 10.1007/s11356-019-04455-0
88. Tai-Young K, Jong-Bae B. Effective Removal of Air Pollutions by the Electrical Discharge. Journal of Environmental Science and Engineering A. 2017; 6(11). doi: 10.17265/2162-5298/2017.11.001

89. La Rocca M, Liseo B, Salmaso L, et al. Nonparametric Statistics. Springer International Publishing; 2020. doi: 10.1007/978-3-030-57306-5
90. Tarun Mohanty A. Measuring GDP and Economic Growth: An Economic Barometer. International Journal of Tax Economics and Management. 2019; 2(1): 42-58. doi: 10.35935/tax/21.5842
91. Tetteh B, Baidoo ST. Environmental degradation, energy use, and globalization in Ghana: New empirical evidence from regime switching and neural network autoregression models. Sustainability: Science, Practice and Policy. 2022; 18(1): 679-695. doi: 10.1080/15487733.2022.2110680
92. Thangasamy R, Deo M. The Nexus Between Environmental Pollution, Energy Use and Economic Growth of EAGLEs: A Panel Econometric Analysis. International Journal of Ecology and Environmental Sciences. 2022; 49(3). doi: 10.55863/ijees.2023.2491
93. Thi D, Tran VQ, Nguyen DT. The relationship between renewable energy consumption, international tourism, trade openness, innovation and carbon dioxide emissions: international evidence. International Journal of Sustainable Energy. 2023; 42(1): 397-416. doi: 10.1080/14786451.2023.2192827
94. Timur MC, Doğan-Çalişkan Z. The Importance of Energy Sources in the Prevention of Environmental Pollution. International Journal of English Literature and Social Sciences. 2017; 2(4): 68-73. doi: 10.24001/ijels.2.4.9
95. Tudor C. The Nexus between Pollution and Obesity and the Magnifying Role of Media Consumption: International Evidence from GMM Systems Estimates. International Journal of Environmental Research and Public Health. 2022; 19(16): 10260. doi: 10.3390/ijerph191610260
96. Uddin MMM. Revisiting the impacts of economic growth on environmental degradation: new evidence from 115 countries. Environmental and Ecological Statistics. 2021; 28(1): 153-185. doi: 10.1007/s10651-020-00479-9
97. van Ruijven BJ, Schers J, van Vuuren DP. Model-based scenarios for rural electrification in developing countries. Energy. 2012; 38(1): 386-397. doi: 10.1016/j.energy.2011.11.037
98. Vetter SH, Nayak D, McBey D, et al. Environmental Issues: Greenhouse Gas Emissions. Sustainable Food Science - A Comprehensive Approach. 2023: 216-248. doi: 10.1016/b978-0-12-823960-5.00043-3
99. Patidar VK, Wadhvani R, Shukla S, et al. Quantile Regression Comprehensive in Machine Learning: A Review. In: Proceedings of the 2023 IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS). 2023. doi: 10.1109/sceecs57921.2023.10063026
100. Wang Q, Yang X, Li R, et al. Revisiting the impact of renewable energy on carbon emission in 130 countries—The mediating effect of resource rental rents and human capital. Energy & Environment. 2023: 0958305X2311777. doi: 10.1177/0958305x231177726
101. Wiredu J, Yang Q, Inuwa UL, et al. Energy transition in Africa: The role of human capital, financial development, economic development, and carbon emissions. Environmental Science & Policy. 2023; 146: 24-36. doi: 10.1016/j.envsci.2023.04.021
102. Yan C, Li H, Li Z. Environmental pollution and economic growth: Evidence of SO2 emissions and GDP in China. Frontiers in Public Health. 2022; 10. doi: 10.3389/fpubh.2022.930780
103. Yilmaz R. Industrial Development and the Environmental Kuznets Curve: A Case Study on Ergene Basin (Turkish). Sosyal Bilimler Metinleri. 2022; 2022(2): 99-108. doi: 10.56337/sbm.1158780
104. You Y, Huang H, Shao L, et al. Research on the optimization and improvement of business environment based on the customer satisfaction model of 'Access to Electricity'. E3S Web of Conferences. 2023; 369: 01009. doi: 10.1051/e3sconf/202336901009
105. Ünvan YA. A credit default swap application by using quantile regression technique. Communications in Statistics - Theory and Methods. 2020; 50(7): 1573-1586. doi: 10.1080/03610926.2019.1711126
106. Zhang T, Yin J, Li Z, et al. RETRACTED: A dynamic relationship between renewable energy consumption, non-renewable energy consumption, economic growth and CO2 emissions: Evidence from Asian emerging economies. Frontiers in Environmental Science. 2023; 10. doi: 10.3389/fenvs.2022.1092196
107. Zhong Q, Wang JL. Neural Networks for Partially Linear Quantile Regression. Journal of Business & Economic Statistics. 2023; 42(2): 603-614. doi: 10.1080/07350015.2023.2208183