Renewable energy demand, financial reforms, and environmental quality in West Africa

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Abstract Sustainable Development Goal (SDG-7) stipulates the need for clean energy, reduced carbon dioxide emissions, prevention of environmental degradation, promotion of biodiversity, and ecosystem preservation. Toward achieving these goals, this study provides new evidence on the causal link between renewable energy demand, financial reforms, economic growth, foreign direct investment, and environmental quality among emerging West African economies. The study adopted the fully modified ordinary least squares, dynamic ordinary least squares, pooled mean group estimation, and Granger causality test for its analysis. It was found that renewable energy demand has been favorable to the environmental health of West African economies. Also, financial reforms made within the region contributed to increasing the ecological footprints of the region. Direct investments from foreigners showed encouraging results as they improved the quality of the environment. We also found a unidirectional causality from ecological footprints to renewable energy demand and financial reforms but a bidirectional relationship with economic growth and foreign direct investment. Moreover, it was evident that ecological footprints Granger cause financial reforms and economic growth but not vice versa. Policy recommendations outlined encourage governments and policymakers to embark on intensive clean energy technologies and effective green financial reforms to help achieve Sustainable Development Goals.

Keywords Renewable energy demand · Financial reforms · Economic growth · Environmental quality · West Africa

Introduction

The significant share of fossil energy in our current energy structure has skyrocketed greenhouse gas emissions (Zhang et al. 2020). Carbon dioxide (CO2) emissions from fossil fuels and other gasses are key contributors to greenhouse gas emissions and their consequences (Xu et al. 2020; Yang et al. 2015). CO2 emissions pose a significant risk to biodiversity and long-term sustainability (Nathaniel and Iheonu 2019). Unfortunately, human activities are still the dominant source of global greenhouse gasses (Li et al. 2019). It has been a never-ending debate about CO2 emissions and global warming ever since the turn of the century (Liu and Xiao 2019).
2018), prompting coordinated worldwide action from various sources.

Energy demand is constantly increasing in production and consumption due to increasing population density and industrialization. Most of the world’s energy resources are fossil fuels, including natural gas, coal, and oil (Khan et al. 2020a, b; Shahbaz et al. 2021). Evidently, increasing fossil fuel consumption proportionately increases CO₂ emissions in the atmosphere, which eventually promotes environmental pollution (Khan et al. 2020a, b). Pollution resulting from CO₂ emissions from diverse sources has impacted human health adversely and contributes to mortality (Nathaniel and Adeleye 2021). In Africa, the high mortality rate makes it even more alarming (Nathaniel and Adeleye 2021). In view of this, low-carbon and green energy production has become a prevalent trend due to these global challenges (Bauer et al. 2016; Fang et al. 2020). With the public’s knowledge of global CO₂ emissions, new technical ways to lower pollution, fossil fuel usage, and improve energy demand efficiency have become critical (Shahbaz et al. 2021). To ensure a green future environment, we must move from traditional fossil fuel energy to renewable energy (Zhang et al. 2021) and the greatest fundamental hurdle to overcome in solving this feasible task is the cost of production and other financial restrictions (Shahbaz et al. 2021).

Fortunately, some studies have found that financial development is critical in addressing environmental pollution through renewable energy generation (Destek and Sarkodie 2019; Katircioğlu and Taşpinar 2017; Sarkodie and Strezov 2019; Xu et al. 2020). By improving the environment and promoting environmentally friendly activities through research, good financial systems can help to reduce environmental deterioration and facilitate clean technology investments in renewable energy projects (Zhang 2011). Therefore, it has become important for countries with long-term visions to have a well-developed financial system, which prioritizes a green economy.

To combat this threat, literature on this subject recommends that African economies focus on clean, renewable energy sources, reduce emissions, and improve environmental quality (Nathaniel and Iheonu 2019; Zhang et al. 2019). Oil, natural gas, and other natural resources with high emissions are often produced by developing countries, including Africa (Khan et al. 2020a). Africa is known for its abundance of clean energy sources, but the substantial reliance on non-renewable energy sources, which deteriorate the environment, is concerning (Aiyu et al. 2018; da Silva et al. 2018). With Africa exploring a free trade agreement, research has become extremely important as this agreement is expected to create $3.4 trillion in combined gross domestic products (GDP) and reduce red tape and streamline customs for a total of $292 billion in potential revenue benefits (WorldBank 2021). This calls for financial reforms in various sectors, renewable energy investments, and foreign direct investments. Also, a call for studies that consider such a prominent course and sustainability is needed as it is rarely available. Narrowing this problem, West African economies share many things in common as the countries in the region embark on a journey to create a common currency (Eco). This will have a greater impact on their investment trend, trade, financial reforms, and energy usage. As a result, this study is narrowed to some selected countries in the West of Africa to enhance a deeper analysis.

Despite the numerous studies on this subject, various research methods are necessary to generate new insights and avoid distorted findings, especially from the African perspective. As a result, this study provides five significant contributions to the body of knowledge. First, the study is among the earliest to examine the influence of renewable energy demand (RED), financial reforms (FR), foreign direct investment (FDI), natural resource rent (NRR), and economic growth (EG) on West Africa’s environmental health using ecological footprints (EF). Second, research on the causal relationship between RED, FR, FDI, NRR, EG, and environmental quality (EF) is limited in West Africa, and this study aims to address the gap using the pooled mean group estimator. Thirdly, based on previous economic growth and ecological footprint models, possible components such as natural resource rent, financial reforms, and renewable energy demand are introduced. The addition of such components would aid in determining the contribution of renewable energy demand, financial reforms, and natural resource profits to West Africa’s pollution control efforts and policies. Fourth, as Africa gears toward internal free trade, development and pollution in the region become inevitable. As a result, this study will be among the early ones to provide a radar for these economies to achieve Sustainable Development Goals. Lastly, earlier studies on this subject used CO₂ emissions (negative measure) to estimate environmental health. However, we adopt a positive measuring tool (ecological footprints) in this study to assess environmental health. EF has a more comprehensive, broader, and better measure of environmental health compared to CO₂ emissions (Rudolph and Figge 2017; Destek and Sinha 2020). Figure 1 shows West Africa’s ecological footprint trends. To make a better and meaningful contribution in this area of research, the study seeks to answer the following questions.

1. How has renewable energy demand impacted environmental health in West Africa?
2. Have financial reforms affected the environmental health of West African countries?
3. To what extent has economic growth in West Africa affected their environmental health?
4. Are there causal links among ecological footprints, renewable energy demand, financial reforms, and economic growth among West African economies?

Even though the study adopts ecological footprints as a better measurement tool over CO₂ based on suggestions from several studies, there are still some concerns. Contemporary studies have criticized the use of various indicators to assess environmental quality. It is believed that these indicators (ecological footprints and CO₂) are broader and cover a wide range of factors in their calculation and may not give a true reflection of the various variables’ impact. As a result, future studies must go the extra mile to deduct irrelevant factors that were added during the calculation of these indicators. For example, the total ecological footprints indicator includes carbon, fishing, crop land, built-up land, forest products, and grazing land. In that regard, studies that have no relationship with fishing grounds or crop land must try and deduct these components to get a true figure for accurate results.

**Literature review**

On reducing climate change and improving environmental quality, many scholars have attached importance to it and focused on identifying and assessing the possible factors that are likely to influence CO₂ emission and eventually decrease the environment’s quality in general. Table 1 below summarizes some major studies conducted in recent years on environmental quality, renewable energy, financial developments, and economic growth.

Considering the objectives of this research, various studies have analyzed factors that affect environmental quality from the international level decentralized through to the industrial level. This topic has gained much attention in the last decade or two, which provides enough foundation for more studies to enhance the quality of the environment. Given this, it is no surprise that the impact of many variables on the environment has piqued economists’ and environmentalists’ interest. Furthermore, scholars use a variety of methodologies and techniques to address the environmental problem at different levels. EG has been the biggest impact among the different parameters in recent studies on CO₂ and environmental degradation (Ma et al. 2019; Khan et al. 2020a; Nathanial and Adeleye 2021). The next section reviews various literature on renewable energy demand and financial reforms on environmental quality, which forms the core part of this study.

**Environmental quality measurement**

Some studies are directed to the relationship among EG, energy use, and environmental deterioration for more than four decades, using models developed within the EKC structure (Destek and Sinha 2020). Numerous indicators of environmental health are adopted, including sulfur dioxide (Jayanthakumaran and Liu 2012), CO₂ emissions (Khan et al. 2018, 2019; Abokyi et al. 2019; Sarkodie and Ozturk 2020), and EF (Aydin et al. 2019; Destek and Sinha 2020; Nathanial and Adeleye 2021). EF is a favorable indicator, while the first two are negative indicators. Due to the criticism leveled against CO₂ emissions, recent research has focused on EF as an indicator of environmental quality (Altıntaş and Kassouri 2020; Arshad Ansari et al. 2020; Baz et al. 2020; Destek and Sinha 2020; Sharif et al. 2020; Nathanial and Adeleye 2021).

**Renewable energy demand and environmental quality**

The function of renewable energy demand (RED) has been explored since it significantly impacts CO₂ emissions. CO₂
| Literature                          | Region/country | Methodology used                                      | Variables used                                                                 | Major/related findings                                      |
|------------------------------------|----------------|-------------------------------------------------------|-------------------------------------------------------------------------------|----------------------------------------------------------------|
| Chiu and Chang (2009)              | OECD           | Panel threshold                                       | CO₂, renewable energy supply, consumer price index, real GDP                  | RE has a negative impact on CO₂                              |
| Zhang (2011)                       | China          | Johansen cointegration theory, Granger causality test, VECM, and variance decomposition | CO₂, GDP, FD, financial intermediation efficiency, stock market scale, stock market efficiency, FDI | FD increases CO₂                                              |
| Mahesh and Shoba Jasmin (2013)     | India          | Review                                                | Renewable energy sources (solar, bio-fuel, small hydro, biomass and waste energy, wind) | RE has a favorable mitigation potential on CO₂               |
| Dong et al. (2017)                 | BRICS          | Panel VECM                                            | CO₂, GDP, natural gas consumption, REC                                        | RE has a negative effect on CO₂                             |
| Balsalobre-Lorente et al. (2018)   | EU-5 countries | Least square models                                   | CO₂, GDP, renewable energy use, trade openness, natural resource abundant      | EG has a negative impact on CO₂, RE has a positive effect on CO₂ |
| Acheampong (2018)                  | 116 countries  | PVAR                                                  | CO₂, EC, EG, trade openness                                                  | EG negatively impacts CO₂, EC has a negative effect on CO₂   |
| Liu and Xiao (2018)                | China          | STIRPAT, system dynamics model                        | CO₂, population, GDP, energy intensity, energy structure, fixed assets investment, industrial structure | EG decreases CO₂                                            |
| Shahbaz et al. (2018)              | Japan          | NARDL, TNARDL models                                  | CO₂, energy use, real GDP                                                    | REC and EG have a positive impact on CO₂                    |
| Nguyen and Kakinaka (2019)         | 107 countries  | Panel cointegration                                   | CO₂, REC, non-renewable energy consumption, real GDP, oil price,              | REC is positively associated with CO₂ in low-income countries, REC is negatively associated with CO₂ in high-income countries |
| Khan et al. (2019)                 | 192 countries  | Panel quantile regression                             | CO₂, REC, FD, trade openness, FDI, urban population, labor force, and merchandise trade | RE affects CO₂ negatively, FD increases CO₂                |
| Sarkodie and Strezov (2019)        | 5 developing countries | Driscoll-Kraay standard errors, U test estimation approach, and panel quantile regression with non-additive fixed effects | CO₂, FDI, GDP, total greenhouse gas emission, energy use | EC increases CO₂, FDI degrades the environment              |
| Acheampong et al. (2019)           | 46 sub-Saharan countries | Fixed and random effect estimation technologies, IV-GMM | CO₂, income, FDI, RE, trade openness                                        | RE has a decreasing impact on CO₂; FDI has negative effects on CO₂ |
| Arshad Ansari et al. (2020)        | 37 Asian countries | GMM                                                   | EF, MF, economic growth, urbanization, energy consumption, globalization     | EG has a negative effect on EF, EC has a negative effect on EF |
| Khan et al. (2020b)                | 9 oil-exporting countries | CS-ARDL                                              | CO₂, exports, imports, EG                                                   | EG has a positive effect on CO₂                             |
| Aziz et al. (2020)                 | Pakistan       | Quantile ARDL                                         | EF, economic growth, forest area, agricultural production, renewable energy consumption | RE decreases EF                                             |
| Baz et al. (2020)                  | China, India, Pakistan | NARDL model                                          | EF, energy consumption, economic growth, capital                             | EG increases EF                                              |
| Shen et al. (2021)                 | China          | CARDL                                                  | CO₂, natural resource rent, green investment, EC, FD                         | FD has a unidirectional relationship with CO₂               |
emissions and EF are the two most frequent indicators used by researchers to represent environmental quality. In terms of renewable energy demands, Shafiei and Salim (2014) discovered that, as OECD countries’ demand for renewable energy grows, CO₂ emissions decrease. In the Işık et al. (2019)’s study, a positive effect of renewable energy demand on CO₂ emissions was found in the USA. In a similar study in sub-Saharan Africa, Hanif (2018) examined the relationship between CO₂ emissions caused by fossil fuels, renewable energy use, solid fuel consumption, and urban expansion. It was revealed that renewable energy greatly diminishes CO₂ emissions in the countries studied. According to Zoundi (2017), the extortion of renewable energy consumption has some constraints regarding reduced economic growth and conditioned countries. Also, Jebli and Youssef (2015) demonstrated that renewable energy consumption increases EG and eventually affects the environment’s quality. Similarly, Apergis and Payne (2014) discovered a long-run link between CO₂ emissions and renewable energy demand. With the increasing impact of renewable energy consumption on the environment, Sinha et al. (2018) assert that the initial cost of renewable energy investment to fulfill demand inhibits developing nations from focusing entirely on renewable energy sources. Using data from five developing nations, Sarkodie and Strezov (2019) examined the energy-CO₂ emissions nexus and found that energy use increases CO₂. He et al. (2019) looked at the effect of energy demand and EG on EF in Malaysia and discovered that the former contributed significantly to the latter. Energy demand, population, and EG are the main causes of environmental degradation in OPEC countries, according to Fakher (2019).

### Financial reforms and environmental quality

Several prior research adopted financial reforms’ proxies in different regions and established its relationship with environmental quality. It was determined by Al-Mulali and Binti Che Sab (2012) that increased CO₂ emissions result from financial development. According to Zhang (2011), financial institutions have a vital role in lowering the environmental pollution. Similarly, Tamazian and Bhaskara Rao (2010) argue that financial development impacts CO₂ emissions adversely, although Zhang (2011) claims a positive impact in China. Acaravci and Ozturk (2012), on the other hand, assert that there is no effect of financial developments on CO₂ in Turkey. According to Sarkodie and Strezov (2019), a well-functioning financial system encourages FDI inflows, deteriorating environmental quality. Majied and Mazhar (2019)’s study on 131 countries reveals that financial development enhances environmental quality by decreasing EF and energy demand. However, they found that FDI and GDP accelerate EF. There has been a heated debate in the

| Variables used | Methodology used | Literature Region/country | Major/related findings |
|----------------|-----------------|---------------------------|------------------------|
| EF, economic growth, renewable energy consumption, non-renewable energy consumption, trade openness | FMOLS, DOLS, and CCEMG | Destek and Sinha (2020) 24 OECD | RE abates environmental degradation |
| CO₂, EF, urban population, GDP, financial development | Static and dynamic econometric techniques | Nathaniel and Adeleye (2021) 44 African countries | Energy use deteriorates the environment; FD accelerates environmental degradation |
| Energy use demand; renewable energy demand; environmental degradation; gross fixed capital formation | Static and dynamic econometric techniques | This study 11 West African economies | RED increases FR, EG decreases EF, FDI increases EF |
| EF, renewable energy demand; financial reforms; FDI, economic growth, natural resource rent, population | Static and dynamic econometric techniques | This study 11 West African economies | RED decreases EF, FR increases EF, EG decreases EF, FDI increases EF |

RE, renewable energy; FD, financial developments; CO₂, carbon emissions; EG, economic growth; EC, energy consumption; EF, ecological footprints; MF, material footprints; REC, renewable energy consumption; FDI, foreign direct investments.
literature on FDI and its effects on environmental quality, renewable energy usage, and other aspects. According to Stretesky and Lynch (2009), FDI in the form of technology commodities can reduce air pollution. Similarly, different scholars opine that FDI reduces air pollution and increases economic growth by raising an economy’s productivity, resulting in high energy usage. Furthermore, polluting firms invest in developing nations to minimize production costs since these economies lack proper environmental rules that allow them to consume more energy, resulting in higher CO₂ emissions (Acharyya 2009; Lau et al. 2014). Therefore, these deficiencies in environmental rules attract such FDIs and raise CO₂ emissions. In view of this, the relevance of FDI is examined in the study.

From the literature reviewed, there seem to be several limitations and gaps that need addressing to curb the environmental challenges, and this study advocates for such a course. We noticed that almost all the studies regarding renewable energy, financial reforms, and environmental pollution used CO₂ emissions to measure environmental health. However, EF has been argued to be a better indicator than CO₂, and this study utilizes it in the renewable energy demand and financial reforms space. Also, few studies have adopted EF as an indicator and applied it with either EG or RED or both. However, none of such studies used it to address issues of financial reforms and or renewable energy demand, EG, FDI, natural resource rent, and population altogether, especially in the African context. Furthermore, various methodologies have been used in previous studies regarding the topic with limited variables, including Liu and Xiao (2018) and Baz et al. (2020) who used FMOLS and DOLS for EG and EF, and Destek and Sinha (2020) who used FMOLS and DOLS for RE and EF. More so, this study is unique

Fig. 2 Conceptual framework

Table 2 Variables used and their data sources

| Abbreviation | Name of variable                      | Unit of measurement                                      | Data Source                                      |
|--------------|---------------------------------------|----------------------------------------------------------|-------------------------------------------------|
| EF           | Ecological footprints                 | Ecological footprints (gha)                               | Global Footprints Network (2021)                 |
|              |                                       |                                                          | [https://data.footprintnetwork.org/](https://data.footprintnetwork.org/) |
| RED          | Renewable energy demand               | Renewable energy consumption (% of total final energy consumption) | World Bank (2021)                               |
|              |                                       |                                                          | [https://data.worldbank.org/](https://data.worldbank.org/) |
| FR           | Financial reforms                     | Domestic credit to the private sector (% of EG)           | World Bank (2021)                               |
|              |                                       |                                                          | [https://data.worldbank.org/](https://data.worldbank.org/) |
| FDI          | Foreign direct investment             | Foreign direct investment, net inflows (% of EG)          | World Bank (2021)                               |
|              |                                       |                                                          | [https://data.worldbank.org/](https://data.worldbank.org/) |
| EG           | Economic growth                       | EG (current US$)                                          | World Bank (2021)                               |
|              |                                       |                                                          | [https://data.worldbank.org/](https://data.worldbank.org/) |
| NRR          | Natural resource rent                 | Total natural resources rents (% of EG)                   | World Bank (2021)                               |
|              |                                       |                                                          | [https://data.worldbank.org/](https://data.worldbank.org/) |
| POPN         | Population                            | Total population                                          | World Bank (2021)                               |
|              |                                       |                                                          | [https://data.worldbank.org/](https://data.worldbank.org/) |
and fills the methodological gaps by adopting DOLS, FMOLS, PMG estimator, and Granger causality tests to analyze the impact of these variables on environmental health, which has never been done in a single study on the subject. This gives a broader and meaningful contribution to the body of knowledge regarding the relationships among the variables used. To enhance the understanding of this study, we develop a conceptual framework for the study involving all variables used in the study, as seen in Fig. 2.

Data and methodology

Data collection and variables used

The study adopts panel data for 11 West African economies from 1990 to 2017. The countries selected were based on data available to meet the objectives of this research. Table 2 below provides the data used, their variable explanation, and their measurement unit and source.

Empirical model

The study’s theoretical structure was centered on an endogenous model with renewable energy demand, financial reforms, foreign direct investment, natural resource rent, economic growth, and population. Thus, this equation is formulated below (1).

\[ \text{EF}_it = \beta_0 + \beta_1 \text{RED}_it + \beta_2 \text{FR}_it + \beta_3 \text{FDI}_it + \beta_4 \text{NRR}_it + \beta_5 \text{EG}_it + \beta_6 \text{POPN}_it + u_{it} \]

where EF is ecological footprints, RED is renewable energy demand, FR is financial reforms, FDI represents foreign direct investment, NRR denotes natural resource rent, EG stands for economic growth, and POPN represents population. \( \beta_1 - \beta_6 \) are the parameter estimates, \( \beta_0 \) is the intercept, \( t \) is the period, and \( u \) represents the error term.

In achieving efficient, dependable, and consistent outcomes and examining the long-term link between variables, we express Eq. (1) to their natural logarithm in Eq. (2).

\[ \log_e(\text{EF}) = \beta_0 + \sum \log_e(\text{RED}, \text{FR}, \text{FDI}, \text{NRR}, \text{EG}, \text{POPN}) \]

Hence, the functional model can be written as

\[ \ln \text{EF}_it = \beta_0 + \beta_1 \ln \text{RED}_it + \beta_2 \ln \text{FR}_it + \beta_3 \ln \text{FDI}_it + \beta_4 \ln \text{NRR}_it + \beta_5 \ln \text{EG}_it + \beta_6 \ln \text{POPN}_it + u_{it} \]

Cross-sectional dependency test

The general expectation is that the panel data model disturbances are cross-sectional, especially when the \((N)\) dimension is vast. Ignoring cross-sectional independence could greatly impact unaccounted residual dependence, leading to inefficiency and a statistically invalid test. Due to the above issues, the study first examined the cross-sectional dependence using Breusch and Pagan (1980)’s LM test. It is used to test for heteroskedasticity and assumes that the error terms are normally distributed.

Unit root test

We used the augmented Dicker-Fuller (ADF) to analyze variables’ stationarity. It is expressed as

\[ \Delta y = a_i + p_i y_{i,t-j} + \gamma_{i} \bar{y}_{i,t-1} + \sum_{j=1}^{k} \gamma_{j} \Delta \bar{y}_{i,t-j} + \sum_{j=0}^{k} \Delta \bar{y}_{i,t-j} + \epsilon_{it} \]

where \( \bar{y}_{i,t-1} = (\frac{1}{N}) \sum_{i=1}^{N} y_{i,t-1} \), \( \Delta \bar{y}_{i,t-j} = (\frac{1}{N}) \sum_{i=1}^{N} y_{i,t-j} \) and \( t_i \) (N, T) is the t-statistics of the estimates and \( P \) is the individual ADF statistics.

Cointegration analysis

The Kao and Pedroni cointegration tests were adopted to establish the cointegration among the variables used. We first apply the Kao cointegrating test. The ADF t-statistics is mathematically expressed as
ADF = \frac{\hat{\text{ADF}} + \left( \frac{\sqrt{\text{ADF}}}{n} \right)}{\sqrt{\hat{\theta}_2^2 + (10\hat{\theta}_0^2)}} 

(5)

where \( \theta_2^2 = \sum_{n}^{} - \sum_{u}^{} \sum_{\varepsilon}^{} \), \( \theta_0^2 = \Omega_0 - \Omega_u \Omega_u^{-1} \), \( \Omega \) denotes the long-run covariance matrix and \( \hat{\text{ADF}} \) refers to t-statistic in ADF regression for cointegration.

Moving further, the study used confirms the results achieved by the Kao cointegration test through the application of Pedroni (2004)’s cointegrating technique. The Pedroni cointegration test is based on intra- and inter-dimensional cointegration with parenthetic lag lengths. It can be expressed mathematically as

\[ \text{EF} = \alpha + \delta_1 X_{it} + \delta_2 X_{it-1} + \ldots + \delta_p X_{it-p} + \epsilon_{it} \]

(6)

\( \alpha \) and \( \delta_i \) are the intercepts and gradient coefficients and can differ across cross-sections, \( t=1, T; i=1, N; p=1, EF, x, \) and \( p \) are considered similar and orderly integrated \((\hat{I}(1))\). Under the null hypothesis of no cointegration, the residuals \( \epsilon_{it} \) will be \( \hat{I}(1) \).

Long-run estimates

To generate our variables’ long-run estimates, the dynamic ordinary least square (DOLS) and fully modified ordinary least square (FMOLS) for elasticity were prioritized over the traditional ordinary least square (OLS) because the FMOLS is the modification of the OLS. They cater to serial correlation problems as well as the endogeneity bias predominance. Getting rid of endogeneity issues using a non-parametric method, the regressors and error terms are sequentially correlated (Dogan and Seker 2016). As a result, the FMOLS is quite effective. A parametric approach, lags, and leads are used by the DOLS estimator. The FMOLS approach to measuring the long-run relationship between the variables proposed by (Pedroni 2000) can be expressed as

\[ \text{EF} = \omega_0 + \beta X_{it} - i + \sum_{j=1}^{j} \gamma_j X_{it-j} + \mu_{it} \]

(7)

where \( \text{EF} \) refers to the dependent variable ecological footprints. The \( X_{it} \) denotes the independent variables used for the study. The long-run variance is given by

\[ \Omega_t = \lim T \rightarrow \infty \left[ \left( \frac{1}{T} \right) \left( \sum_{t}^{T} \right) \right] \]

(8)

FMOLS estimator is subsequently extended to Eq. (9), as indicated below.

\[ \hat{\beta} = \frac{1}{n} \sum_{i=1}^{n} \left[ \sum_{t=1}^{T} \left( X_{it} - \bar{X}_t \right)^2 \right]^{-1} \left( \sum_{t=1}^{T} \left( X_{it} - \bar{X}_t \right) \left( \text{EF}_t - \bar{\text{EF}} \right) \right] \]

(9)

where \( \text{EF} = \text{EF}_0 - \text{EF}_{eq} - \left( \frac{\hat{\Omega}_{t,0}}{\hat{\Omega}_{t,1}} \right) \Delta X_{it} \); and

\[ \hat{\gamma} = \hat{\tau}_{t,0} + \hat{\Omega}_{t,0} - \left( \frac{\hat{\Omega}_{t,0}}{\hat{\Omega}_{t,1}} \right) \left( \hat{\tau}_{t,1} + \hat{\Omega}_{t,1} \right) \]

Finally, we establish the directional causality among the variables by applying the pool mean group (PMG) estimator and the Granger causality.

Results and discussion

Descriptive statistics

In Table 3, we display the results of the descriptive statistics conducted for all variables used, the mean, maximum, minimum, volatility, skewness, kurtosis, and distribution normality. The kurtosis indicates that all variables show a platykurtic distribution in determining whether the distribution is too peaked since they are all greater than one \((1)\). Also, RED, FR, FDI, and NRR indicate a left-skewed distribution. However, EG, EF, and population also show a right-skewed distribution. Also, all the variables are generally distributed, according to the Jarque–Bera test statistic. All other statistics of the respective variables can be found in Table 3.

Cross-section dependency test

Table 4 displays the results of the cross-section dependency test (CD test). The test was conducted in the various panel options: ordinary least squares and fixed effects. The table
Panel unit root test

In Table 5, the Augmented Dicker-Fuller test results can be seen. This was to test the stationarity of the variables for further analysis. At level, FDI was significant at 1% level, NRR at 5% level, and POP at 10% level. All other variables were insignificant at a level and cannot reject the null hypothesis. The variables were then assessed in their 1st difference under the same test method, and all became stationary at the 1% level. We then conclude that the variables are integrated simultaneously and can be used for econometric modeling.

Cointegration test results

Kao residual cointegration

One of the fundamentals of this study was to determine the existence of long-run relationships among constructs. In Table 6, we used the Kao cointegration test to confirm a long-run association among the variables, and if they are cointegrated. With a p-value of 0.0000, we accept the alternative hypothesis indicating a long-run association among the variables.

Pedroni residual cointegration test results

In testing for the cointegration among the variables, the Pedroni cointegration test was also adopted after the Kao, and the results are displayed in Table 7. In the table, eleven (11) results are displayed from the test. With all 11 results obtained, panel PP-statistic (0.0000, 0.0000) and panel ADF-statistic (0.0000, 0.0000), group PP-statistic (0.0000), and group ADF-statistic (0.0000) were found significant at 1% level. Overall, 6 out of the 11 tests were significant, which means that the null hypothesis can be rejected. This confirms the Kao cointegration test results.

From Table 8, the results of DOLS and FMOLS indicated an explanatory power of 99.97% and 63.5%, respectively. The left-hand side reveals the results from the FMOLS with coefficient, t-values, and p-values. Likewise, the right-hand side displays the results from the DOLS.

Regarding RED and environmental quality measured by EF, the FMOLS results found a negative (−0.0428) significant (0.0000) relationship. This is confirmed by the DOLS results and revealed a significant negative relationship between the variables. This means that a 1% increase in the demand for renewable energy in West Africa improves the region's environmental quality by 4.28% (FMOLS) and 42.9% (DOLS). From this, we conclude that West African economies' demand for renewable energy has been favorable to their EF. This is consistent with the works of Apergis and Payne (2014), Zhou and Li (2019), and Khan et al. (2020a) who found renewable energy usage to reduce CO2 emissions and Nguyen and Kakinaka (2019) and Aziz et al. (2020) who found renewable energy consumption to decrease EF.

On FR and developments in the region, the FMOLS results revealed a significant positive impact on environmental quality. This means that a 1% increment in FR increases their EF by 3.9%, which is a decline in environmental quality. These results align with Zhang (2011) and Nathaniel and Adeleye (2021), who concluded that financial developments degrade the environment. The DOLS could not confirm as it indicated an insignificant impact like Acaravci and Ozturk (2012), who found no impact between FR and environmental quality in Turkey. FDI, which forms an integral part of every developing country, was found to significantly affect environmental quality among West African economies. The results showed that a 1% increment in

| Table 5 Augmented Dicker-Fuller (ADF) results |
|-----------------------------------------------|
| Test | Level | 1st diff |
|      | Statistic | Prob | Statistic | Prob |
| EF   | 8.7622 | 0.9945 | 156.518 | 0.0000*** |
| RED  | 11.7565 | 0.9622 | 107.458 | 0.0000*** |
| FR   | 31.7810 | 0.0812 | 97.0939 | 0.0000*** |
| FDI  | 62.6479 | 0.0000*** | 111.948 | 0.0000*** |
| NRR  | 37.5822 | 0.0204** | 123.255 | 0.0000*** |
| EG   | 2.2159 | 1.0000 | 110.043 | 0.0000*** |
| POP  | 31.2557 | 0.0910* | 141.584 | 0.0000*** |

| Table 6 Kao residual cointegration test results (null hypothesis: no cointegration) |
|-----------------------------------------------|
| T-value | Prob |
| ADF | −5.640799 | 0.0000*** |

| Table 7 Pedroni residual cointegration test results (null hypothesis: no cointegration) |
|-----------------------------------------------|
| Alternative hypothesis: common AR coefs. (within-dimension) |
| Statistic | Prob | Weighted Prob |
| Panel v-statistic | −1.7054 | 0.9559 | −2.0807 | 0.9813 |
| Panel rho-statistic | 0.7428 | 0.7712 | 1.0642 | 0.8564 |
| Panel PP-statistic | −6.2833 | 0.0000*** | −5.7752 | 0.0000*** |
| Panel ADF-statistic | −4.6935 | 0.0000*** | −4.5177 | 0.0000*** |
| Alternative hypothesis: individual AR coefs. (between-dimension) |
| Statistic | Prob |
| Panel rho-statistic | 1.9849 | 0.9764 |
| Group PP-statistic | −10.8724 | 0.0000*** |
| Group ADF-statistic | −5.5993 | 0.0000*** |

Statistical significance at 1%***, 5%**, and 10%*; reject null at 5% significance
direct investment from foreigners improved the environmental quality by 19.52% (FMOLS) and 7.51% (DOLS). This may be attributed to the fact that, as the world goes toward sustainability, these economies are getting interested in green investments that develop the country and promote the quality of the environment. Khan et al. (2020a) found similar results. NRR, a very important variable among West African economies, was identified to have a positive relationship with EF. This is confirmed from the table by FMOLS and DOLS with 0.1146 coefficients. This indicates that the compensation (rents) from the natural resources keeps causing harm to the environment. As the rents increase, environmental quality decreases by increasing EF. Economic growth measured by GDP in US$ shows a positive significant (FMOLS = 0 0.0747, DOLS = 0.0713) relationship with environmental quality. A 1% increase in the growth of West African economies increases their environmental degradation by 7.47% and 7.13%, respectively. As a result of deforestation and mining, most African economies rely on these industries, which have impacted their environment. This finding conforms to Liu and Hao (2018), who found economic growth to increase EF among 69 countries. However, it is inconsistent with Dong et al. (2017) and Balsalobre-Lorente et al. (2018), who also found economic growth to decrease CO₂ among BRICS and EU-5 countries, respectively. The population and its growth in West Africa are found to positively affect the quality of the environment by 86% (FMOLS) and 1.64% (DOLS). As the population of the region increases, so does their EF. A summary of the FMOLS and DOLS results are captured in Fig. 3.

The results for the pooled mean group estimates are displayed in Table 9. The study adopted it to determine the short- and long-run directional causality among some key variables used for the study. The PMG estimator allows short-term dynamics to differ between countries while limiting all cross-section data’s long-term coefficients.

From Table 9, the short-run causalities can be found on the left side and the long run on the other side. In the short run, we found a unidirectional causality from EF to FR, RED and NRR. Also, a unidirectional causality was found from RED to FR, EG to RED, and population to

![Fig. 3 Summary of FMOLS and DOLS results](image-url)
EF. However, EF and EG, EF and FDI, and FDI and FR had bidirectional causalities.

In the long run, only RED to FR, FDI to FR, and NRR to EF had unidirectional causal relationships. EF had a bidirectional relationship with RED, FR, EG, and population. Also, a bidirectional relationship was found between EG and RED. Our study found no causal relationship between EF and FDI in the long run. A summary of the various causalities can be seen in Fig. 4.

The Granger causality test was adopted to enhance the study and its findings (Granger 1969). Granger causality is widely used because of its computational simplicity. Also, as other tests determine what causes what, Granger causality determines whether one variable is useful to forecast another variable. We used this to test if the variables used can be useful when forecasting the other variables, and the results are seen in Table 10.

With the null hypothesis developed, the Granger causality test rejected some hypotheses and revealed that EFs Granger cause FR, EG, and POP in West Africa. Also,
POP Granger causes EFs, FDI Granger causes FR, FDI Granger causes EG, RED Granger causes FDI, and vice versa, EG Granger causes FR. Population also Granger causes FR and vice versa, and POPN Granger causes EG at 10% significance and vice versa at 5% significant level. Other results found can be seen in Table 10.

Policy implications

Based on these revelations, we make the following policy recommendations.

Considering the positive impact of RED on environmental quality in West Africa, we admonish policymakers to adopt clean technology by expanding renewable energy consumption as a tool to improve environmental quality. Also, the bidirectional causality found between renewable energy and ecological footprints strongly indicates how both affect each other and the attention they require. Due to the importance of energy in poverty reduction and development, these countries should establish energy development programs. Such programs will help shift the areas' energy consumption to clean and renewable energy consumption to improve environmental quality in these countries significantly. In that regard, unless West African governments and related stakeholders exploit the region's wealth of "clean energy" sources such as solar and geothermal energy and biomass and biogas, tidal and wind power in earnest, the prospect of biodiversity becoming grossly uninhabitable abounds.

In addition, our findings suggest that FR has been detrimental to the quality of the environment. In addition to this, a bidirectional causal relationship existed between these two variables. This confirms that the relationship between financial reforms and ecological footprints is double-edged and must be handled with strategic policies to get the best out of them. Therefore, countries should improve their financial systems by providing more incentives for sustainable and clean energy production projects. They should also support research and development efforts that focus on helping achieve United Nations Sustainable Development Goal 7 (UN SDG-7) of ensuring affordable and clean energy. Aside from that, governments should promote financial institutions because they assist in providing funding for environmentally friendly projects that benefit the country. Limited financial resources hinder renewable energy consumption and sustainability; however, growth in financial services can assist firms to have access to more funds to embrace sustainable initiatives and investments.

Regarding FDIs, the study showed a favorable impact on the environment. However, its sustenance is key to the long-term development of the region. Therefore, host nations among these regions should be aware of the environmental implications of FDIs before introducing foreign investors to their country, especially countries with high EF or biocapacity deficits. To that effect, green investments that enhance recycling and promote a circular economy and sustainability must be attracted and invited into the countries while limiting investments that degrade the environment.

The Western section of Africa is heavily resource-dependent. Resources form a major factor in the region’s economy. Activities (mining, natural resource exploration, agriculture) and resources (petroleum, coal, natural gas, among others) stimulate deforestation, depletion of biocapacity, and an increase in EF. Consequently, another strategy to decrease the EF for sustainability is to boost sustainable activities in the natural resource industry and increase the consumption of less polluting sources. The rents generated from the sector must be invested in recyclable projects that offset the resources lost. This will help balance biocapacity or keep it within positive figures.

Finally, economic growth has been found to affect environmental quality negatively. Furthermore, a bidirectional causality was found between economic growth and ecological footprints in the short and long run. A two-way causality indicating how strong these variables are related in the interim and long term must not be taken for granted. These findings have been found in advanced countries who are trying to reduce CO₂ emissions and their associated effects. As these emerging economies aspire to be like the advanced countries, governments should not only focus on just growing their economy but growing it sustainably and familiarizing with the UN SDGs so that their economies can be kept green as they grow.

Conclusion

This study evaluated the relationship between environmental quality and renewable energy demand, financial reforms, foreign direct investment, economic growth, natural resource rent, and population. After several tests, we found that renewable energy demand in West Africa has been favorable to their environmental quality, reducing their ecological footprints. Also, the region’s financial reforms positively affected the quality of the environment as ecological footprints were found to increase accordingly. Foreign direct investments had a negative impact on ecological footprints. Also, economic growth declined environmental quality as EG affects ecological footprints positively. Using the PMG estimator, the study found that ecological footprints have a bidirectional relationship with renewable energy demand, financial reforms, economic growth, and population.
Finally, in determining which variables forecast the other, the Granger causality test revealed that ecological footprints Granger cause financial reforms, economic growth, and population in West Africa. These findings and their suggested policy implications will provide great insights to policymakers on the influencers of environmental pollution and serve as a foundation for future studies.

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**Declarations**

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**Authors contribution**

- **B. Ohuobi:** conceptualization, methodology, software, writing – original draft preparation, validation, investigation.
- **Y. Zhang:** writing – reviewing and editing, supervision.
- **E. Nketiah:** data curation, writing – reviewing and editing.
- **G. Adu-Gyamfi:** data curation, writing – reviewing and editing.
- **C. Acheampong:** conceptualization, methodology, software, writing – original draft preparation, validation, investigation.
- **E. Nketiah:** data curation, writing – reviewing and editing.
- **G. Adu-Gyamfi:** data curation, writing – reviewing and editing.
- **D. Cudjoe:** writing – reviewing and editing, supervision.

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