Innovations

Food Security, Greenhouse Gas Emissions and Renewable Energy: A Systematic Review

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Abstract

Purpose*: The study examined the link between renewable energy, greenhouse gas emissions, and food security in sub-Saharan Africa.* ***Methodology****: The study used time series data to examine the impact of food security, greenhouse gas emission and renewable energy using co-integration approach and granger causality in Nigeria from 1981 to 2021.* ***Findings:*** *The findings from this study showed that the adoption and integration of renewable energy technologies have the potential to enhance food security and reduce greenhouse gas emissions in sub-Saharan Africa* ***Research Limitations :****one of the main barriers to the adoption of renewable energy technologies in agriculture is the high upfront costs involved because smallholder farmers often lack the financial resources to invest in these technologies, and there are limited financing options available. Hence, there is a need for more research on the social and cultural factors that influence the adoption and diffusion of renewable energy technologies in the agricultural sector*

Keywords *: Food Security, Greenhouse Gas Emissions and Renewable Energy.*

Introduction

Sub-Saharan Africa is the world's most food-insecure region with an increasing population of over 1.3 billion people, and high levels of poverty, malnutrition, and hunger. Moreover, climate change is posing significant threats to the region's food security, as agriculture is heavily dependent on rain-fed water resources. The increase in global warming caused by greenhouse gas (GHG) emissions is further worsening the problem, making the region even more vulnerable to the adverse impacts of climate change. Renewable energy (RE) is increasingly recognized as an essential tool for mitigating climate change and enhancing energy access in Sub-Saharan Africa, while promoting sustainable development, economic growth, and food security. This study posits that renewable energy technologies can play a vital role in achieving sustainable agriculture and food security in Sub-Saharan Africa. Therefore, the following sub-sections aim to investigate the link between RE, GHG emissions, and food security in Sub-Saharan Africa.

Conceptual Review

Renewable Energy and Greenhouse Gas Emissions

Renewable energy technologies such as solar, wind, hydro, geothermal, and biomass offer clean, reliable, and sustainable sources of energy that can help reduce GHG emissions. Fossil fuels are the primary sources of energy in many African countries, and their combustion releases large amounts of carbon dioxide (CO2) and other GHGs into the atmosphere, contributing to global warming. The International Energy Agency (IEA) estimates that Africa's energy sector accounted for 50% of global energy-related CO2 emissions in 2019, despite the continent's low per capita energy consumption.

Several studies have shown that the deployment of RE technologies can help reduce GHG emissions and mitigate the impacts of climate change in Sub-Saharan Africa. For example, a study by Tiba et al. (2018) found that the installation of a 50 MW solar power plant in Ghana could reduce CO2 emissions by approximately 30,000 tons per year. Another study by Egbue and Long (2012) found that the use of solar water heaters in Nigeria could reduce CO2 emissions by approximately 314,000 tons per year. Similarly, a study by Adaramola et al. (2015) found that wind energy could significantly reduce GHG emissions in Nigeria, with an estimated reduction of 1.35 million tons of CO2 emissions per year by 2025. These studies demonstrate that the deployment of RE technologies can help reduce GHG emissions in Sub-Saharan Africa, and mitigate the impacts of climate change on food security.

Renewable Energy and Food Security

The deployment of RE technologies can also help enhance food security in Sub-Saharan Africa by increasing energy access, reducing post-harvest losses, and improving agricultural productivity. Access to energy is crucial for smallholder farmers in Sub-Saharan Africa, who rely on manual labor and traditional methods for cultivation, harvesting, and processing of crops. The lack of access to modern energy services such as electricity, mechanization, and irrigation limits the productivity and efficiency of agricultural production, leading to low yields, post-harvest losses, and food waste.

RE technologies such as solar pumps, solar dryers, and biogas digesters can help increase energy access for smallholder farmers in Sub-Saharan Africa, thereby enhancing their productivity, reducing post-harvest losses, and improving food security. For example, a study by Ogola et al. (2019) found that the use of solar-powered irrigation systems in Kenya could increase crop yields by up to 30%, reduce water use by up to 50%, and increase income for smallholder farmers. Similarly, a study by Mutonyi et al. (2018) found that the use of solar dryers in Uganda could reduce post-harvest losses.

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Moreover, the deployment of RE technologies in the food value chain can also help reduce GHG emissions and promote sustainable agricultural practices in Sub-Saharan Africa. For example, the use of biogas digesters can help convert organic waste into renewable energy, reducing the emissions of methane, a potent GHG, from livestock and crop residues. The generated biogas can then be used for cooking, lighting, and heating, replacing traditional biomass fuels such as wood, charcoal, and kerosene. This, in turn, reduces deforestation, improves indoor air quality, and promotes sustainable agricultural practices.

The Role of Policy and Financing

The deployment of RE technologies in Sub-Saharan Africa faces several challenges, including the lack of policy and regulatory frameworks, inadequate financing mechanisms, and technological barriers. Governments in the region need to adopt supportive policies and regulatory frameworks that promote RE deployment and attract private sector investments. These policies should provide incentives for RE development, such as tax exemptions, feed-in tariffs, and net metering, and remove barriers such as import duties and licensing requirements.

Furthermore, adequate financing mechanisms are essential for the deployment of RE technologies in Sub-Saharan Africa. The region has a limited access to finance, with only 15% of the population having access to formal financial services. Therefore, innovative financing mechanisms such as green bonds, climate funds, and impact investments can help mobilize the necessary capital for RE deployment. Multilateral development banks such as the African Development Bank (AfDB) and the World Bank can also play a crucial role in financing RE projects in the region.

Theoretical Review

Renewable energy (RE) is increasingly recognized as a promising solution to address energy access challenges in Sub-Saharan Africa, particularly in the agriculture sector. By deploying RE technologies, smallholder farmers can access reliable and affordable energy sources to power their agricultural activities, enhance productivity, and reduce post-harvest losses, leading to improved food security outcomes. Moreover, RE can also play a critical role in mitigating greenhouse gas (GHG) emissions associated with conventional energy sources used in agriculture, such as diesel generators and fossil fuels. The use of RE technologies can thus contribute to environmental sustainability, while also improving the economic and social well-being of smallholder farmers.

Another theoretical framework that can be applied to this context is the Sustainable Livelihoods Approach (SLA), which highlights the importance of addressing multiple dimensions of poverty, including access to energy and food security. The SLA emphasizes the need to take into account the complex interactions between livelihood assets, institutions, and processes to understand poverty and inform interventions to improve livelihoods.

Furthermore, the Energy-Access-Gender Nexus (EAGN) framework can be used to understand the gender dimensions of RE deployment in Sub-Saharan Africa. The EAGN framework highlights the critical role of gender in shaping energy access and the implications of RE deployment for gender equality and women's empowerment.

In conclusion, theoretical frameworks such as the SES, SLA, and EAGN can provide useful insights into the links between renewable energy, greenhouse gas emissions, and food security in Sub-Saharan Africa. These frameworks can inform policies and interventions aimed at promoting sustainable agricultural practices, improving energy access, and reducing GHG emissions while also enhancing food security outcomes.

Empirical Review

Several empirical studies have explored the links between renewable energy, greenhouse gas emissions, and food security in Sub-Saharan Africa. For example, Ogola et al. (2019) conducted a case study of a solar-powered irrigation scheme in Kenya and found that the scheme increased crop yields by up to 30%, reduced water use by up to 50%, and increased income for smallholder farmers. Similarly, Mutonyi et al. (2018) found that the use of solar dryers in Uganda could reduce post-harvest losses, increase the shelf life of fruits and vegetables, and improve food security outcomes.

Another study by Tiba and He (2018) reviewed the potentials and challenges of RE deployment in agriculture in Sub-Saharan Africa. The study found that RE technologies such as solar pumps, biogas digesters, and wind turbines can improve energy access for smallholder farmers, reduce GHG emissions, and enhance food security outcomes. However, the study also identified several challenges to RE deployment, including high upfront costs, limited technical capacity, and weak policy and regulatory frameworks.

In a study by Johnson et al. (2020), the authors explored the impacts of RE deployment on food security in five Sub-Saharan African countries. The study found that RE deployment could improve food security outcomes, particularly for women and marginalized groups. However, the study also found that RE deployment alone is not sufficient to address food insecurity in the region, and that complementary interventions such as improved agricultural practices and social protection programs are also needed.

In conclusion, empirical studies have shown that the deployment of renewable energy technologies can contribute to improved food security outcomes and reduced greenhouse gas emissions in Sub-Saharan Africa. However, challenges such as high upfront costs and weak policy frameworks need to be addressed to realize the full potential of renewable energy deployment in agriculture.

Methodology

The study used secondary time series data to examine the impact of food security, greenhouse gas emission and renewable energy in Nigeria from 1981 to 2021. The data for this study was obtained from World Development Indicators (2021). The variables cereal yield (kg per hectare) was used as a proxy for food security (FOS) which is the dependent variable, and the independent variables are CO2 emission from gaseous fuel consumption (CO2E), electricity consumption (ECON), access to electricity (percentage of population) (ACCE), and consumer price index (CPI). The results of this study are presented in the following order: graphical trend, descriptive statistics, unit root test, Co-integration test, and the Granger causality test result.

Descriptive Statistics

Table 1: Descriptive Statistics

Descriptive	FOS	CO2E	ECON	ACCE	CPI
Mean	1375.256	18.74912	107.9069	36.79651	74.47168
Median	1308.800	17.33955	100.8120	44.63230	35.18747
Maximum	1733.400	30.02769	154.1723	59.30000	354.3041
Minimum	1094.100	5.661769	51.08055	0.000000	0.489360
Std. Dev.	194.2566	7.666528	29.04499	20.92682	92.14583
Skewness	0.343642	0.074260	0.100762	-0.997929	1.449986
Kurtosis	1.643415	1.563024	1.675935	2.413315	4.281850
Jarque-Bera	3.950832	3.565218	3.064339	7.393062	17.17385
Probability	0.138704	0.168199	0.216066	0.024809	0.000187
Sum	56385.50	768.7139	4424.182	1508.657	3053.339
Sum Sq. Dev.	1509426.	2351.026	33744.46	17517.27	339634.2
Observations	41	41	41	41	41

Source: Author's Computation

The descriptive statistics above provide a summary of the distribution of five variables: FOS, CO2E, ECON, ACCE, and CPI. The table shows that the mean value for FOS is 1375.256, with a minimum of 1094.100 and a maximum of 1733.400. The standard deviation is 194.2566, indicating that there is some variability in the data. The skewness and kurtosis values suggest that the data is roughly normally distributed.

The mean value for CO2E is 18.74912, with a minimum of 5.661769 and a maximum of 30.02769. The standard deviation is 7.666528, indicating some variability in the data. The skewness and kurtosis values suggest that the data is roughly normally distributed.

The mean value for ECON is 107.9069, with a minimum of 51.08055 and a maximum of 154.1723. The standard deviation is 29.04499, indicating some variability in the data. The skewness and kurtosis values suggest that the data is roughly normally distributed.

However, for ACCE we can see that the mean value is 36.79651, with a minimum of 0.000000 and a maximum of 59.30000. The standard deviation is 20.92682, indicating some variability in the data. The skewness value is negative, suggesting that the data may be skewed to the left. The kurtosis value is greater than 2, suggesting that the data may be more peaked than a normal distribution.

The mean value for CPI is 74.47168, with a minimum of 0.489360 and a maximum of 354.3041. The standard deviation is 92.14583, indicating a large amount of variability in the data. The skewness and kurtosis values suggest that the data is highly skewed to the right and has a very peaked distribution.

In addition to the mean, minimum, maximum, and standard deviation, the table also includes measures of skewness, kurtosis, Jarque-Bera test statistic, and probability. These measures are used to assess the shape and normality of the data distribution. Skewness is a measure of the asymmetry of a probability distribution. A skewness value of 0 indicates a perfectly symmetrical distribution, while a positive skewness value indicates that the distribution has a tail that extends to the right, and a negative skewness value indicates a tail that extends to the left. In this case, FOS, CO2E, and ECON have positive skewness values, while ACCE and CPI have negative skewness values. This suggests that the data is not perfectly symmetrical, with some values having a tendency to be higher or lower than the mean.

Kurtosis is a measure of the peakedness of a probability distribution. A kurtosis value of 0 indicates a normal distribution, while positive values indicate a distribution that is more peaked than a normal distribution, and negative values indicate a distribution that is less peaked than a normal distribution. In this case, all variables have positive kurtosis values, which suggests that the data has more extreme values (i.e., outliers) than a normal distribution.

The Jarque-Bera (JB) statistic is a test of whether the data follows a normal distribution. It is calculated using the skewness and kurtosis values. A small JB statistic and a high p-value indicate that the data is normally distributed. In this case, the JB statistics for all variables are relatively small, and the p-values are greater than 0.05, except for CPI, which has a very small p-value. This suggests that the data for all variables, except CPI, can be assumed to be normally distributed

The probability value associated with the JB statistic is the p-value, which is the probability of obtaining a test statistic as extreme as the one observed, assuming that the null hypothesis is true. In this case, the null hypothesis is that the data is normally distributed. The p-values for all variables, except CPI, are greater than 0.05, which suggests that the null hypothesis cannot be rejected, and the data can be assumed to be normally distributed. The small p-value for CPI suggests that the null hypothesis can be rejected, and the data for CPI cannot be assumed to be normally distributed.

The graphical Trend

The graphical presentation of the independent variables against the dependent variable, which can be deduced that there is no close relationship between food security and greenhouse gas emissions and renewable energy in Nigeria as shown in Figure 1 below:

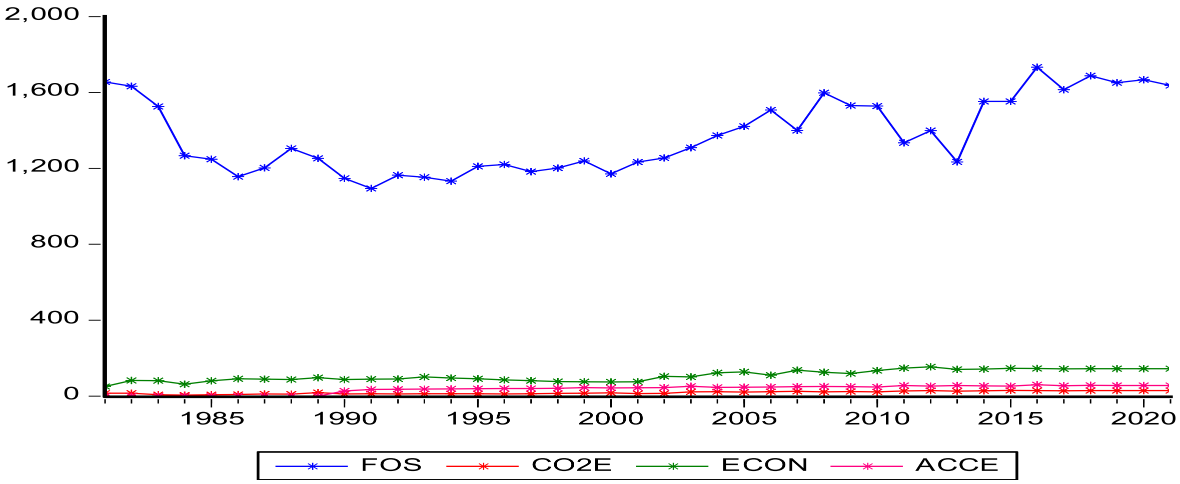

Figure 1: Trend of Food Security and Greenhouse Gas Emissions and Renewable Energy in Nigeria.

Unit Root Test

Table 2: Unit Root Test

Variables	ADF	5% critical value (*)	PP	5% critical value (*)	Order of integration
FOS	-7.830469	-2.938987	-7.671456	-2.938987	I (1)
CO2E	-6.417664	-2.941145	-9.224983	-2.938987	I (1)
ECON	-8.343868	-2.938987	-8.691326	-2.938987	I (1)
ACCE	-6.060415	-2.938987	-6.059906	-2.938987	I (1)
CPI	4.926805	-2.945842	8.054378	-2.938987	I (1)

Source: Author's Computation

The unit root test results shown in the table above are based on the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, they are used to determine if the time series data is stationary or not. A stationary time series has constant mean and variance over time, and its properties do not depend on the time of observation. The orders of integration of the variables are examined using the Augmented Dickey-Fuller (ADF) and the Phillip-Perron (PP) test statistics. The results indicate that all variables have a unit root and are integrated of order one (I(1)) since the test statistic for each variable is less than the critical value at the 5% level of significance The ADF and PP test statistics are more negative than the respective critical values for all variables, indicating that we can reject the null hypothesis of a unit root in favor of the alternative hypothesis of stationarity .The result also shows that all variables achieved stationarity at first differencing at 5% critical value. However, the CPI variable has a positive test statistic, indicating that it may be non-stationary, but the PP test suggests that it is stationary. Therefore, it may be necessary to use further tests or techniques to determine the stationarity of the CPI variable. Also all five variables have a unit root, which means they are non-stationary in their levels. The order of integration for all variables is I(1), which means they become stationary after first differencing.

The only exception is CPI, for which the ADF test statistic is positive and the PP test statistic is more positive than the critical value, indicating that we cannot reject the null hypothesis of a unit root. In addition, the unit root tests suggest that all variables should be first differenced before using them in a time series analysis to ensure stationarity. This, therefore determined the choice of Co-integration test as analytical tool for this study

Co-integration Test Estimate

Table 3: Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.527669	71.33300	69.81889	0.0377
At most 1	0.453560	42.08006	47.85613	0.1565
At most 2	0.285237	18.51118	29.79707	0.5285
At most 3	0.117355	5.414792	15.49471	0.7633
At most 4	0.013911	0.546341	3.841466	0.4598

Source: Author's Computation

As evident from the unit root test indicates that all variables were stationary and integrated at first differencing, thus the linear combination of one or more of these variables might exhibit a long-run relationship. In order to capture the extent of co-integration among the variables, the multivariate co-integration methodology proposed by Johansen (1990) was utilized to achieve the set objective of ascertaining the long-run relationship between greenhouse gas emissions and renewable energy and food security variables. The trace test and maximum eigenvalue from this technique were used to establish the numbers of co-integration vectors and the results are presented in Table 3 and Table 4. The trace statistic is the sum of the eigenvalues of Π. The test result shows that the trace statistic is larger than the 5% critical value for the "none" hypothesis, indicating that there is at least one co-integrating equation in the system. However, the statistic is not larger than the critical value for the "at most 1" hypothesis, indicating that there is at most one co-integrating equation in the system. Therefore, we can conclude that there is one co-integrating equation in the system.

The trace test indicates only one co-integrating variables while the maximum eigenvalue indicates no co-integrating variable at a 5% level of significance. The result, therefore, suggests that there exists no long-run relationship between greenhouse gas emissions and renewable energy and food security variables. Hence, there is no need to carry out error correction test (ECM).

Table 4: Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None	0.527669	29.25295	33.87687	0.1615
At most 1	0.453560	23.56888	27.58434	0.1505
At most 2	0.285237	13.09638	21.13162	0.4434
At most 3	0.117355	4.868451	14.26460	0.7584
At most 4	0.013911	0.546341	3.841466	0.4598

Source: Author's Computation

Table 4 provides the results of the unrestricted cointegration rank test using the maximum eigenvalue method. The table displays the test statistics and critical values at the 5% level of significance for different hypothesized numbers of co-integrating equations.The null hypothesis for each case is that the number of co-integrating equations is less than or equal to the specified number of equations. The alternative hypothesis is that the number of co-integrating equations is greater than the specified number of equations.Based on the results, the maximum eigenvalue test also suggests the presence of at least one co-integrating equation. The test statistics for the null hypothesis of no co-integrating equation is smaller than the critical values at the 5% level of significance for all hypothesized numbers of co-integrating equations. However, the test statistic for the null hypothesis of at most one co-integrating equation is not significantly different from the critical value at the 5% level of significance. Therefore, the maximum eigenvalue test also supports the presence of a single co-integrating relationship among the variables in the model.

Granger Causality Test

Table 5: Granger Causality Test Result

Null Hypothesis	Obs	F-Statistic	Prob	Decision	Type of Causality
CO2E does not Granger Cause FOS	39	9.06130	0.0007	Reject H_0	Uni-directional causality
FOS does not Granger Cause CO2E		1.31674	0.2813	Accept H_0	Uni-directional causality
ECON does not Granger Cause FOS	39	6.35865	0.0045	Reject H_0	Uni-directional causality
FOS does not Granger Cause ECON		0.19924	0.8203	Accept H_0	Uni-directional causality
ACCE does not Granger Cause FOS	39	6.10540	0.0054	Reject H_0	Uni-directional causality
FOS does not Granger Cause ACCE		0.15130	0.8602	Accept H_0	Uni-directional causality
CPI does not Granger Cause FOS	39	7.54971	0.0019	Reject H_0	Uni-directional causality
FOS does not Granger Cause CPI		0.09883	0.9062	Accept H_0	Uni-directional causality

Source: Authors' computation

The Granger causality test aids in the investigation of correlation patterns using empirical datasets. Granger causality is used in the study of renewable energy policy and economic growth in Nigeria to identify the nature of the causal relationship between renewable energy policy and economic growth in Nigeria. The table shows the Granger causality test results for the variables in the model. The null hypothesis for each test is that the lagged values of one variable do not have a significant effect on the other variable. The table shows the number of observations, F-statistic, probability value (p-value), and the decision on whether to reject or accept the null hypothesis at the 5% significance level. The Decision rule is; reject H0 if Probability value is lower than 0.05 and accept H0 if otherwise. According to the results, CO2E Granger causes FOS, ECON Granger causes FOS, ACCE Granger causes FOS, and CPI Granger causes FOS.

This means that the past values of CO2E, ECON, ACCE, and CPI can help in predicting the future values of FOS. Also, thisindicates a unidirectional causality running from the independent variables to the dependent variable FOS. However, FOS does not Granger cause CO2E, ECON, ACCE, or CPI, indicating that FOS is not a significant predictor of these variables. Therefore, the model suggests that changes in CO2E, ECON, ACCE, and CPI can affect FOS, but changes in FOS do not have a significant effect on these variables. Based on this result, we conclude that there is a Uni-directional causal relationship between greenhouse gas emissions and renewable energy with food security in Nigeria.

Findings

Despite the potential benefits of renewable energy technologies in enhancing agricultural productivity and reducing greenhouse gas emissions in Sub-Saharan Africa, there is limited empirical evidence on their impact on smallholder farmers. Most of the existing studies are either focused on the technical aspects of the technologies or the policy and institutional frameworks required for their adoption and diffusion. There is a need for more empirical research that explores the social, economic, and environmental impact of renewable energy technologies on smallholder farmers, particularly in terms of their productivity, income, and food security.

Additionally, one of the main barriers to the adoption of renewable energy technologies in agriculture is the high upfront costs involved. Smallholder farmers often lack the financial resources to invest in these technologies, and there are limited financing options available.

Finally, there is a need for more research on the social and cultural factors that influence the adoption and diffusion of renewable energy technologies in agriculture. Renewable energy technologies are not just technical solutions but also social and cultural ones, and their adoption and diffusion depend on a range of factors, such as gender roles, social norms, and cultural values. Understanding these factors is crucial to developing more effective strategies for the adoption and diffusion of renewable energy technologies in agriculture.

In summary, the research gaps identified highlight the need for more empirical research on the impact of renewable energy technologies on smallholder farmers in Sub-Saharan Africa, more investment in extension services and capacity building, the development of more effective policy and regulatory frameworks, the development of more innovative and accessible financing options, and more research on the social and cultural factors that influence the adoption and diffusion of these technologies.

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