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Agricultural Production, Renewable Energy Consumption, Foreign Direct Investment, and Carbon Emissions: New Evidence from Africa

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Abstract: This paper explores the nexus between agricultural production, renewable energy, foreign direct investment (FDI), and carbon emissions in Africa, where there is limited evidence on the topic. Relying on panel data covering thirty-one African countries obtained from the World Bank World Development Indicators and FAOSTAT databases, we answered the question of whether agricultural production (proxied by livestock production, fertilizer consumption, and land under cereal cultivation), the use of renewable energy, and FDI increase or reduce carbon emissions. Using the panel autoregressive distributed lag model for analysis, our results show that net FDI, fertilizer consumption, livestock production significantly increased carbon emissions, both in the short run and long run. Meanwhile, renewable energy use consumption significantly decreased carbon emissions, both in the short run and long run. Specifically, a 1% increase in net FDI increased total carbon emissions by 0.003% in the short run and by 0.01% in the long run. Renewable energy consumption significantly decreased carbon emissions, both in the short run and long run. A 1% increase in renewable energy consumption decreased total carbon emissions by 0.16% in the short run and by 0.22% in the long run. Additionally, fertilizer consumption and livestock production significantly increased carbon emissions in the short run and long run. A 1% increase in fertilizer consumption increased total carbon emissions by 0.01% in the short run and by 0.04% in the long run, while a 1% increase in livestock production increased total carbon emissions by 0.20% in the short run and by 0.56% in the long run. The findings call for investment in renewable energy technologies and consumption while advocating for large-scale uptake of climate-smart agriculture, and environmentally friendly targeted foreign direct investments on the continent.

Keywords: greenhouse gas emissions; agricultural production; FDI; renewable energy; panel ARDL; Africa

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1. Introduction

Achieving net-zero emissions and pursuing sustainable development are current topics around the globe. The global economy is witnessing rapid development, with its negative impacts on the global climate system, which is affecting humans, systems, and sectors [1]. The global average surface temperature has increased by 1.09 °C from 1850–1900 to 2011–2020 [1]. There is a consensus in the scientific literature that increased anthropogenic activities have caused a significant rise in global greenhouse gas emissions, which has caused global climate change [1,2]. Global net anthropogenic greenhouse gas emissions have been increasing, and the 2019 value (59 ± 6.6 $GtCO_2$-eq) was 54 percent higher than the 1990 value (21 $GtCO_2$-eq) [3].

Africa contributes only 9 percent of global greenhouse gas emissions, while East Asia contributes 27 percent [3]. The two economic sectors that contribute most to greenhouse gas emissions are agriculture, forestry, and other land use (AFOLU) and energy sectors [4]. AFOLU is central for food security and sustainable development [5]. The contribution of AFOLU activities to global total net anthropogenic greenhouse gas emissions is between 21 and 37 percent, while the energy sector contributes approximately 35 percent [1,4,6,7]. Agricultural production, increasing energy consumption, and investments in both agriculture and energy could increase carbon emissions. The attainment of the Sustainable Development Goal (SDG)-2 of ending hunger stands to be jeopardized by 2030 if global warming caused by anthropogenic greenhouse gas emissions does not stop.

Agriculture is an important economic sector in Africa. On average, the sector contributes about 15 percent to the gross domestic product (GDP) of the African economy, employing more than 50 percent of the total work force [8,9]. The prioritization of the sector in the development agenda of the New Partnership for Africa's Development (NEPAD) and the Comprehensive African Agricultural Development Programme (CAADP) further explains the importance of the sector to the continent [9]. The sector has witnessed significant increases in output since NEPAD came into existence. Within the same period, fertilizer consumption, livestock production, foreign direct investment, energy consumption, and greenhouse gas emissions have all increased [10–14]. Carbon emissions from AFOLU and the energy sector will increase if appropriate mitigation measures are not in place [4]. Several studies [15–22] have noted the importance of transitioning from non-renewable energy consumption to renewable and clean energy use in (foreign) investments and production activities (including in agriculture) in global carbon emissions reduction goals.

Ironically, it is Africa, which has most of its rural population inclined toward agricultural production and contributes least to global greenhouse gas emissions, that appears to be the most vulnerable to the climate crisis [23,24]. The continent has an enormous population, with significant numbers of people living in poverty. Reducing poverty on the continent would require significant investments in agriculture. Efforts required to improve agriculture and poverty reduction require financial capital in the form of FDI and the efficient use of renewable energy resources, along with the sustainable management of these resources to reduce CO_2 emissions. It is important to note that increasing agricultural production requires more foreign direct investment, more energy consumption (especially fossil fuel), and hence leads to greater carbon emissions. Most related studies rarely consider the joint effects of agricultural production, renewable energy, foreign direct investment (FDI), and carbon emissions in Africa, even though they remain pertinent. Rather, the related studies consider a limited combination of the joint effects. For instance, the literature [19,25,26] establishes that energy consumption increases carbon emissions and promotes socio-economic growth and development.

A strand of that literature [27–31] established a positive effect between economic activities, using GDP as a proxy, and carbon emissions, implying that increased economic growth is associated with increased carbon emissions. Meanwhile, Kasman & Duman (2015) [32] found that GDP has an inverse effect on carbon emissions. Others [15,33,34] found no significant effects, thereby presenting mixed results.

Heterogeneous effects have been observed between FDI and CO_2 emissions. Some literature [35,36] has observed a positive relationship between FDI and CO_2 emissions, other portions of the literature [37–39] show a negative relationship. We find the nexus between agricultural production, renewable energy consumption, FDI, and carbon emissions to be relevant in African's quest to improve agricultural production, which appears to be lagging behind the rest of the Global North. This requires the revamping of agricultural production by attracting the needed FDI to revolutionize the sector. And properly manage renewable energy, and reduce carbon emissions. Most of the literature, however, largely fail to examine the nexus between agricultural production, renewable energy, and CO_2 emissions, but rather examines these variables (agricultural production, renewable energy, and CO_2 emissions) in silos or in a limited combination(s). This is despite the fact that these variables form a solid foundation for sustainable agricultural development and the management of the climate crises. This article is motivated by this concern, given that the complex issue adds to the discussion of sustainable development in Africa. A clear understanding of the impact of agricultural production, foreign direct investment, and renewable energy consumption on carbon emissions remains an essential focus in driving sustainable development.

The question of whether agricultural production, renewable energy, and foreign direct investment (FDI) affect carbon emissions and the magnitude thereof, has received considerable attention, but with mixed results. For example, the related literature on renewable energy and carbon emissions presents three strands of evidence. One argues for a positive relationship between renewable energy and carbon emissions, another indicates an inverse relationship between the two, and a third maintains a middle ground (neutral relationship). Thus, mixed and inconclusive evidence exists in the extant literature. For instance, Acheampong (2018) [15], Dogan and Seker (2016) [17], Dogan and Seker (2016) [18], Jebli et al. (2016) [20], Liu et al. (2017) [21], Zhang et al. (2019) [22], Boluk and Mert (2014) [40], and Menyah and Wolde Rufael (2010) [41] showed that increased renewable energy consumption generally reduced carbon dioxide (CO_2) emissions. Specifically, Saidi and Hammami (2015) [30], Salahuddin and Gow (2014) [34], Boluk and Mert (2014) [40], indicated that renewable energy contributed to a 50% reduction in carbon emissions. The related literature by Myszczyszyn and Suproń (2021) [42], Gessesse and He (2020) [43], Tong et al. (2020) [44], Apergis et al. (2010) [45], Arouri et al. (2012) [46], Pao and Tsai (2010) [47] Saboori and Sulaiman (2013) [48], and Ozturk and Acaravci (2010) [49] showed a positive relationship between energy consumption and carbon emissions. Hasnisah et al. (2019) [50] argued for middle ground, showing that an insignificant relationship exists between renewable energy and carbon emissions. Generally, the findings appear inconclusive. A similar trend is observed for the relationship between FDI and carbon emissions. Nguyen (2021) [51] observed a positive relationship between FDI and $CO_{2.}$ Shahbaz et al. (2015) [52] indicated that FDI positively influenced carbon emissions in high-income countries, while an inverse relationship was observed in low-income countries. Wang and Huang (2022) [53] indicated that, in the short run, an increase in the level of FDI led to an increase in CO_2 emissions, while in the long run, no significant impact was recorded in their study of East Asia. Xie et al. (2020) [36] indicated that the impact of FDI on carbon emission shifted from significant to negative. Liu et al. (2021) [54] indicated that FDI positively impacted on carbon emissions in their study in China. We summarize that the literature appears inconclusive.

More so, the relationship between agriculture and carbon emissions is also inconclusive. For instance, Pegels and Altenburg (2020) [55] noted that the excessive use of inorganic fertilizers causes pollution to the environment, with negative repercussions on human health and with a higher economic burden. Rehman et al. (2019) [56] found that energy use, agricultural productivity, and the area under cultivation increased carbon emissions in Asia. Zhang et al. (2019) [22] examined the nexus between agricultural energy consumption, agricultural output, and carbon emissions in China and observed that agricultural output decreased carbon emissions. Furthermore, we find limited accounts of studies that connect the nexus among carbon emission, fertilizer consumption, livestock production, renewable energy, FDI, and land under cultivation in Africa. Again, the literature on the determinants of carbon emissions in Africa rarely considers livestock production as one of the factors even though livestock production constitutes an important greenhouse gas emitter.

Our study fills the gap in the literature by examining the impacts of fertilizer consumption, livestock production, renewable energy, FDI, and land used for cereal production on greenhouse emissions in Africa. Agriculture is proxied in the study by livestock production, fertilizer consumption, and land under cereal cultivation. Livestock production plays an important role in the provision of animal protein and energy for humans. Demand for animal protein in meat and dairy has led to an ever-increasing production. The production of animal protein to meet demand has contributed to GHG emissions. The Food and Agriculture Organization (2017) [57] reports that emissions from livestock production account for 7.1 $GtCO_2$-eq per year, representing 14.5% of all anthropogenic GHG emissions. Cereal cultivation also accounts for AFOLU emissions [58]. Cereal crops account for 50% of caloric intake of most families in Africa [59]. Maize, sorghum, rice, and wheat are important staple food commodities in Africa. The demand for cereals far outweighs the supply, and this has led to massive imports of cereals in Africa to close the demand–supply gap and tackle food insecurity issues [60]. The increase in crop production, particularly cereals, through area expansion and crop intensification, increases carbon emissions and biodiversity loss [61–63]. The intensification of crop production to meet the growing demand for food further exacerbates the demand for fertilizer. Fertilizer consumption in Africa is important for increased productivity. The use of fertilizers, particularly nitrous oxide, significantly contributes to GHG emissions and accounts for 717MT CO_2-eq per year [64]. Synthetic fertilizer emissions accounted for 8.3% of agricultural emissions in 2019 [65,66]. The combined effect of energy, FDI, and AFOLU (particularly fertilizer use, expansion in agriculture for food supply) has not been documented.

The rest of the article proceeds as follows: the next Section presents the related literature pertinent to the study. This is followed by the methodology (Section 3) and the results and discussion (Section 4). Section 5 concludes and offers policy recommendation worth considering.

2. Empirical Literature Review

2.1. Impacts of Renewable Energy Consumption on Carbon Emissions

Several studies have investigated the impact of renewable energy consumption on carbon emissions. Dogan and Seker (2016) [17] explored the factors shaping carbon emissions in the European Union. Employing the dynamic ordinary least squares estimator, the paper confirmed the environmental Kuznets curve hypothesis and found that renewable energy consumption and trade yielded a negative and significant impact on carbon emissions. In contrast, non-renewable energy consumption increased carbon emissions in the European Union.

Dogan and Seker (2016) [18], by employing panel estimation techniques with cross-sectional dependence, investigated the impact of output, renewable and non-renewable energy consumption, trade, and financial development on carbon emissions in the top countries listed in the Renewable Energy Country Attractiveness Index. The paper confirmed the environmental Kuznets curve hypothesis and found that renewable energy consumption, trade openness, and financial development all yielded negative and significant impact on carbon emissions, while non-renewable energy consumption increased carbon emissions in the countries.

Jebli et al. (2016) [20] explored the impacts of gross domestic product, renewable and non-renewable energy consumption, and international trade on carbon emissions in twenty-five OECD countries. They applied the fully modified ordinary least-squares and dynamic ordinary least-squares regression techniques, and the paper verified the environmental Kuznets curve hypothesis. The paper also showed that renewable energy consumption and international trade all yielded negative and significant impacts on carbon emissions, while non-renewable energy consumption increased carbon emissions in these countries.

Liu et al. (2017) [21] analyzed the effect of renewable energy and agriculture on carbon dioxide emissions in four selected ASEAN countries carbon emissions using panel estimation techniques. Although the paper did not confirm the environmental Kuznets curve hypothesis, interesting results were observed. The paper found that renewable energy consumption and agriculture reduced carbon emissions, while non-renewable energy consumption increased carbon emissions in the countries. Additionally, the paper observed that bidirectional causalities existed from non-renewable energy to emissions and to agriculture, from economic growth to agriculture, and from agriculture to renewable energy directly.

Radmehr et al. (2021) [26] explored three-way linkages between economic growth, renewable energy consumption, and carbon emissions in the European Union using panel spatial simultaneous equations models. The paper shows that there is unidirectional link between carbon emissions and renewable energy consumption, while there is bidirectional link between economic growth and carbon emissions, and economic growth and renewable energy consumption.

İnal et al. (2022) [67] explored the linkages between renewable energy consumption, carbon emissions, and economic growth in oil-producing countries using a second-generation panel estimation technique. The paper shows the under-utilization of renewable energy in the countries due to the insignificant relationship observed between renewable energy consumption and economic growth. However, the paper shows that carbon emissions and economic growth demonstrated a significant positive relationship in some countries such as Algeria, Egypt, and Equatorial Guinea.

Shafiei and Salim (2014) [68] investigated the effect of renewable energy consumption on CO_2 emissions in OECD countries using the STIRPAT econometric framework. The findings indicated that renewable energy consumption has a negative and significant effect on carbon emissions and that non-renewable energy consumption has a positive and significant effect on carbon emissions. Hao (2022) [19] further examined the relationship between renewable energy consumption, carbon emissions, output, and exports using econometric models. The paper showed a long-run relationship and causality among the variables, indicating that renewable energy consumption, output, and export are related to CO_2 emissions.

Furthermore, Aspergis et al. (2010) [45] employed the panel error correction model in analyzing the relationship between renewable energy consumption and CO_2 emissions, and the study revealed a statistically significant positive relationship between CO_2 emissions and renewable energy consumption. The findings further indicated no causality running from renewable energy consumption to $CO_{2,}$ but it rather revealed a unidirectional causality running from CO_2 emission to renewable energy consumption. Hasnisah et al. (2019) [50] examined the impacts of renewable energy consumption on carbon emissions using the fully modified ordinary least-squares and dynamic ordinary least-squares estimation techniques. The paper reveals that renewable energy consumption does not significantly contribute to carbon emissions. Zaidi and Ferhi (2019) [69] investigated the causal relationships between energy consumption, economic growth, and CO_2 emissions in Sub-Saharan using dynamic simultaneous-equation and the result showed a bidirectional relationship between energy consumption and electricity consumption. Additionally, Salahuddin and Gow (2014) [34] studied the nexus between economic growth, energy consumption, and carbon emissions in the Gulf Cooperation Council countries. They found that energy consumption increased carbon emissions in the long-run.

Salim and Rafiq (2012) [70] employed the dynamic OLS and fully modified OLS in examining the relationship between CO_2 emissions and renewable energy consumption. The result revealed a bidirectional causal relationship between renewable energy consumption and CO_2 emissions in the short run. Alam et al. (2011) [71] also revealed a bidirectional Granger causality between renewable energy consumption and CO_2 emission, while Arouri et al. (2012) revealed that renewable energy consumption has a long-run positive impact on CO_2 emissions. Furthermore, similar studies by Zhu et al. (2009) [72], Halicioglu (2009) [73], Soytas and Sari (2009) [74] also revealed that renewable energy consumption has a positive and statistically significant effect on CO_2 emissions.

2.2. Impacts of Agricultural Production on Carbon Emissions

Rehman et al. (2022) [7] examined the impact of crop production, fertilizer usage, and employment on CO_2 emissions by adopting the symmetrical (ARDL) technique and stepwise robust least-squares regression. The short-run result explained that crop production variables and land used for crop production had positive effects on CO_2 emissions, while the fertilizer and employment in agricultural enterprises produced negative effects on CO_2 emissions. Appiah et al. (2018) [75] examined the effects of crop production and livestock production on CO_2 emissions, and found that both livestock and crop production had positive effect on emissions.

Rehman et al. (2019) [56] investigated the impact of agricultural productivity on CO_2 emissions in Pakistan using the autoregressive distributed lag (ARDL) model. The study revealed that long-run estimated coefficients of cropped area, energy consumption, and fertilizers significantly increased CO_2 emissions in Pakistan, while improved seed quality and food grains decreased CO_2 emissions.

Naseem et al. (2020) [76] adopted a cointegration approach of asymmetric autoregressive distributed lag (ARDL) to examine the asymmetrical effect of agriculture on CO_2 emissions in Pakistan. The study revealed the existence of an asymmetrical effect of agriculture on carbon emission in the short and long term. Additionally, Gołasa et al. (2021) [77], Czyżewski and Michałowska (2022) [78], and Zang et al. (2022) [79] explored the relationship between agriculture and CO_2 emissions using the Farm Accountancy Data Network, the fixed-effects model, and the structural vector autoregressive model, respectively. The papers show that agricultural activities have a significant impact on CO_2 emissions. Haller (2022) [80] analyzed the effect of agricultural value chains on carbon footprint in the European OECD countries and applied fixed-effect model for analysis. The paper shows that organically cultivated land and economic growth decreased carbon footprint, while total agricultural land area, fertilizers, fish farming, and road infrastructure investments increased carbon footprint in the region.

Adeleye et al. (2021) [81] investigated the impact of agricultural productivity on environmental degradation in Nigeria and applied the impulse response functions and vector autoregressive model for analysis. The paper shows that the impact of carbon emissions on agricultural productivity was negative. Sui and Lv (2021) [63] examined the correlation between crop production and agricultural carbon emissions by adopting the environmental Kuznets curve (EKC) hypothesis and a decoupling analysis, and the detailed decomposition analysis revealed that agricultural economic growth had a significant effect on the increase in carbon emissions and that agricultural carbon emission intensity was significant in the decline in agricultural carbon emissions. Zhou et al. (2022) [82] investigated shocks in agricultural productivity and carbon emissions by adopting the linear and nonlinear ARDL model. The results suggested that livestock production can help to reduce carbon emissions both in the short- and long-run in the linear model, while increases in crop production deteriorate the environmental quality in the short run.

2.3. Impacts of Foreign Direct Investment (FDI) on Carbon Emissions

The impact of FDI on CO_2 emissions is heterogeneous. For example, Essandoh et al. (2020) [35] observed a positive relationship between FDI and CO_2 emission, while other studies [37–39] observed a negative relationship. Furthermore, Salahuddin et al. (2018) [83] examined the relationship between FDI and CO_2 emissions using the ARDL, and the result of the ARDL estimates revealed that FDI has a positive and significant influence on CO_2 emissions for Kuwait both in the short-run and long-run relationships. Huang et al. (2022) [84] examined the impacts of FDI inflows on carbon emissions. The feasible generalized least squares method was employed, and the result shows that FDI inflows are positively related with carbon emissions, while economic development and regulatory quality negatively influenced carbon emissions in the area. Shahbaz et al. (2015) [52] analyzed data from 99 countries, and empirical results suggested that the impacts of FDI inflows on carbon emissions were heterogeneous due to differences in national income. Consequently, the study further reported an inverted U-shaped association between FDI inflows and carbon emissions in middle-income countries. In high-income countries, the study found that FDI inflows can mitigate carbon emissions, while in low-income countries, the relationship was the opposite. Wang and Huang (2022) [53] investigated the effect of FDI on CO_2 emissions in East Asia with an autoregressive distributed lag model. The results revealed that, in the short run, an increase in the level of FDI in both the current and previous periods would also lead to an increase in CO_2 emissions, while in the long-run, FDI has no significant impact on CO_2 emissions. Khalil and Inam (2006) [85] estimated the impact of trade-related factors on CO_2 emissions in Pakistan using an error correction model. They found that FDI had a positive impact on CO_2 emissions.

Haug and Ucal (2019) [86] analyzed the impact of FDI on CO_2 emissions in Turkey, and it was revealed that FDI had no statistically significant long-term effect on CO_2 emissions. Xie et al. (2020) [36] examined the direct and spillover effects of FDI and CO_2 emissions in emerging countries with a panel smooth regression model with nonlinear and dynamic attributes. The findings revealed that the impact of FDI on total CO_2 emissions shifted from positive to negative as the rate of inflow of FDI increased, thereby confirming the pollution paradise and pollution halo hypotheses. Liu et al. (2021) examined the long-term impact of FDI by employing the advanced panel method based on slope uniformity and correlation test on China's environment. It was seen that the FDI and GDP positively impacted on carbon emissions, while foreign trade had an indirect correlation with carbon emissions. Atici (2012) [37] examined the relationship between FDI and CO_2 emissions by employing both random and fixed-effects panel analysis. Their findings conform to the halo effect hypothesis, that a rise in FDI enhances the environmental quality of the region. Alshubiri and Elheddad (2019) [87] examined the impact of FDI on carbon emissions using panel data from 32 OECD countries. The study revealed a nonlinear relationship between FDI inflows and carbon emission. Additionally, it was observed that, at the left side of the inflection point, FDI was positively related to carbon emissions; at the right side of the inflection point, FDI was negatively correlated with carbon emissions. Odugbesa and Adebayo (2020) [88] investigated the effects of FDI and financial development on carbon emissions with the aid of a linear and nonlinear ARDL. The results showed that the asymmetric effect in the short run from the estimation reveals that the positive and negative shocks in both financial development and FDI have a short-run correlation with CO_2.

3. Methodology

3.1. Data Source

We focused our study on Africa, which has been described as one of the most vulnerable regions to the impacts of climate change in the world. We used data from thirty-one (31) countries in the region (See Table 1 for countries studied).

Table 1. List of countries studied.

Serial Number	Country
1	Algeria
2	Benin
3	Burkina Faso
4	Burundi
5	Cameroon
6	Central African Republic
7	Côte d'Ivoire
8	Egypt
9	Gabon
10	Ghana
11	Guinea
12	Kenya
13	Libya
14	Madagascar
15	Malawi
16	Mali
17	Mauritius
18	Morocco

Table 1. *Cont.*

Serial Number	Country
19	Mozambique
20	Namibia
21	Niger
22	Nigeria
23	Rwanda
24	Senegal
25	South Africa
26	Togo
27	Tunisia
28	Uganda
29	Tanzania
30	Zambia
31	Zimbabwe

Data availability informed the choice of the countries and the period under study (2000 to 2019). We obtained data on the livestock production index from the FAOSTAT database. Land under cereal cultivation, foreign direct investment net inflow, fertilizer consumption, renewable energy consumption, and total greenhouse gas emissions were obtained from the World Bank World Development Indicator Database. We used data spanning a period of 20 years (2000–2019). Total greenhouse gas emissions was the dependent variable, while land under cereal cultivation, foreign direct investment net inflow, fertilizer consumption, renewable energy consumption, and livestock production index were the independent variables. The description of the variables is presented in Table 2.

Table 2. Description of the variables.

Variables	Data Source
Land under cereal production (hectares)	World Development Indicator Database of World Bank
Foreign direct investment net inflow (USD)	World Development Indicator Database of World Bank
Livestock production index number (2014–2016 = 100)	FAOSTAT Database
Renewable energy consumption (% of total final energy consumption)	World Development Indicator Database of World Bank
Fertilizer consumption (kilograms per hectare of arable land)	World Development Indicator Database of World Bank
Total greenhouse gas emissions (kilotons of CO_2 equivalent)	World Development Indicator Database of World Bank

Links to the data: https://databank.worldbank.org/source/world-development-indicators#; https://www.fao.org/faostat/en/#data/QCL (accessed on 10 August 2022).

3.2. Econometric Strategy

We used the panel autoregressive distributed lag framework to model the impacts of agricultural production (proxied by livestock production index, fertilizer consumption, and land area under cereal crops cultivation), energy consumption (proxied by renewable energy consumption), and foreign direct investment on carbon emissions in Africa. The panel autoregressive distributed lag model is free from endogeneity problem, and it also has the ability to determine the cointegration among all the variables at first and second orders [89]. The unit root test is applied to test the stationarity of the variables to determine the orders at which the variables are stationary or non-stationary. Pesaran cross-sectional augmented Dickey–Fuller (CADF) and Im–Pesaran–Shin unit root tests were used in this paper to determine the levels at which the dependent and independent variables are stationary or non-stationary. Kao test and Pedroni test were used to determine whether the variables are cointegrated. The panel autoregressive distributed lag was used to compute the long- and short-run impacts of the independent variables on the dependent variable.

The implicit model of our panel autoregressive distributed lag framework is stated as follows:

$$Y = f(X1,\ X2,\ X3, X4, X5) \tag{1}$$

where;

Y = Total greenhouse gas emissions (ktonsCO_2eq)
$X1$ = Land under cereal cultivation (hectares)
$X2$ = Foreign direct investment net inflow (USD)
$X3$ = Renewable energy consumption (% of total final energy consumption)
$X4$ = Fertilizer consumption (kilograms per hectare of arable land)
$X5$ = Livestock production index

To control for possible heteroskedasticity in our dataset, we converted the real values of the variables into their logarithmic values. The panel autoregressive distributed lag model with the logarithms is presented thus:

$$\ln Y_{it} = \beta_0 + \beta_1 \ln X1_{it} + \beta_2 \ln X2_{it} + \beta_3 \ln X3_{it} + \beta_4 \ln X4_{it} + \beta_4 \ln X5_{it} + \varepsilon_{it} \quad (2)$$

where; i: 1, 2, 3, ..., 31 countries; t: 2000, 2001, 2002, ..., 2019 year; ln denotes natural logarithm; ε is the error term. Furthermore, β_1, β_2, and β_3 define the estimated percentage change in carbon emissions caused by a one percent change in land under cereal cultivation, foreign direct investment net inflow, renewable energy consumption, fertilizer consumption, and livestock production, respectively, while all other factors are constant.

Our study considered three important contributors to greenhouse gas emissions in the agricultural sector—given as area under cereal cultivation, livestock production proxied by livestock production index, and fertilizer consumption. These variables have been reported to contribute significantly to greenhouse gas emissions in the AFOLU sector [58,65,66,90]. Renewable energy consumption was also considered as a variable because the energy sector contributes most to global greenhouse gas emissions. FDI was added as a covariate because of the need for investments in the agricultural and energy sectors. Furthermore, we could not consider other components of the agricultural sector because of the problem of multicollinearity. We are further limited by the number of independent variables (maximum of six independent variables) the panel autoregressive distributed lag model could accommodate. The combination of independent variables that yielded results that satisfy the requirements of our econometric model were as follows: area under cereal cultivation, livestock production index, fertilizer consumption, renewable energy consumption and FDI.

Standard panel regressions, as expressed by the model in Equation (2), can be used to estimate efficiently and consistently if all the variables are stationary at levels. In a situation where some variables are stationary at levels and others stationary at first difference, a dynamic model for panel data with cointegration is required and such model should be an autoregressive distributed lag model (ARDL). The Pooled Mean Group (PMG) and Dynamic Fixed-effect (DFE) models are popular in the literature for computing dynamic heterogeneous panel datasets. To understand the long-run impacts and the long run adjustment rate, it is necessary to identify each country's short run dynamics. The long- and short-run effects of climate change variables and grazing land on cattle production over time and across different African countries, using the panel ARDL, can be estimated thus:

$$\begin{aligned}\Delta \ln Y_{it} = {} & \beta_i + \beta_{1i} \ln Y_{i,t-1} + \beta_{2i} \ln X1_{i,t-1} + \beta_{3i} \ln X2_{i,t-1} + \beta_{4i} \ln X3_{i,t-1} + \beta_{5i} \ln X4_{i,t-1} + \beta_{6i} \ln X5_{i,t-1} \\ & + \textstyle\sum_{j=1}^{p_1} \gamma_{1ij} \Delta \ln Y_{i,t-j} + \sum_{j=1}^{p_2} \gamma_{2ij} \Delta \ln X1_{i,t-j} + \sum_{j=1}^{p_3} \gamma_{3ij} \Delta \ln X2_{i,t-j} + \sum_{j=1}^{p_4} \gamma_{4ij} \Delta \ln X3_{i,t-j} \\ & + \textstyle\sum_{j=1}^{p_5} \gamma_{5ij} \Delta \ln X4_{i,t-j} + \sum_{j=1}^{p_6} \gamma_{6ij} \Delta \ln X5_{i,t-j} + \epsilon_{it},\end{aligned} \quad (3)$$

where; Δ denotes first differences, β_i is a constant, $\gamma_{nij(n=1,\ldots,6)}$ denote short-run coefficients, $\beta_{mi(m=1,\ldots,6)}$ are long-run coefficients and ϵ_{it} is an error term. Equation (3) could be re-stated with an error correction term as follows:

$$\begin{aligned}\Delta \ln Y_{it} = {} & \vartheta_i + \textstyle\sum_{j=1}^{p_1} \gamma_{1ij} \Delta \ln Y_{i,t-j} + \sum_{j=1}^{p_2} \gamma_{2ij} \Delta \ln X1_{i,t-j} + \sum_{j=1}^{p_3} \gamma_{3ij} \Delta \ln X2_{i,t-j} + \sum_{j=1}^{p_4} \gamma_{4ij} \Delta \ln X3_{i,t-j} \\ & + \textstyle\sum_{j=1}^{p_5} \gamma_{5ij} \Delta \ln X4_{i,t-j} + \sum_{j=1}^{p_6} \gamma_{6ij} \Delta \ln X5_{i,t-j} + \lambda_i ECT_{i,t-1} + \epsilon_{it}\end{aligned} \quad (4)$$

where; $ECT_{i,t-1}$ is the error correction term.

It is customary to check the direction of causality in a panel dataset if cointegration exists. We used the Dumitrescu and Hurlin (2012) [91] panel causality test to determine the direction of causation among our variables. The model of the Wald statistics, using the Granger causality among variables, is stated as follows:

$$y_{it} = \alpha_i + \sum_{j-1}^{J} \lambda_i^j y_{i(t-j)} + \sum_{j=1}^{J} \beta_i^j x_{i(t-j)} + \mu_{it} \quad (5)$$

where; y and x are the observables. λ_i^j denotes the autoregressive parameters while β_i^j denotes the regression coefficient estimates, and both are assumed to vary across cross sections. The null and alternative hypotheses are stated as follows

$$H_o : \forall j : \beta_i^j = 0 \; H_o : \forall j : \beta_i^j \neq 0 \quad (6)$$

4. Results and Discussion

4.1. Summary Statistics

Table 3 shows the descriptive statistics results of the dependent and independent variables. The average land area under cereal cultivation in the continent was 2,560,716.83 hectares in the period under study (2000 to 2019), the average net foreign direct investment was USD1,018,455,178.6, average livestock production index was 87.5665, average share of renewable energy consumption 61.54%, average fertilizer consumption was 42.99 kg per hectare of arable land, and average total greenhouse gas emissions was 67,422.4516 kilotons of CO_2 equivalent.

Table 3. Descriptive statistics of the variables.

Variables	Obs	Minimum	Maximum	Mean	Standard Deviation	Skewness	Kurtosis
Land under cereal production (hectares)	620	14.00	21,000,000.00	2,560,716.83	3,441,295.57	3.17	11.30
Foreign direct investment net inflow (USD)	620	−540,000,000	1,2000,000,000	1,018,455,178.6	1,733,325,147	3.02	10.14
Livestock production index	620	26.12	162.27	87.5665	19.36403	−0.429	0.465
Renewable energy consumption (% of total final energy consumption)	620	0.06	96.04	61.54	31.87	−0.83	−0.94
Fertilizer consumption (kilograms per hectare of arable land)	620	0.00	600.08	42.99	99.75	4.00	15.86
Total greenhouse gas emissions (kilotons of CO_2 equivalent)	620	1940.00	560,000.00	67,422.4516	107,521.70	2.78	7.77

For the land area under cereal cultivation, results reveal that for the period under study (2000–2019), the average land area for cereal cultivation was 2,560,716.83 hectares. According to statistics from the World Bank, in 2020, sub-Saharan Africa had an agricultural land area of 10,163,808 square kilometers [92]. The average land area under cereal cultivation represents a fraction of arable land for crop production. Given the importance of cereal crops, particularly rice, maize, millet, sorghum, and wheat for food self-sufficiency in most countries in sub-Saharan Africa, there is a continuous focus on expansion of the cultivated area to meet population expansion and higher demand for cereals in the continent [93].

However, carbons emissions due to land use change, deforestation, and flooding of rice fields have been reported to be high for certain cereal crops, especially rice [94–96].

4.2. Cross Section Dependence Test

Table 4 shows that there is cross section dependence in our dataset. The null hypothesis of cross-sectional independence was rejected.

Table 4. Cross section dependence test.

Variable	CD-Test	p Value
ln$Y$	56.02	0.000
ln$X1$	22.09	0.000
ln$X2$	26.08	0.000
ln$X3$	36.92	0.000
ln$X4$	24.08	0.000
ln$X5$	64.12	0.000

4.3. Correlations among the Variables

Table 5 shows the correlation coefficients among the variables. Our results show that almost all the correlation coefficients were significant, albeit weak. This was part of the preliminary analysis: to establish the degree of relationships among the variables. The results show that all the independent variables exhibited significant a correlation/relationship with carbon emissions. While land under cereal cultivation, net foreign direct investment, fertilizer consumption and livestock production all exhibited significant positive association with carbon emissions, renewable energy consumption however yielded a negative significant relationship with carbon emissions. These are just linear associations of the independent and the dependent variables, and do not in any way suggest any cause and effect between the selected variables in the long run. The result suggests an association, but the effect of each variable is further investigated using the panel ARDL model. We subjected this result to further econometric analysis using the panel ARDL model.

Table 5. Table of correlations among the variables.

Variables	ln$Y$	ln$X1$	ln$X2$	ln$X3$	ln$X4$	ln$X5$
ln$Y$	1.0000					
ln$X1$	0.4965	1.0000				
ln$X2$	0.3261	0.1797	1.0000			
ln$X3$	−0.4978	0.0747	−0.0493	1.0000		
ln$X4$	0.3264	−0.1428	0.2206	−0.4040	1.0000	
ln$X5$	0.2465	−0.0053	0.1234	−0.0841	0.1468	1.0000

4.4. Multicollinearity Test for the Independent Variables

We subjected the explanatory variables to multicollinearity diagnostics testing using the variance inflation factor test. The result is presented in Table 6. The result shows the absence of multicollinearity, as the variance inflation factors did not exceed 5. Our results showed that all the independent variables were not collinear, as the variance inflation factors were below 5. Variance inflation factors of values less than 5 indicate the absence of multicollinearity between the variables in question [97].

Table 6. Multicollinearity statistics based on variance inflation factor (VIF).

Variable	Variance Inflation Factor
ln$X1$	1.072
ln$X2$	1.116
ln$X3$	1.199
ln$X4$	1.306
ln$X5$	1.032

4.5. Stationarity Test of the Variables

We conducted the unit root test to determine whether the dependent and independent variables were non-stationary or stationary. This determined the next type of analysis we could perform. We used the Pesaran cross-sectional augmented Dickey–Fuller (CADF) and Im–Pesaran–Shin unit root tests to determine the levels at which the dependent and independent variables are stationary or non-stationary. The result of the unit-root test is presented in Table 7. The result shows that total greenhouse gas emissions, land under cereal cultivation, net foreign direct investment, and fertilizer consumption were stationary at level under the Pesaran cross-sectional augmented Dickey–Fuller (CADF) test. Meanwhile, net foreign investment and fertilizer consumption were stationary at level under the Im–Pesaran–Shin unit root test. Renewable energy consumption and livestock production have unit roots under the Pesaran cross-sectional augmented Dickey–Fuller (CADF) test, while total greenhouse gas emissions, area under cereal cultivation, renewable energy consumption and livestock production have unit roots under the Im–Pesaran–Shin unit root test. However, all the variables were stationary at the first difference under the Pesaran cross-sectional augmented Dickey–Fuller (CADF) and Im–Pesaran–Shin unit root tests. This suggests that the panel ARDL model is appropriate in this case to model the impact of the independent variables on the dependent variable. From Table 7, the unit root test results show that the total greenhouse gas, land under cereal cultivation, net foreign direct investment, fertilizer consumption, renewable energy consumption, as well as livestock production had unit roots at the level, and after first differencing they were stable under the Pesaran cross-sectional augmented Dickey–Fuller (CADF) and Im–Pesaran–Shin unit root tests at the significant levels of 1% and 5%. Since all the variables were stable at first differencing, a further test to establish if there was a co-integration between the variables was conducted using the Kao test and Pedroni test.

4.6. Cointegration Test

The co-integration test presented in Table 8 reveals a long-run relationship between total greenhouse gas emissions, land area under cultivation, fertilizer consumption, livestock production, and net foreign direct investment. The long-run relationship between total greenhouse gas emissions, land under cereal cultivation, net foreign direct investment (FDI), renewable energy consumption, fertilizer consumption, and livestock production was analyzed using the Kao test and the Pedroni test and presented in Table 8. The results of the co-integration test using the augmented Dickey–Fuller test and the modified Phillips Perron test in Table 8 were all statistically significant at 1% level, and show that there is a co-integration relationship between total greenhouse gas emissions, land under cereal cultivation, net foreign direct investment (FDI), renewable energy consumption, fertilizer consumption, and livestock production. This implies that there was a long-run relationship between total greenhouse gas emissions, land under cereal cultivation, net foreign direct investment (FDI), renewable energy consumption, fertilizer consumption, and livestock production, in Africa between 2000 and 2019. These findings are consistent with the results of Balli et al. (2021 [98] and Li et al. (2016) [99]. The results show that there exists a long-run and short-run relationship between the dependent variable (total greenhouse gas emissions) and explanatory variables (land under cereal cultivation, net foreign direct investment (FDI), renewable energy consumption, fertilizer consumption, and livestock production.

Table 7. Unit root test.

H_0 = All Panels Contain Unit Roots H_0 = Series Have a Unit Roots				
		Pesaran's CADF Test		
	At Level I(0)	**At First Difference I(1)**		
Variable	***t* statistic**	***t* statistic**	**Decision: H_0**	**Result**
ln*Y*	−2.254 ***	−3.357 ***	Reject	I(0) at 1%
ln*X*1	−2.043 **	−3.691 ***	Reject	I(0) at 5%
ln*X*2	−2.395 ***	−3.605 ***	Reject	I(0) at 1%
ln*X*3	−2.029	−2.871 ***	Reject	I(1) at 1%
ln*X*4	−3.344 ***	−3.960 ***	Reject	I(0) at 1%
ln*X*5	−1.986	−3.063 ***	Reject	I(1) at 1%
		Im–Pesaran–Shin unit root test		
	At level I(0)	**At first difference I(1)**		
Variable	***t* statistic**	***t* statistic**	**Decision: H_0**	**Result**
ln*Y*1	−1.3056	−9.1701 ***	Reject	I(1) at 1%
ln*X*1	−0.1979	−9.9797 ***	Reject	I(1) at 1%
ln*X*2	−5.0580 ***	−14.4053	Reject	I(0) at 1%
ln*X*3	0.5124	−6.1160 ***	Reject	I(1) at 1%
ln*X*4	−6.4631 ***	−12.4815 ***	Reject	I(0) at 1%
ln*X*5	0.5981	−7.8781 ***	Reject	I(1) at 1%

Note: ** and *** indicate significance at 5% and 1% levels, respectively.

Table 8. Cointegration test.

H0: No Cointegration **Ha: All Panels Are Cointegrated**		
Kao Test for Cointegration		
Test	**Statistic**	***p* Value**
Augmented Dickey–Fuller *t*	2.5469	0.0054
Unadjusted modified Dickey–Fuller *t*	−3.4240	0.0003
Unadjusted Dickey–Fuller *t*	−3.1548	0.0008
Pedroni test for cointegration		
Test	**Statistic**	***p* Value**
Modified Phillips–Perron *t*	5.9934	0.0000
Phillips–Perron *t*	−3.4469	0.0003
Augmented Dickey–Fuller *t*	−2.9261	0.0017

4.7. Panel ARDL Estimates of the Impacts of Agricultural Production, Renewable Use and Foreign Direct Investment on Greenhouse Gas Emissions

We used the pooled mean group (PMG) and the dynamic fixed-effect (DFE) model to assess the long-run and short-run relationship between the dependent variable (total greenhouse gas emissions) and explanatory variables (land under cereal cultivation, net foreign direct investment (FDI), renewable energy consumption, fertilizer consumption, and livestock production) in the presence of cross-sectional dependence and presented the results in Table 9. The PMG and DFE are second-generation estimation models, and we think that PMG and DFE would provide reliable, consistent and efficient results under cross-sectional dependence. We chose the DFE for further discussion because it had the highest number of significant variables in the short run and long run. The panel ARDL estimation of the impacts of synthetic fertilizer agricultural production, renewable energy use and foreign direct investment on carbon emissions showed varied results in the short-run and the long-run (Table 9).

Table 9. Panel ARDL results from pooled mean group and mean group estimators.

Variables		
	PMG	**DFE**
Panel A: Long-run estimates		
ln$X$1	−0.05	0.004
	(−1.19)	(0.06)
ln$X$2	0.01	0.01
	(2.54) **	(2.31) **
ln$X$3	−1.42	−0.22
	(−8.38) ***	(−2.37) **
ln$X$4	0.13	0.04
	(7.27) ***	(2.06) **
ln$X$5	0.08	0.56
	(1.69) *	(7.43) ***
Panel B: Short-run estimates		
ECT	0.13	0.20
	(3.08) ***	(7.67) ***
Δln$X$1	0.01	0.01
	(0.53)	(1.02)
Δln$X$2	0.002	0.003
	(0.58)	(3.91) ***
Δln$X$3	−0.34	−0.16
	(−2.05) **	(−4.15) ***
Δln$X$4	0.02	0.01
	(2.12) **	(4.04) ***
Δln$X$5	0.22	0.20
	(3.44) ***	(4.11) ***
Constant	−2.05	−1.64
	(−3.03) ***	(−6.14) ***
Observations	620	

Note: z-values are presented in parenthesis. *** denotes statistical significance at 1%, ** denotes statistical significance at 5%, and * denotes statistical significance at 10%. ECT is the error correction term/speed of adjustment towards the long run equilibrium.

Net FDI significantly increased carbon emissions, both in the short run and long run. A 1% increase in net FDI increased total carbon emissions by 0.003% in the short run and by 0.01% in the long run. Net FDI significantly increased carbon emissions both in the short run and long run, suggesting that FDI investments may be causing pollution in the host countries. These investments in various sectors, agricultural and manufacturing industries inclusive, may not be driven by the utilization of clean and efficient technologies. The use of obsolete technologies has the potentials for carbon emissions. FDI may have both positive and negative effects in an economy. Though it is important for economic growth, however, without considerable regulations in the actions of investors, there may be significant disruptions to the environment from carbon emissions. Maroufi & Hajilary (2022) [100] reports in their study of the impacts of economic growth, FDI and gas consumption on carbon emission in Iran, that FDI is positively and significantly related to carbon emissions in the long run, hence indicating that FDI leads to a reduction in environmental degradation.

Renewable energy consumption significantly decreased carbon emissions both in the short run and long run. A 1% increase in renewable energy consumption decreased total carbon emissions by 0.16% in the short run and by 0.22% in the long run. Renewable energy consumption significantly decreased carbon emissions both in the short run and long run, showing a need for the adoption of cleaner fuels in Africa. Renewable energy consumption reduces carbon emissions in the short and long-run, hence indicating a need for economies and households to transition to the use of cleaner fuels from renewable sources. Renewable energy consumption has been reported to have the potentials to reduce carbon emissions in global economies [19,101].

Fertilizer consumption significantly increased carbon emissions, both in the short run and long run. A 1% increase in fertilizer consumption increased total carbon emissions by 0.01% in the short run and by 0.04% in the long run. The livestock production index significantly increased carbon emissions, both in the short run and long run. A 1% increase in livestock production increased total carbon emissions by 0.20% in the short run and by 0.56% in the long run. The fertilizer consumption and livestock index significantly increased carbon emissions, both in the short run and long run. This poses a challenge to the achievement of food security and implies the use of unsustainable production practices. Fertilizer consumption significantly increased carbon emissions in the short and long run. The need for increased yields to guarantee food security has driven the increased consumption of fertilizer to boost soil fertility. However, continuous use of fertilizer, without regard to the damage to the environment, can pose greater dangers in the near future. Carbon and non-carbon emissions from manures, particularly synthetic fertilizers, need to be minimized. Livestock production is reported to significantly affect carbon emissions, both in the long and short run. Livestock production, particularly of ruminants, leads to carbon emissions both through land-use changes for grazing, leading to deforestation and the transportation of animals [102,103], and through enteric fermentation and manure management.

4.8. Granger Test for Panel Causality

We used the Dumitrescu and Hurlin (2012) [91] Granger test to determine causality in our dataset, and the results are presented in Table 10. The existence of long-run relationships among the variables indicates that Granger causality exists in at least one direction for each combination of two variables. Our paper finds that the lag error terms (ECTt−1) for carbon emissions and livestock production, fertilizer consumption, land under cereal cultivation, renewable energy consumption, and net foreign direct investment is significant at the 1% significance level. This confirms the existence of bidirectional causality between agricultural production, net foreign direct investment, renewable energy consumption and carbon emissions in the long run.

The causality test result, as presented in Table 10, shows that total greenhouse gas emissions Granger-causes land under cereal cultivation, and that land under cereal cultivation Granger-causes total greenhouse gas emissions (bidirectional causality exists). This suggests that the total greenhouse gas emissions may influence the area of land devoted to cereal crop production in Africa. It has been established that changes in land use for cereal crop production cause increases in greenhouse gas emissions in Africa. Nassem et al. (2020) [76] found that agriculture Granger-causes carbon emissions, while carbon emissions do not Granger-cause agriculture, hence indicating a unidirectional causality.

The unidirectional causality between net foreign direct investment and total greenhouse gas emissions suggests an increase in environmental pollution with the increasing net foreign direct investments. An increase in FDI has the potential to increase greenhouse gas emissions in the long run and in the short run. This calls for policy actions to match each foreign direct investment.

The results further show that bidirectional causality exists between total greenhouse gas emissions and renewable energy consumption. This relationship may suggest greenhouse gas emissions may drive policies directed at energy supply and consumption in Africa, and that a tendency towards unsustainable use of fossil fuels has the potential to degrade the environment. Improvements in the use of renewable energies and a shift from fossil fuel use may reduce greenhouse gas emissions in the long run. Farhani and Shahbaz (2014) [104] found causality between renewable and non-renewable energy consumption and carbon emissions, while Ponce and Khan (2021) [105] established a negative correlation between renewable energy and carbon emissions.

Table 10. Dumitrescu and Hurlin (D-H) Granger non-causality test results.

Hypothesis	Z-Bar	Z-Bar Tilde	Conclusion
$\ln Y \rightarrow \ln X1$	3.8727 ***	2.5907 ***	Total greenhouse gas emissions Granger-causes land under cereal cultivation, and land under cereal cultivation Granger-causes total greenhouse gas emissions (bidirectional causality exists).
$\ln X1 \rightarrow \ln Y$	12.5735 ***	9.4001 ***	
$\ln Y \rightarrow \ln X2$	−0.9436	−1.1787	Total greenhouse gas emissions does not Granger-cause net foreign direct investment, but net foreign direct investment does Granger-cause total greenhouse gas emissions (unidirectional causality exists).
$\ln X2 \rightarrow \ln Y$	6.0225 ***	4.2732 ***	
$\ln Y \rightarrow \ln X3$	3.8293 ***	2.5567 **	Total greenhouse gas emissions Granger-causes renewable energy consumption, and renewable energy consumption Granger-causes total greenhouse gas emissions (bidirectional causality exists).
$\ln X3 \rightarrow \ln Y$	7.2872 ***	5.2629 ***	
$\ln Y \rightarrow \ln X4$	3.4865 ***	2.2884 **	Total greenhouse gas emissions Granger-causes fertilizer consumption, and fertilizer consumption Granger-causes total greenhouse gas emissions (bidirectional causality exists).
$\ln X4 \rightarrow \ln Y$	12.9431 ***	9.6894 ***	
$\ln Y \rightarrow \ln X5$	6.0195 ***	4.2708 ***	Total greenhouse gas emissions Granger-causes livestock production, and livestock production Granger-causes total greenhouse gas emissions (bidirectional causality exists)
$\ln X5 \rightarrow \ln Y$	4.6574 ***	3.2048 ***	
$\ln X1 \rightarrow \ln X2$	1.1826	0.4854	Land under cereal cultivation does not Granger-cause net foreign direct investment, but net foreign direct investment does Granger-cause land under cereal cultivation (unidirectional causality exists).
$\ln X2 \rightarrow \ln X1$	8.5073 ***	6.2179 ***	
$\ln X1 \rightarrow \ln X3$	6.2233 ***	4.4304 ***	Land under cereal cultivation does Granger-cause renewable energy consumption, but their bidirectional link could not be confirmed (unidirectional causality exists)
$\ln X3 \rightarrow \ln X1$	1.9912 **	1.1182	
$\ln X1 \rightarrow \ln X4$	−0.3359	−0.7031	Land under cereal cultivation does not Granger-cause fertilizer consumption, but fertilizer consumption does Granger-cause land under cereal cultivation (unidirectional causality exists).
$\ln X4 \rightarrow \ln X1$	5.0709 ***	3.5284 ***	
$\ln X1 \rightarrow \ln X5$	12.6919 ***	9.4928 ***	Land under cereal cultivation does Granger-cause livestock production, but their bidirectional link could not be confirmed (unidirectional causality exists).
$\ln X5 \rightarrow \ln X1$	1.7231 *	0.9084	
$\ln X2 \rightarrow \ln X3$	7.2518 ***	5.2353 ***	Net foreign direct investment Granger-causes renewable energy consumption, and renewable energy consumption Granger-causes net foreign direct investment (bidirectional causality exists).
$\ln X3 \rightarrow \ln X2$	3.6040 ***	2.3804 **	
$\ln X2 \rightarrow \ln X4$	3.4259 ***	2.2410 **	Net foreign direct investment does Granger-cause fertilizer consumption, but their bidirectional link could not be confirmed (unidirectional causality exists).
$\ln X4 \rightarrow \ln X2$	1.9748 **	1.1054	
$\ln X2 \rightarrow \ln X5$	11.7345 ***	8.7435 ***	Net foreign direct investment does Granger-cause livestock production, but livestock production does not Granger-cause net foreign direct investment (unidirectional causality exists).
$\ln X5 \rightarrow \ln X2$	0.7712	0.1634	
$\ln X3 \rightarrow \ln X4$	1.0837	0.4079	Renewable energy consumption does not Granger-cause fertilizer consumption, but fertilizer consumption does Granger-cause renewable energy consumption (unidirectional causality exists).
$\ln X4 \rightarrow \ln X3$	13.2044 ***	9.8939 ***	
$\ln X3 \rightarrow \ln X5$	8.0205 ***	5.8369 ***	Renewable energy consumption Granger-causes livestock production, and livestock production Granger-causes renewable energy consumption (bidirectional causality exists).
$\ln X5 \rightarrow \ln X3$	4.1889 ***	2.8381 ***	
$\ln X4 \rightarrow \ln X5$	11.3327 ***	8.4291 ***	Fertilizer consumption does Granger-cause livestock production, but livestock production does not Granger-cause fertilizer consumption (unidirectional causality exists).
$\ln X5 \rightarrow \ln X4$	0.7900	0.1781	

Note: H_0: one variable does not Granger-cause the other variable for at least one panel variable. ***, **, and * denote statistical significance at 1%, 5%, and 10% levels.

Total greenhouse gas emissions Granger-causes fertilizer consumption, and fertilizer consumption Granger-causes total greenhouse gas emissions (bidirectional causality exists). The relationship may suggest that the consumption of fertilizers for increased crop productivity may be a result of total greenhouse gas emissions that indirectly reduces soil fertility and affects agricultural production. Fertilizer consumption also Granger-causes greenhouse gas emissions, because chemical fertilizers emit carbon into the atmosphere. Nitrogen volatilization and leaching are serious challenges contributing to greenhouse gas emissions. The result is similar to the findings of Koondhar et al. (2021) [106], Owino et al. (2020) [107] and Lal (2004) [108], who found fertilizer to increase greenhouse gas emissions.

Total greenhouse gas emissions Granger-causes livestock production, and livestock production Granger-causes total greenhouse gas emissions (bidirectional causality exists). Greenhouse gas emissions cause global warming, which is the main culprit for climate change. Global warming affects livestock production through heat stress, feed conversion, pasture and water availability, and these in turn affects growth, milk production, reproduction, disease incidences, and metabolic activity in livestock [109]. Livestock production index Granger-causes total greenhouse gas emissions, and this is expected as it has been established that livestock account for a significant amount of methane (CH_4) and nitrous oxide emissions globally.

Land under cereal cultivation does not Granger-cause net foreign direct investment, but net foreign direct investment does Granger-cause land under cereal cultivation (unidirectional causality exists). FDI in the areas of agriculture, particularly for cereal crops, has the potential to increase land under cereal production. Governments, organizations, and even small-scale farmers who are recipients of these FDI will dedicate more lands to agricultural production, and this also has the potential for putting marginal lands to use through capital investments for irrigation, technological application and fertilizer to improve soil fertility.

The results further reveal that a unidirectional causality exists, as land under cereal cultivation does Granger-cause renewable energy consumption. The sustainable use of energy for agricultural production would herald a shift from the use of fossil fuels for tractor operations, the heating of greenhouses and provision of farm inputs and equipment to the use of renewable energy. More so, most countries in Africa lie in the tropical region and have sunshine power which could be harnessed as energy for agricultural production. Land under cereal cultivation does not Granger-cause fertilizer consumption but fertilizer consumption does Granger-cause land under cereal cultivation (unidirectional causality exists). The quantity of fertilizer needed is determined by the nature, fertility and size of arable land. Land under cereal cultivation does Granger-cause livestock production, but their bidirectional link could not be confirmed (unidirectional causality exists). Land is important for livestock production.

Net foreign direct investment Granger-causes renewable energy consumption and renewable energy consumption Granger-causes net foreign direct investment (bidirectional causality exists). Net FDI can cause heavy investments in renewable energy supply and uptake in the host countries. The need for strong policy and regulations in the operations of foreign investors by host countries can catalyze the adoption of renewable energy sources in production processes. This will, in the long run, mitigate and reduce the carbon emissions from such investments. Net foreign direct investment does Granger-cause fertilizer consumption, but their bidirectional link could not be confirmed (unidirectional causality exists). Net FDI in the areas of improved crop productivity can be tailored to the supply chain of fertilizer to reach all crop farmers, especially rural farmers, and an efficient supply chain and proper pricing can positively affect fertilizer consumption. Likewise, net foreign direct investment does Granger-cause livestock production, but livestock production does not Granger-cause net foreign direct investment (unidirectional causality exists). Foreign Direct Investments are huge sources of investment in the agricultural sectors of developing nations. FDI in livestock production through grants and loans has the potentials to encourage increased participation in livestock production to meet the protein needs of a growing population, and products for industries, as well as the provision of export products. The result however contradicts the findings of Akpan et al. (2017) [110] in Nigeria, who found that FDI does not Granger-cause livestock production. However, they emphasized the results may be due to policies and volume of FDI in the agricultural sector.

The result further shows that renewable energy consumption does not Granger-cause fertilizer consumption, but fertilizer consumption does Granger-cause renewable energy consumption (unidirectional causality exists). This may be as a result of energy utilization in the production of fertilizers. Manufacturing industries may utilize renewable energies for lower costs and reduction in environmental pollution. The result further establishes that renewable energy consumption Granger-causes livestock production and livestock production Granger-causes renewable energy consumption (bidirectional causality exists). Sustainable production in agriculture and climate-smart agriculture promotes the use of renewable energy and clean fuels in livestock production activities. Fertilizer consumption does Granger-cause livestock production, but livestock production does not Granger-cause fertilizer consumption (unidirectional causality exists). The use of fertilizers improves soil fertility and crop productivity, and this has the potential to cause farmers to include livestock production to diversify their farming enterprise.

4.9. Robustness Checks

We carried out robustness test using the random effect, fixed-effect, and ordinary least square methods to confirm the consistency of the signs of the long-run coefficients and by extension their significance. Using the random effect, fixed-effect, and ordinary least square methods, we have demonstrated that foreign direct investment net inflow, renewable energy consumption, fertilizer consumption, and livestock production index are all statistically significant and have consistent signs in each case (see Table 11). Land under cereal production which was not statistically significant in the dynamic fixed-effect model, was statistically significant in the other three models. However, the sign was also consistent in the four models. The results from the DFE estimation are consistent with the estimates using the random effect, fixed-effect, and ordinary least square methods. The heteroskedasticity indicates that the null hypothesis of constant variance (homoskedasticity) was accepted. We therefore reject the presence of heteroskedasticity in our dataset.

Table 11. Comparison of the results obtained from the dynamic fixed-effect with results obtained from random effect, fixed-effect, and ordinary least square models.

Variables	DFE Long-Run Estimates	Fixed-Effect Estimates	Random Effect Estimates	OLS Estimates
ln$X$1	0.004	0.04	0.06	0.31
	(0.06)	(2.61) ***	(3.77) ***	(20.70) ***
ln$X$2	0.01	0.006	0.006	0.04
	(2.31) **	(5.22) ***	(5.09) ***	(5.89) ***
ln$X$3	−0.22	−0.19	−0.21	−0.43
	(−2.37) **	(−6.39) ***	(−7.23) ***	(−16.75) ***
ln$X$4	0.04	0.02	0.02	0.11
	(2.06) **	(4.71) ***	(4.57) ***	(5.74) ***
ln$X$5	0.56	0.59	0.58	0.83
	(7.43) ***	(25.42) ***	(24.25) ***	(6.77) ***
Constant	−2.05	7.59	25.03	2.88
	(−3.03) ***	(27.64) ***	(7.47) ***	(4.90) ***
Breusch–Pagan/Cook–Weisberg test for heteroskedasticity Assumption: Normal error terms				H0: Constant variance chi2(1) = 0.03 Prob > chi2 = 0.8566

t-values (for OLS and fixed-effect models) and z-values (for random effect model) are in parentheses. ***, ** denote statistical significance at 1%, and 5% level, respectively.

5. Conclusions and Policy Recommendations

This paper interrogates the pathway through which agricultural production (proxied by fertilizer consumption per unit area of agricultural land, land under cereal cultivation, and livestock production index), renewable energy, and Foreign Direct Investment (FDI) impact carbon emissions in Africa. We do so by using panel data, covering a period of twenty years (2000–2019) for thirty-one (31) countries in Africa, obtained from the World Bank World Development Indicators database and the FAOSTAT database. The panel ARDL revealed that an increase in the land area of cereal cultivated, net foreign direct investment, fertilizer consumption and livestock production increased total carbon emissions in the area, both in the short run and in the long run. Conversely, an increase in the utilization of renewable energy consumption brought about a decline in the level of total carbon emissions both in the short run and in the long run. The trend results show that total greenhouse emissions, land area under cereal cultivation, net FDI, livestock production and fertilizer application exhibit increasing trend across the countries. The cointegration test shows that there is a long-run relationship between total greenhouse gas emissions, land under cereal cultivation, net FDI, renewable energy consumption and livestock production in Africa. The Granger test for panel causality verifies the existence of long-run relationships among the variables, indicating that Granger causality exists in at least one direction.

The overall evidence from the findings of this study shows that investment in agricultural production activities and foreign direct investment increases carbon emissions, and makes the African countries more vulnerable to the effects of climate change as a result of high emission of greenhouse gases. Conversely, investment and sustained utilization of renewable energy sources reduces carbon emissions. Thus, it can be concluded that alternative renewable energy sources are a solution to high levels of carbon emissions and the climate change crisis, and that their implementation does not have a detrimental effect on the economic growth of African countries.

Based on these results, some key policies arise. Countries should attempt to formulate environmental policies for their country and assess the environmental impact of foreign direct investment on their environmental policies before introducing foreign investors into their countries as this will go a long way to mitigate the rate of carbon emissions. Additionally, for the sake of sustainable agriculture and enhanced food security status, it is necessary to avoid or reduce the excessive use of fertilizers and emphasize green agriculture or climate-smart agriculture. Policymakers in Africa should design well-targeted policies in the agricultural sector to reduce the harmful effects of carbon emissions on agricultural production.

The governments of these countries should be proactive and take positive steps aimed at reducing the level of carbon emission by diversifying their energy sources and by investing more on programs to effectively utilize renewable energy sources, such as biofuel, solar power, and wind energy among others.

Policies aimed at increasing agricultural production for food self-sufficiency should be centered towards sustainable production practices to reduce carbon emissions into the environment. The goals of climate policies should be to mitigate carbon emissions from all sectors since Africa is recorded to have high emissions of greenhouse gases. The significant impact of climate change on agriculture and other sectors necessitates the need for strong policy actions that will regulate foreign direct investments, especially in agricultural production. Renewable energy consumption should be advocated in place of the consumption of fossil fuels. However, investment in renewable energy sources should be promoted to increase the utilization in developing countries, which will be dependent on each country's peculiarity in terms of mineral resources, technological advancement and network. Countries in Africa, in attracting foreign direct investments, should establish strict regulations that qualify the foreign investments. This is imperative to avoid environmental pollution and degradation that negatively impacts the livelihoods of the inhabitants. Use of clean fuels and technologies that are environmentally friendly must be advocated, and there is a need to match policies with actions, using the relevant regulating bodies. The results may be minimal in the short run but would likely have strong positive impacts in the long-run. The results further lead to the conclusion that, though FDIs are useful tools for huge capital investments in agriculture in developing countries, strong policy actions and improvements in the countries' readiness should be reciprocated by investors.

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