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Carbon Dioxide Emissions and Crop Production: Finding A Sustainable Balance

Jeremiah Ejemeyovwi[1]*, Gershon Obindah[2], Tiena Doyah[3]

[1]Department of Economics and Development Studies, Covenant University, Nigeria, [2]Department of Economics and Development Studies, Covenant University, Nigeria, [3]Department of Economics and Development Studies, Covenant University, Nigeria.
*Email: jeremiah.ejemeyovwi@covenantuniversity.edu.ng

ABSTRACT

Amidst fears of food insecurity in Africa and climate change challenges to economic growth, the study observes the trend of carbon dioxide emissions (co_2em) and crop production with an objective to contribute to the body of knowledge, the empirical investigation of the nature of relationship existing between them. The fully modified ordinary least squares method (with some pre-estimation and post-estimation tests) was adopted given the order of stationarity integration of the variables in the model. The result showed that there exists a positive significant long-run relationship between the two variables. This implies that co_2em and crop production over time associated with crop productivity and further contributes to the achievement of the goal two of the sustainable development goals 2, 3, 7 and 9.

Keywords: Carbon Dioxide, Greenhouse Gas Emissions, Crop Production, Food Security, Fully Modified Ordinary Least Squares
JEL Classifications: Q2, Q3, Q4

1. INTRODUCTION

Evaluating the economic impact of carbon dioxide emissions (co_2em) faces a fundamental challenge of complexity: It is difficult to extensively investigate the different pathways of climatic impacts on economic outcomes (Dell et al., 2008). Greenhouse-gas concentrations in the atmosphere now stand at around 399.96 parts per million (ppm) CO_2 equivalents, compared to 280 ppm before the Industrial Revolution (STERN Review, 2015). Emissions have been driven by economic development over time for which CO_2 has played a major role. co_2em per capita have been strongly correlated with GDP per capita across time and countries. World cities are responsible for 70% of harmful Green-house emissions while occupying 2% of its land (UNHABITAT, 2011). North America and Europe have produced around 70% of co_2em from energy production since 1850 while, developing countries - non-annex 1 parties under the Kyoto protocol - account for <1-quarter of cumulative emissions (STERN Review, 2015).

Future emissions growth will come mostly from today's developing countries, because of more rapid population growth and GDP growth than developed countries, as well as, an increasing share of energy-intensive industries. The non-Annex 1 parties are likely to account for over three quarters of the increase in energy-related co_2em between 2004 and 2030, according to the International Energy Agency, with China alone accounting for over one-third of the increase. Total emissions are likely to increase more rapidly than emissions per head, as global population growth is likely to remain positive at least to 2050 (STERN Review, 2015). There is no question that the continued build-up of greenhouse gases will increase the temperature of the earth (IPCC, 2007).

Studies carried out in Nigeria include: Carbon emissions and the business cycle (Alege et al., 2017); energy supply and climate change in Nigeria (Akinyemi et al., 2014); food security, institutional framework and technology: Examining the nexus in Nigeria using autoregressive distributive lag approach (Osabuohien et al., 2017) and so on. In terms of foreign studies, Mendelsohn et al. (2001); Aldy (2004); Raleigh and Urdal (2007); Ros and Nang (2011); Crost et al. (2015) and so on carried out studies on CO_2 and agriculture using different approaches. Literature review revealed some gaps such as missing stylised facts comparison between income groups (high, low and middle-income classifications) as well as the study the impact of *co_2em* on crop production in Nigeria, hence, this study.

Against the above background, this study documents the stylised facts of *co_2em* and crop production across income groups over time as its first objective and also tests for the existence of long-run relationship existing between *co_2em* and crop production in Nigeria as its second objective. The study applies the fully modified ordinary least squares (FMOLS) estimation technique. A review of related literature is presented next and then followed by the theoretical framework, the methodology and the conclusion, recommendation, and suggestion for further studies.

2. INSIGHTS FROM LITERATURES

The complex nature of climate -economy relationship is apparent in a brief literature review. Some studies, like Adams (1990), Mendelsohn et al. (2001), Deschenes and Greenstone (2007), Guiteras (2007), Zhai and Jhuang (2009), Ros and Nang (2011), Crost et al. (2015), as well as, Burke and Emerick (2016), have observed the relationship between climate change and agriculture using different methodologies and case studies. Other studies, as reviewed in the Intergovernmental panel on climate change 4th Assessment Report (IPCC, 2007), have observed ocean fisheries, freshwater access, storm frequency, migration, tourism and many other potential issues. This paper focuses on investigating the association and degree of impact between and crop production incorporating the peculiarities of different regions.

An experiment was conducted to investigate the effects of increased atmospheric temperature and CO_2 concentration during crop growth on the chemical composition and *in vitro* rumen fermentation characteristics of wheat straw. The field experiment was carried out within agro-ecological experimental station from November (2012) to June (2013) in Changshu - China. The result showed that the chemical composition of the wheat straw was affected by temperature and CO_2 and the *in vitro* digestibility of wheat straw was reduced, especially in the combined treatment of temperature and CO_2 (He et al., 2015). The paper focused on the chemical composition effect of CO_2 and temperature on wheat straw – underlying the subject of this paper.

Aldy (2004) addressed the hypothesis that income-CO_2 relationship reflects changes in the composition of an economy as it develops and the associated role of emissions-intensive trade. The hypothesis was tested using a novel dataset of 1960–1999 State - level *co_2em* to estimate pre-trade (production-based) CO_2 environmental Kuznet curve (EKC) and post-trade (consumption-based) CO_2 environmental Kuznet curve. As the first EKC analysis of *co_2em* in the U.S. states, it was found that consumption-based EKC peaked at significantly higher incomes than production-based EKC, suggesting that emissions-intensive trade drives part the income-emissions relationship (Aldy, 2004).

According to a study by Gray et al. (2014), ground and aircraft-based measurements show that the seasonal amplitude of the northern hemisphere's (Canada, United States, Russia, and Europe) atmospheric CO_2 concentrations have increased by as much as 50% over the past 50 years. This increase, according to the research, has been connected to changes in temperate and arctic ecosystem properties and processes such as enhanced photosynthesis, increased heterotrophic respiration, and expansion of woody vegetation. Specifically, the northern hemisphere extra-tropical maize, wheat, rice, and soybean production grew by 240% between 1961 and 2008, thereby increasing the amount of net carbon uptake by croplands during the northern hemisphere growing season. Maize alone accounts for two-thirds of this change, owing mostly to agricultural intensification within concentrated production zones in the midwestern United States and northern China. Maize, wheat, rice, and soybeans account for about 68% of extra tropical dry biomass production.

Food-producing capacity and livestock production can be significantly affected by climate change for years to come. While some areas may experience a decrease in crop production, others are likely to increase. CO_2 concentration and temperature are two important factors affecting crop production (Emam et al., 2015). It was noted that while increasing CO_2 concentration (a key driver of climate change) could raise production of some crops (e.g., wheat), the changing climate, in general, is likely to have a negative effect on the length and quality of the growing season. In addition, having a higher intensity of droughts and floods could have countless consequences on crop production and agriculture. On the other hand, temperature increase (a characteristic of climate change) of a few degrees is expected to generally raise crop production in temperate regions and greater warming may decrease crop yields (Raleigh and Urdal, 2007).

Akbostanci et al. (2009) investigated the relationship between income and environmental degradation in Turkey using time-series data spanning 1968–2003. The results showed that CO_2 and income tend to have a monotonically increasing relationship in the long run. This goes against the EKC hypothesis that posits an inverted u-shaped curve. Agriculture is expected to be one of the most important drivers of global warming, as well as a critical sector that will be most vulnerable to this climate change (Mendelsohn and Williams, 2007). It is important to note that CO_2 is not the only factor that contributes to increase in crop production (photosynthesis). Other factors that contribute to crop production are nitrogen, phosphorus, potassium, water, and optimum temperatures. Excess concentration of CO_2 or any of these resources cause saturation for the crop which in turn could cause decrease in photosynthesis. Climate change has been variously defined in the literature as a change in the climatic condition of a region which could be attributed to natural variability and anthropogenic (man-made) activities that persist for an extended period of time. According to the IPCC, it is the statistically significant variations that persist for an extended period, typically decades or longer. It includes shifts in the frequency and magnitude of sporadic weather events, as well as, the slow continuous rise in global mean surface temperature (Ifeanyi-Obi et al., 2012).

Hence, there is a need for a climate change threshold; to know the amount of CO_2 necessary in the atmosphere for plants to survive as well as know the amount by which it becomes harmful for man and even the agricultural produce. For example, a high concentration of CO_2 could cause a reduction in the nutritional quality of some important food staples, such as wheat.

The utilisation of technology such as machineries for production, mechanised farming, and so on by the Industrialised world has contributed immensely to the amount of CO_2 in the atmosphere. CO_2 in the atmosphere contributes both positively and negatively to crops. The positive contribution could be attributed to the amount of CO_2 needed by plants to be healthy while the negative contribution is the rising temperature (which could be harmful to plants when excessive), the increasing probability of erosion through flood and drought caused by climate change, inconsistent weather conditions (uncertain rain and sun), and so on.

Below is a chart showing the linkage between technology utilisation, co_2em and agriculture output in this study (Figure 1).

3. THEORETICAL FRAMEWORK AND METHODOLOGY

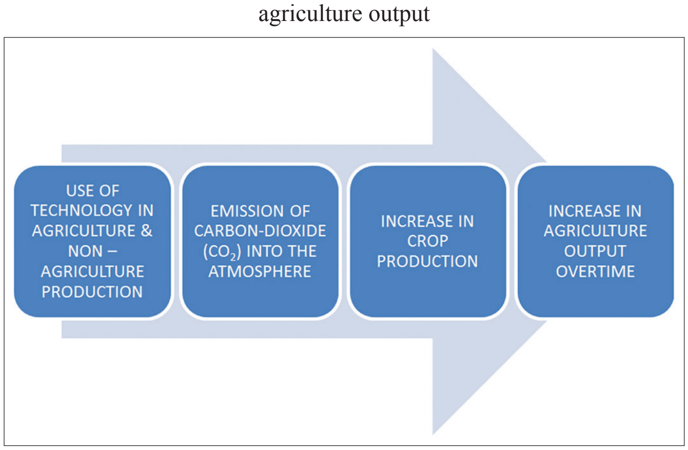
The theories adopted by this research are the anthropogenic global warming theory and the Arthur Lewis two-sector economy model. The anthropogenic global warming theory posits that human induced co_2em is the root cause of climate change. Backers of the theory contend that the 0.7°C warming of the last century and a half is mostly due to man-made gases (from burning carbon-based fuels). Computer programs predict that the Earth's temperature could rise an extra 3°C by 2100. Arthur Lewis hypothesized a model established on the assumption of two sectors existing in the economy - capitalist/industrial/modern sector, as well as, the traditional subsistence sector. The application of this theory to this paper emphasizes the side-effect of technology in the industrial sector - CO_2 emitted into the atmosphere which could cause climate change and subsequently, have an effect on crop production (in the traditional sector).

3.1. Methodology

3.1.1. Model specification

The study adopts the model that explains the determinants of crop production, including co_2em by Osabuohien et al. (2017)

Figure 1: The transmission from technology usage to increase in agriculture output



on food security which is in line with theory, dropping the institutional variable with the inclusion of co_2em variable as the key independent variable in this study. The other independent variables are agriculture machinery (tractors) per 100 square of arable land (*amtal)*; land tenure system (*lucp*) which tends to increase food production thereby increasing the availability of food, electrical power distribution/loss (EPDL) and gross domestic product growth rate (*gdpgr*), a control variable. The dependent variable in the model is crop production index (CPI) which represents an index of the value of crop production to measure the level of agriculture productivity across countries.

The model can be simplified implicitly as:

$$CPI=f(co_2em, amtal, epdl, gdpgr, lucp) \quad (1)$$

Where CPI represents crop production; co_2em represents co_2em; *amtal* represents agriculture machinery (tractors) per 100 square of arable land; *lucp* represents land tenure system and 'gdpgr represents the gross domestic product growth rate. Equation (1) shows that crop production is a function of co_2em, agriculture machinery, land tenure system, gross domestic product growth rate.

Equation (1) can be specified explicitly as:

$$CPI=A.co_2em^{\alpha 2}\ amtal^{\alpha 3}\ epdl^{\alpha 4}\ gdpgr^{\alpha 5}\ lucp^{\alpha 6} \quad (2)$$

The study utilizes the Cobb Douglas production function, given that a production process (input and output system) is undergone to produce crops. Taking the log of the variables in order to linearise the equation, we have:

$$CPI=\alpha_1+\alpha_2\ co_2em+\alpha_3\ amtl+\alpha_4\ epdl+\alpha_5\ gdpgr+\alpha_6\ lucp+e \quad (3)$$

3.1.2. Technique of estimation

The augmented dickey fuller (ADF) unit root test was employed to test for stationarity to know the most appropriate methodology (according to theory because most time series data are non stationary at levels) to be applied to the study and the econometric estimation technique (informed by the stationarity test) to be utilised to assess the interplay between co_2em and CPI among other associated variables is the FMOLS method. The FMOLS technique corrects for endogeneity and serial correlation while producing optimal long-run co-integrating estimates (Phillips and Hansen, 1990) and is also reliable in the cases of a dataset with af combination of stationarity at levels and first difference.

3.1.3. Data sources and measurement

The two variables of interest in this study are co_2em and CPI. The apriori expectation to be tested using this model says that CO_2 (regressor) is expected to have a positively and statistically significant relationship with CPI (regress and Annual time series data (1970–2015) was used in the dataset utilised in this study and all data was sourced from World Bank (2018). The data used according to the location were: For stylised facts, world (total/global), high-income countries, low and middle-income countries; and for the econometric analysis: Nigeria.

4. RESULTS AND DISCUSSION

4.1. Stylised Facts: Patterns on Crop Production and Across the Income Groups

The income groups in focus for the achievement of the first objective of this paper are the high-income countries, low & middle-income countries and the world (as a group). This selection is used to capture the correlation between emissions and crop production in the industrialised areas in comparison to the less-industrialised countries. The time period of 1981–2014 was selected based on data availability.

Crop production across the income groups is measured by the "CPI". The CPI shows the agricultural production for each year relative to the base period (2004–2006=100). It includes all crops except for fodder crops (animal food). The aggregates are calculated from underlying values in international dollars, normalised to the base period (World Bank, 2018). The values are indexed at base periods to monitor changes in price levels over time.

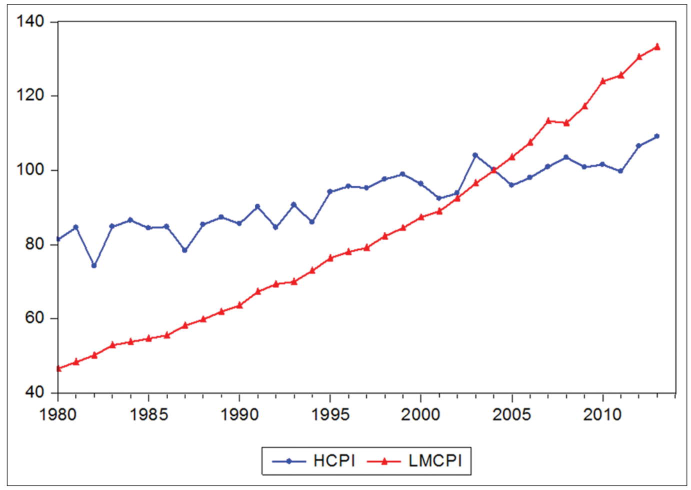
The CPI of "high-income countries" group has been high relative to the "low and middle-income countries" group between the period of 1981 and 2005 before the low and middle-income countries group seemed to be higher than the high-income countries group after that period. However, there has been increase in aggregate crop production over time for all countries. CPI of high-income countries for the time period (1981–2014) has a mean of 92.73, its maximum value of 109.09 (in 2014) and its minimum value of 74.19 (1983). CPI of low and middle-income countries for the time period has a mean of 82.88, its minimum value of 46.56 (1981) and a maximum value of 133.25 (2014). The increase in the crop production more in the low and middle-income countries could be attributed to the fact that these countries produce more of raw materials and are likely exported while developed countries handle the intermediate production in their industries (Figures 2 and 3).

co_2em in the atmosphere across the income groups consist of the emissions from the consumption of solid, liquid, gas fuels and gas flaring (burning fossil fuels) and the manufacture of cement(World Bank, 2017). It is measured in Kilotons (kt). co_2em has been persistently increasing over time for all countries. However, for "high-income countries" group, it has been relatively higher than all low and middle-income group. The levels of co_2em in high-income countries for the time period (1981–2014) until its relative fall below that of low and middle-income country group. co_2em has a mean of 12.26 million kilotons, a maximum value of 13.72 million kilotons (2007) and its minimum value of 10.24 million kilitons (1983). co_2em of low and middle-income countries for the time period has a mean of 12.04 million kilotons, its minimum value of 6.18 million kilotons (1981) and a maximum value of 3.10 (2011). Few low and middle-income countries have implemented drastic reduction measures but have pursued increased food production which tends to explain the continuous increase in co_2em over time especially from 2004 till recent time.

4.2. Econometric Results

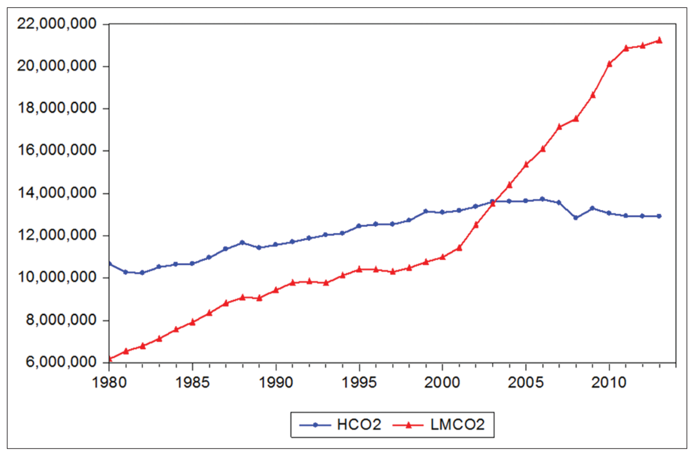
This section reports and discusses the empirical results from the econometric analysis (FMOLS) employed in this study after the

Figure 2: Crop production index (World, High-income Countries and Low and Middle-income Groups, 1981–2014)



Compiled by Authors; Data Source: World Bank (2018)

Figure 3: Carbon dioxide emissions (World, High-income Countries and Low and Middle-income Groups, 1981–2014)



Compiled by Authors; Data Source: World Bank (2018)

stationarity test and the multicollinearity test (correlation) as well as some other post-estimation tests. The ADF unit root test result shows that all the variables in the model are stationary at first difference (co_2em, agriculture machinery, land tenure system, and gross domestic product growth rate) but one (CPI, the dependent) is stationary at levels. The correlation results show the degree of association between the independent to ensure that the OLS assumption of "no perfect multicollinearity between the independent variables" is adhered to and the results show that the highest correlation is 0.64 between land tenure system and agriculture machinery. The ADF and correlation results are shown in Tables 1 and 2.

The FMOLS econometric estimation technique was applied to this study to achieve the second stated objective - for long-run relationship estimates; while some pre and post-estimation tests (Ramsey RESET test, the histogram normality test, the Breusch Godfrey Serial Correlation LM test, and the Breusch Pagan Godfrey heteroskedasticity test) were also applied to increase that the reliability of the estimated results for policy analysis (Tables 3 and 4).

Table 1: The ADF unit root test result

Variable	ADF t-statistics value	Critical value at (5%)	Remark	Order of integration
DCPI	3.99	2.94	Stationary	I (1)
DCO_2EM	6.55	2.93	Stationary	I (1)
DAMTAL	5.00	2.95	Stationary	I (1)
DEPDL	9.34	2.93	Stationary	I (1)
LGDPGR	5.87	2.92	Stationary	I (0)
DLUCP	3.74	2.94	Stationary	I (1)

Source: Authors' computation via E-views software

Table 2: Correlation matrix for variables in the model (multicollinearity)

	LCO2EM	LAMTAL	LEPDL	LGDPGR	LUCP
LCO2EM	1.000000				
LAMTAL	0.440955	1.000000			
LEPDL	0.037240	0.700565	1.000000		
LGDPGR	0.209209	−0.228679	−0.356076	1.000000	
LUCP	0.258364	0.624305	0.233708	−0.115582	1.000000

Source: Author's computation using E-views result

Table 3: Ramsey reset test results

Test	Value	Degree of freedom	Prob. value
t statistic	0.3137	16	0.7577
F statistic	0.0984	(1, 16)	0.7577

Source: Authors' computation via E-views software

Table 4: Econometric estimation results

Dependent variable: CPI	FMOLS
LCO_2EM	0.1305 [2.33]
LAMTAL	0.6089 [10.58]
LEPDL	−0.0787 [1.46]
LGDPDR	0.1775 [0.89]
LUCP	1.74 [4.81]
R - squared	0.9830
Adjusted R- squared	0.9769
SE of Regression	0.0339
Long-run variance	0.0007
Mean dependent var	1.7655
SD dependent var	0.22
Sum squared residual	0.0160
Prob. (F statistic)	0.0000

Figures in square bracket "[]" represent the t-statistic values. Source: Authors' computation via E-views software. CPI: Crop production index

The ADF test results (Table 1) show that CO_2 *em*, agriculture machinery (tractors) per 100 square of arable land (*amtal)*, EPDL land tenure system (*lucp*) were stationary at order one – I (1) while gross domestic product growth rate (*gdpgr*) was stationary at order zero – I (0). This indicates that to find the long-run relationship, the Johansen co-integration method cannot be used but the ARDL bounds testing or the FMOLS could be used. The correlation matrix results which indicate existence or absence of perfect multicollinearity shows that there is absence of multicollinearity in the variables given that the number values of the correlation coefficient are far below 1.0. The Ramsey RESET test result checks for possible model misspecification and omitted variable bias. The RESET test results' P value of the F statistic is above 0.05. Therefore, the model specification is acceptable.

Figure 4 shows a pre-estimation test for normality of the variables in the dataset. The Jarque Bera probability value is significantly higher than 0.05 which implies that the alternative hypothesis of normality is accepted. The Breusch-Godfrey Serial Correlation LM Test: Table 5 tests for the presence of serial correlation within the variables. The result shows that there is absence of serial correlation given that the probability value is above 0.05. The Breusch-Pagan-Godfrey Heteroskedasticity test (Table 6) shows that there is absence of Heteroscedasticity in the dataset. The pre-estimation and post-estimation tests make the findings and inference from this study very reliable and trustworthy.

In terms of the general interpretation of the FMOLS, the R – squared is very high as expected for time series data (between 0.5 and 1.0) while the P value of the F statistics for the FMOLS was 0.0000 (i.e., <0.05). This shows that the goodness of fit of the variables and the joint significance of the model is reasonably realistic and reliable. Specifically interpreting for the major variable of interest (co_2em), the t-statistic of the FMOLS estimated coefficient is statistically significant (>2), implying that there is an individually statistically significant positive relationship existing between the two major variables of interest (co_2em and crop production). Furthermore, the coefficients show that a 1 unit increase in co_2em in the atmosphere will lead to a less than proportionate increase (given that the data was logged and the interpretation is based on elasticities) in CPI in the long-run in Nigeria. This suggests that the influence of co_2em is statistically significant but yet, it is uniquely small. However, it contributes significantly and positive to CPI.

The most popular contributors to co_2em in the atmosphere are technologies used in industrialization processes. The usage of technology is encouraged by theories such as the exogenous growth model which emphasizes the use of technology, of which much technology used in production emit CO_2 into the atmosphere, thereby increasing the amount of CO_2 in the atmosphere. Some examples of technology used in the industrialization process are machineries such as tractors, ploughers and others used in non - agricultural production such as electric power generators.

5. CONCLUSION

The study highlighted the trend of co_2em and crop production across the different income groups in the world from and also examined the long-run relationship between the two variables using Nigeria as a case study (1970–2015) using the FMOLS, with the inclusion of some pre-estimation and post-estimation tests to know the reliability level of the result. The results showed that indeed, a positive significant relationship exists between the two variables. Therefore, it should be noted that co_2em has a long-run positive impact on crop production despite its usual notion of pure negativity.

Figure 4: Barque bera normality test

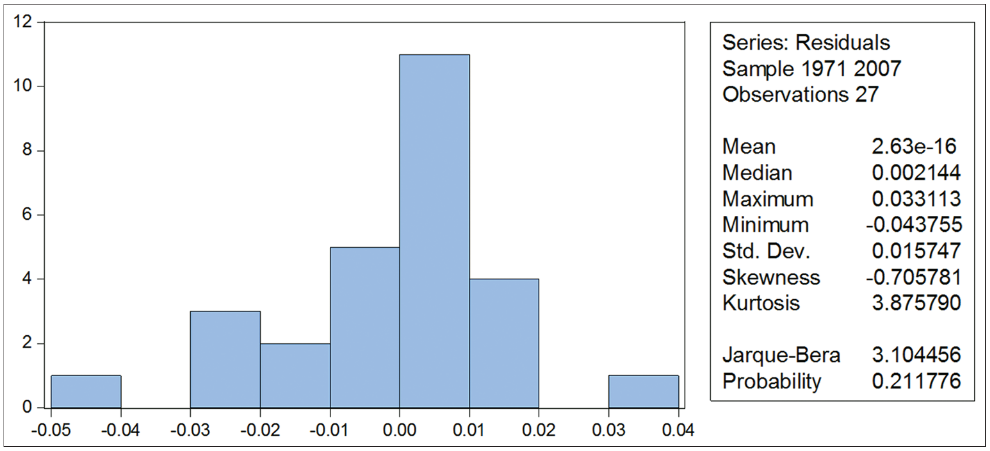


Table 5: Breusch-Godfrey serial correlation LM test

Test	Value		Prob. value
F statistic	3.4095	Prob F (2, 12)	0.0672

Source: Authors' computation via E-views software

Table 6: Heteroskedasticity test: Breusch-Pagan-Godfrey

Test	Value		Prob. value
F statistic	1.1054	Prob F (19, 14)	0.4317

Source: Authors' computation via E-views software

Worthy of note also is the fact that the availability of machinery (tractors) and the availability of arable land tenure system contribute majorly to crop production and hence food security. This finding is consistent with the findings of (Osabuohien et al., 2017). This is very crucial for Nigeria given the fact that there is the abundance of land, which could be tilled and cultivated for agriculturally productive use. The active interactions between the component members of the agriculture value chain which include the government, the farmers, and the exporters and so on should endeavor to make efforts to ensure the continuous increase in crop production thereby reducing the rate of food insecurity.

In this regard, as suggestions for further studies, it will be interesting to determine the major factors responsible for the ever increasing CO_2 trend in future research. In addition, there is a need to determine the optimal value of required in the atmosphere to support plant photosynthesis for future crop production especially in low income countries with a relatively high population. Also, a causality analysis between co_2em and agriculture should also be considered and importantly, the inclusion of various variables in the model utilised in this study should be attempted.

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