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RESEARCH ARTICLE

The relationship between carbon dioxide and agriculture in Ghana: a comparison of VECM and ARDL model

Samuel Asumadu-Sarkodie[1] **· Phebe Asantewaa Owusu**[1]

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Abstract In this paper, the relationship between carbon dioxide and agriculture in Ghana was investigated by comparing a Vector Error Correction Model (VECM) and Autoregressive Distributed Lag (ARDL) Model. Ten study variables spanning from 1961 to 2012 were employed from the Food Agricultural Organization. Results from the study show that carbon dioxide emissions affect the percentage annual change of agricultural area, coarse grain production, cocoa bean production, fruit production, vegetable production, and the total livestock per hectare of the agricultural area. The vector error correction model and the autoregressive distributed lag model show evidence of a causal relationship between carbon dioxide emissions and agriculture; however, the relationship decreases periodically which may die over-time. All the endogenous variables except total primary vegetable production lead to carbon dioxide emissions, which may be due to poor agricultural practices to meet the growing food demand in Ghana. The autoregressive distributed lag bounds test shows evidence of a long-run equilibrium relationship between the percentage annual change of agricultural area, cocoa bean production, total livestock per hectare of agricultural area, total pulses production, total primary vegetable production, and carbon dioxide emissions. It is important to end hunger and ensure people have access to safe and nutritious food, especially the poor, orphans, pregnant women, and children under-5 years in order to reduce maternal and infant mortalities. Nevertheless, it is also important that the Government of Ghana institutes agricultural policies that focus on promoting a sustainable agriculture using environmental friendly agricultural practices. The study recommends an integration of climate change measures into Ghana's national strategies, policies and planning in order to strengthen the country's effort to achieving a sustainable environment.

Keywords Carbon dioxide · Agricultural emissions · Cointegration · VECM · ARDL · Ghana

JEL Classification Q54 · Q57

Acronyms

AIC	Akaike Information Criterion
ARDL	Autoregressive Distributed Lag
CHAL	% annual change (Agricultural area)
COAGRAPROD	Coarse Grain, Production (Tons)
COCOBE	Cocoa, beans Production (Tonnes)
FPE	Final Prediction Error
FRUPROD	Fruit excl Melons, Production (Tons)
HQ	Hannan-Quinn Information Criteria
LIVEHEC	Livestock total per hectare of agricultural area (No/Ha)
LR	Sequential Likelihood-Ratio
MDGs	Millennium Development Goals
PULPROD	Total Pulses Production
RNTPROD	Roots and Tubers, Total Production (Tons)
SC	Schwarz Information Criterion
SDG	Sustainable Development Goal
VAR	Vector Autoregression

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✉ Samuel Asumadu-Sarkodie
asumadusarkodiesamuel@yahoo.com

1 Sustainable Environment and Energy Systems, Middle East Technical University, Northern Cyprus Campus, Guzelyurt, Turkey

VECM	Vector Error Correction Model
VEGPROD	Vegetable Production (Tons)

Abbreviations

Chi2	Chi square
Coef.	Coefficient
cointEq	Cointegrated equation
df	Difference
Prob	Probability
Std. Err.	Standard error

Greek Letter

π Rank

Introduction

The growth rate of carbon dioxide has increased over the past 36 years (1979–2014), "averaging about 1.4 ppm per year before 1995 and 2.0 ppm per year thereafter" (Earth System Research Laboratory 2015). The Sustainable Development Goal 13 focuses on actions that help mitigate climate change and its impact. There is an increasing global effort towards climate change mitigation since the emergence of the Millennium Development Goals (Asumadu-Sarkodie and Owusu 2016a, b, c). Nonetheless, approaches toward reducing greenhouse gas effect through emission-reduction policies (Busch et al. 2012) have been skewed toward the energy and industrial sector. Burney et al. (2010) argues that global agricultural output has increased with increasing population since the middle of the twentieth century. A doubling in global food demand (Tilman et al. 2002) to meet the rapidly growing population poses threat to agricultural and environmental sustainability. Agriculture has been identified as one of the main sources of greenhouse gas emissions (GHG) (Burney et al. 2010) due to unsustainable agricultural practices in order to boost productivity, which leads to food security.

Agriculture is one of the major drivers in Ghana's growing economy. With regards to agricultural GDP by sectors as at 2010, crop production accounts for 66.2 %, forestry accounts for 12.2 %, fisheries account for 7.3 %, cocoa production accounts for 8.2 %, and livestock production accounts for 6.1 %, respectively (Ministry of Food and Agriculture). Out of 3,396,000 ha of the area designated for starchy and cereal staple production, the largest area of about 992,000 ha is used for maize production followed by cassava production of about 875,000 ha, yam production of about 385,000 ha, plantain production of about 328,000 ha, sorghum production of about 253,000 ha, cocoyam/taro production of about 205,000 ha, rice production of about 181,000 ha, and millet production of about 177,000 ha, respectively (Ministry of Food and Agriculture). With regards to industrial crop production, cocoa production occupies the largest area of about 1,600,000 ha, followed by oil palm production of about 360,000 ha, tomato production of about 50,000 ha, seed cotton production of about 20,000 ha, other vegetables account for 20,000 ha, pineapple accounts for 328,000 ha, and other (coconut, banana, kola, rubber, tobacco, etc.). Production account for 2,000,000 ha, summing up to 4,060,000 ha (Ministry of Food and Agriculture).

In the same vein, livestock production has been increasing from 1999 to 2010. Cattle production rose from 1,288,000 heads to 1,454,000 heads, sheep production rose from 2,658,000 heads to 3,779,000 heads, goat production rose from 2,931,000 heads to 4,855,000 heads, pig production rose from 332,000 heads to 536,000 heads, and poultry production rose from 18,810,000 birds to 43,320,000 birds, respectively. However, annual fish production has decreased from 452,900 to 415,436 Mt. (Ministry of Food and Agriculture). At first sight, Ghana's food and agricultural portfolio seem appreciably due to increasing food production to meet a growing Ghanaian population to achieve food security. To the best of our knowledge, the causal nexus between food production and carbon dioxide emissions are yet to be assessed.

The remainder of the study is sectioned into Literature Review, Methodology, Results and Discussion, Conclusion and Policy Recommendations.

Literature review

A vast number of scientific studies have analyzed the relationship between agriculture production and traces of gas such as follows: carbon dioxide (CO_2), nitric oxide (NO), nitrous oxide (N_2O), ammonia (NH_3), and methane (CH_4). Borah and Baruah (2015) investigated the nitrous oxide (N_2O) emissions from wheat production by employing an estimation method to identify the physiological and anatomical factors of the wheat plant that contribute to the variations in nitrous oxide (N_2O) emissions. Their study concluded that the variations in nitrous oxide (N_2O) emissions were due to the genetic differences in the wheat genotype. Liu et al. (2015) analyzed the relationship between greenhouse gas emissions and straw management from mono-rice cultivation system by considering the soil quality and crop productivity. Their study concluded that combining rice straw mulching and green manuring was effective in stabilizing greenhouse gas emissions and soil health. Hussain et al. (2015) analyzed the effects of crop management practices on greenhouse gas emissions in rice fields by employing a meta-analysis. Their study concluded that modifying tillage permutations, managing organic and fertilizer, and selecting crop regimes can mitigate greenhouse gas emissions. Bakhtiari et al. (2015) investigated the greenhouse gas emissions and the energy balance for saffron using Cobb-Douglas production function in EViews 7 software. Their study concluded that the cultivation of saffron emits 2325.5 kg CO_2eq. ha^{-1} greenhouse gas emissions.

Roth et al. (2014) investigated methane (CH_4) and nitrous oxide (N_2O) emissions from pig farming under tropical climate. They concluded that N_2O emissions were related to nitrate composition while CH_4 emissions depended on moisture. Hagemann et al. (2012) analyzed the greenhouse gas emissions from milk production by using the standard regression analysis. Their study concluded that the estimation of contribution of milk production towards greenhouse gas emissions was uncertain based on the choice of the estimate and the method employed in assessing emissions at the individual level of the animal.

Our study is related with Li et al. (2014) who analyzed the agricultural CO_2 emissions in China from 1994 to 2011 by using the logarithmic mean divisa index as a decomposition technique. They concluded that economic development contributed immensely towards CO_2 emissions. Nonetheless, their dataset employed is limited to make a general conclusion regarding the said topic. Our study employs 9 variables and 52 observations using the Vector Error Correction Model (VECM) and Autoregressive and Distributed Lag (ARDL) model as econometric techniques.

In the area of multivariate causal relationship, a number of studies have investigated the causal relationship between carbon dioxide emissions, energy consumption, population, gross domestic product (GDP), etc. For example, Lozano and Gutiérrez (2008) analyzed the causal relationship between GDP, carbon dioxide, energy consumption, and population using a non-parametric approach. Their proposed model was applicable to USA. Huang et al. (2008) analyzed the causal relation between energy consumption and GDP for 82 countries using the generalized method of moments which they found no evidence between energy consumption and GDP. Zhang and Cheng (2009) analyzed the Granger causality between carbon dioxide, economic growth, population, and energy consumption. In their study, neither carbon dioxide emissions nor energy consumption leads to economic growth. Soytas and Sari (2009) analyzed the relationship between carbon dioxide emissions, energy consumption, and economic growth using the long run Granger causality test. They concluded that carbon dioxide emissions Granger-cause energy consumption, but however not valid in the reverse. Adom and Bekoe (2012) forecasted the 2020 electrical energy requirement for Ghana by employing the ARDL and Partial adjustment model (PAM). Their study concluded that domestic electricity consumption is mainly explained by the income factor in Ghana.

Our study methodology is related with Farhani and Ozturk (2015) who studied the long-run causal nexus between carbon dioxide emissions, real GDP, urbanization, energy consumption, trade openness, and financial development in Tunisia by using the ARDL bound testing method and the error correction method. Their study concluded that real GDP has a monotonic relationship with carbon dioxide, which rejected the validity of the environmental Kuznets curve hypothesis.

Nevertheless, the causal relationship between carbon dioxide emissions and agriculture is sporadic and limited especially in developing countries. Developing countries like Ghana are mostly ignored in the debate on mitigating carbon dioxide emissions ever since the United Nations framework convention on climate change (UNFCC) instituted the Kyoto protocol. Nonetheless, Ghana acceded to the Kyoto Protocol in November 2002 and has been listed in non-Annex 1 countries that can only contribute in the clean development mechanism as her contribution to reducing emission levels of her greenhouse gases (UNTC). Ghana as a growing economy from lower-middle-income to a middle-income-economy has suffered many drawbacks in the field of health (Asumadu-Sarkodie and Owusu 2015), water management (Asumadu-Sarkodie et al. 2015a, b), energy management (Asumadu-Sarkodie and Owusu 2016b, c), etc. One reason associated with the drawbacks is a limited scientific research in the aforementioned areas to provide local and private investors with the required support to make decisive choices toward their investment in Ghana. Attempts to unveil the developmental issues in Ghana within the scientific arena are sporadic and limited. Therefore, a multidisciplinary approach that tackles the core issues in Ghana in the scientific space would boost nation building. Ghana's contribution to reducing carbon dioxide emissions as established in the MDGs and SDG (13) is yet to be assessed.

As our contribution to existing literature, we investigate the relationship between carbon dioxide and agriculture in Ghana by comparing VECM and ARDL which are different and absent from the literature listed in the study. Significantly, the study will increase the awareness of sustainable development in developing countries and serve as a reference tool for integrating climate change measures into agricultural policies, practices, and planning by the Government of Ghana.

Methodology

The study investigates the relationship between carbon dioxide and agriculture in Ghana by comparing the VECM and ARDL model. A time series data spanning from 1961 to 2012 were employed from Food Agriculture Organization (FAO). Ten study variables were used in the study, which include the following: CO_2—carbon dioxide emissions (kt), LIVEHEC—total livestock per hectare of agricultural area (No/Ha), CHAL—annual change of agricultural area (%), RNTPROD—total roots and tubers production (tons), VEGPROD—total primary vegetables production (tons), PULPROD—total pulses production (tons), FRUPROD—total fruit production excluding melons (tons), COAGRAPROD—total coarse grain production (tons), and COCOBE—cocoa beans production (tons). The selection of the variables was based on their major constitution of Ghana's agricultural sector.

A linear function can be used to express the relationship between carbon dioxide and agriculture in Ghana, showed in Eq. (1):

$$CO2_t = f(\mathrm{CHAL}_t,\ \mathrm{COAGRAPROD}_t,\ \mathrm{COCOBE}_t, \mathrm{FRUPROD}_t, \mathrm{LIVEHEC}_t,\ \mathrm{PULPROD}_t,\ \mathrm{RNTPROD}_t, \mathrm{VEGPROD}_t) \quad (1)$$

The empirical specifications for the model can be quantified as:

$$\begin{aligned} CO2_t = {} & \beta_0 + \beta_1\mathrm{CHAL}_t + \beta_2\mathrm{COAGRAPROD}_t \\ & + \beta_3\mathrm{COCOBE}_t + \beta_4\mathrm{FRUPROD}_t \\ & + \beta_5\mathrm{LIVEHEC}_t + \beta_6\mathrm{PULPROD}_t \\ & + \beta_7\mathrm{RNTPROD}_t + \beta_8\mathrm{VEGPROD}_t + \varepsilon_t \end{aligned} \quad (2)$$

Where $CO2_t$ is the dependent variable while CHAL_t, $\mathrm{COAGRAPROD}_t$, COCOBE_t, $\mathrm{FRUPROD}_t$, $\mathrm{LIVEHEC}_t$, $\mathrm{PULPROD}_t$, $\mathrm{RNTPROD}_t$, and $\mathrm{VEGPROD}_t$ are the explanatory variables in year t, ε_t is the error term and $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7$, and β_8 are the elasticities to be estimated.

Vector autogression (VAR) model is first considered in the study following the work of Asumadu-Sarkodie and Owusu (2016d), Chang (2010), Fei et al. (2011), Gul et al. (2015), Soytas and Sari (2009), and Zhang and Cheng (2009), which can be expressed as:

$$Y_t = \delta + A_1 Y_{t-1} + \cdots + A_p Y_{t-p} + \varepsilon_t \quad (3)$$

The corresponding VEC model can be expressed as:

$$\begin{aligned} \Delta y_t = {} & \beta_{y_0} + \beta_{y_1}\Delta y_{t-1} + \cdots + \beta_{y_p}\Delta y_{t-p} + \gamma_{y_1}\Delta x_{t-1} \\ & + \cdots + \gamma_{y_p}\Delta x_{t-p} - \lambda_y(y_{t-1} - \alpha_0 - \alpha_1 x_{t-1}) + v_t^y \end{aligned} \quad (4)$$

$$\begin{aligned} \Delta x_t = {} & \beta_{x_0} + \beta_{x_1}\Delta y_{t-1} + \cdots + \beta_{x_p}\Delta y_{t-p} + \gamma_{x_1}\Delta x_{t-1} \\ & + \cdots + \gamma_{x_p}\Delta x_{t-p} - \lambda_x(y_{t-1} - \alpha_0 - \alpha_1 x_{t-1}) + v_t^x \end{aligned} \quad (5)$$

Where $y_t = \alpha_0 + \alpha_1 x_t$ is the long-run cointegrating relation existing between two variables of interest and, λ_y and λ_x are the error correction parameters measuring the reaction of y and x towards the deviations from long-run equilibrium.

Engle-Granger (Engle and Granger 1987), Johansen's method (Johansen 1995), or single equation methods like Dynamic Ordinary Least Squares (DOLS), Fully-Modified Ordinary Least Squares (FMOLS), and VEC models have been used in econometrics to examine the long run and cointegration between variables, which as a requirement, all variables must be I(1) or a prior knowledge and specification requirement of variables are I(0) and I(1). Nevertheless, Pesaran and Shin (1998) showed that cointegration among variables can be estimated as an ARDL model with the variables in cointegration at either I(0) or I(1) without pre-specification of variables which are either I(0) or I(1). Moreover, Pesaran and Shin (1998) argue that ARDL model can have different number of lag terms without the requirement of symmetry lag lengths like other cointegration estimation methods. The study employs the ARDL method of cointegration to estimate long-run equilibrium relationship between CO2 and the independent variables (CHAL, COAGRAPROD, COCOBE, FRUPROD, LIVEHEC, PULPROD, RNTPROD, and VEGPROD). Following the work of Adom and Bekoe (2012), Fuinhas and Marques (2012), Kankal et al. (2011), and Ozturk and Acaravci (2011), ARDL Cointegration regression form of ARDL model can be expressed as:

$$\begin{aligned} \Delta CO2_t = {} & \alpha_0 + \delta_1 CO2_{t-1} + \delta_2 CHAL_{t-1} + \delta_3 COAGRAPROD_{t-1} + \delta_4 COCOBE_{t-1} + \delta_5 FRUPROD_{t-1} + \delta_6 LIVEHEC_{t-1} \\ & + \delta_7 PULPROD_{t-1} + \delta_8 RNTPROD_{t-1} + \delta_9 \mathrm{VEGPROD}_{t-1} + \sum_{i=1}^{p}\beta_{1j}\Delta \mathrm{CO2}_{t-i} \\ & + \sum_{i=0}^{p}\beta_{2j}\Delta\mathrm{CHAL}_{t-i} + \sum_{i=0}^{p}\beta_{3j}\Delta\mathrm{COAGRAPROD}_{t-i} + \sum_{i=0}^{p}\beta_{4j}\Delta\mathrm{COCOBE}_{t-i} \\ & + \sum_{i=0}^{p}\beta_{5j}\Delta\mathrm{FRUPROD}_{t-i} + \sum_{i=0}^{p}\beta_{6j}\Delta\mathrm{LIVEHEC}_{t-i} + \sum_{i=0}^{p}\beta_{7j}\Delta\mathrm{PULPROD}_{t-i} \\ & + \sum_{i=0}^{p}\beta_{8j}\Delta\mathrm{RNTPROD}_{t-i} + \sum_{i=0}^{p}\beta_{9j}\Delta\mathrm{VEGPROD}_{t-i} + \varepsilon_{1t} \end{aligned} \quad (6)$$

Where α is the intercept, p is the lag order, ε_t is the error term, and Δ is the first difference operator. In order to test the long-run equilibrium relationship between CO2, CHAL, COAGRAPROD, COCOBE, FRUPROD, LIVEHEC, PULPROD, RNTPROD, and VEGPROD, F tests are used in the study. The null hypothesis of no cointegration between

CO2, CHAL, COAGRAPROD, COCOBE, FRUPROD, LIVEHEC, PULPROD, RNTPROD, and VEGPROD is $H_0: \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = \delta_7 = \delta_8 = \delta_9 = 0$ against the alternative hypothesis $H_1: \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq \delta_6 \neq \delta_7 \neq \delta_8 \neq \delta_9 \neq 0$.

According to Pesaran et al. (2001), the computed *F*-statistic is compared with the first and the second critical values known as the lower bound and upper bound, respectively. If the computed *F*-statistic goes above the upper bound, the null hypothesis of no cointegration between CO2, CHAL, COAGRAPROD, COCOBE, FRUPROD, LIVEHEC, PULPROD, RNTPROD, and VEGPROD is rejected; otherwise, if it goes less the lower bound, the null hypothesis of no cointegration between CO2, CHAL, COAGRAPROD, COCOBE, FRUPROD, LIVEHEC, PULPROD, RNTPROD, and VEGPROD cannot be rejected. Nevertheless, if *F*-statistic lies between the lower and the upper bounds, the null hypothesis of no cointegration CO2, CHAL, COAGRAPROD, COCOBE, FRUPROD, LIVEHEC, PULPROD, RNTPROD, and VEGPROD become inconclusive, which can either be clarified through Johansen's test of cointegration (Johansen 1995) or by checking the constancy of the cointegration space using the cumulative sum recursive residuals and the cumulative of square of recursive residuals, respectively (Brown et al. 1975).

Descriptive analysis

Table 1 presents the descriptive analysis of 52 observations from the time series variables. All the variables exhibit a long-right-tail (positive skewness) with LIVEHEC having the longest right tail. While CO2, RNTPROD, COAGRAPROD, and VEGPROD exhibit platkurtic distribution, the other variables exhibit leptokurtic distribution of the normal. Jarque-Bera test statistic which operates under the null hypothesis that series are normally distributed shows that PULPROD, COAGRAPROD, and VEGPROD are normally distributed while the remaining variables reject the null hypothesis at 5 % *p* value. All the independent variables show a positive monotonic relationship with CO2 (dependent variable); however, the strength of association is stronger between CO_2 and RNTPROD as rho (ρ) approaches 1. Figure 1 shows the trend of endogenous variables. Almost all the endogenous variables increases periodically; however, CHAL exhibits a quick rise and fall scenario (see Fig. 1). The increasing population in Ghana has led to increasing demand of agricultural production, which is also time dependent.

Unit root test

Performing unit root test is vital in minimizing spurious regression since it ensures that variables used in a regression are stationary by differencing them and estimating the equation of interest through the stationary processes (Mahadeva and Robinson 2004). Group unit root test using Levin, Lin and Chu test (Levin et al. 2002), Breitung t-stat (Breitung 1999), Im, Pesaran and Shin W-stat (Im et al. 2003), Augmented Dickey Fuller—Fisher Chi-square, and Phillips-Perron—Fisher Chi-square methods (Choi 2001; Hadri 2000; Maddala and Wu 1999) assumes a common and individual unit root process as a null hypothesis of a unit root. However, we fail to accept the null hypothesis at level based on 5 % *p* value. The model proposed is stationary at level, but non-stationary at first differences (Table 2).

Lag selection for vector error correction model

After performing unit root tests, the next step is to identify the optimal lag for the VEC model. Vector autoregression (VAR) lag order selection criteria are used to select the optimal lag to the test of cointegration in the research analysis. Table 3 shows VAR Lag order selection criteria. Four lags are employed in this multivariate model because the sequential modified likelihood-ratio test statistic (LR), final prediction error (FPE), Akaike information criterion (AIC), Schwarz information criterion (SC) and Hannan-Quinn information criteria (HQ) select 4 as the optimal lag as indicated by "*" in Table 3.

Results and discussion

In this section, empirical evidence and discussions of the major findings are outlined.

Cointegration test and vector error correction model

Using the optimal lag selected by information criteria tests, Johansen's method of cointegration is estimated. Table 4 presents the summary of Johansen cointegration test (Johansen 1995) by max-eigenvalue and trace methods. Based on 5 % significance in the results shown in Table 4, we strongly reject the null hypothesis of no cointegration and fail to reject the null hypothesis of at most six cointegrating equations. Thus, we accept the null hypothesis that there are six cointegrating equations in the multivariate model.

Using the optimal lag and the number of cointegrating equations, the study estimates the vector error correction model. Table 5 shows the long-run multivariate causality of the error correction model. Findings from the analysis show that no long-run multivariate causality exits between CO_2 and the other endogenous variables. However, short-run causality exists running from COCOBE, FRUPROD, LIVEHEC, and PULPROD to CO_2. However, since there was no evidence of long-run multivariate causality, it is realistic to ascertain the direction of the causal relationships between CO_2 and the other endogenous variables using Granger causality test (Granger 1988).

Table 6 presents a summary of a pairwise Granger causality Wald test. The null hypothesis that CHAL does not Granger

Table 1 Descriptive statistical analysis

Statistic	CO2	CHAL	COAGRAPROD	COCOBE	FRUPROD	LIVEHEC	PULPROD	RNTPROD	VEGPROD
Mean	4488	0.6115	1,085,025	404,813	1,838,997	1.6552	14,541	8,268,879	424,301
Median	3335	0.5900	908,850	393,446	1,308,140	1.3400	14,500	4,666,045	398,172
Maximum	10,103	2.9500	2,415,110	879,348	4,603,330	4.300	25,000	22,591,600	827,863
Minimum	1346	0.0000	356,328	166,700	704,000	0.7100	5000	2,899,000	160,000
Std. Dev.	2676	0.7149	590,330	169,966	1,178,798	0.8528	4604	6,061,616	185,414
Skewness	0.778	1.1426	0.5766	0.9200	1.1716	1.5396	0.0356	0.8804	0.3470
Kurtosis	2.376	4.0237	2.2591	3.175	3.1163	4.6153	3.0153	2.4468	2.1164
Jarque-Bera	6.089	13.585	4.0707	7.4013	11.9256	26.1969	0.0115	7.3808	2.7354
Probability	0.048*	0.0011*	0.1306	0.0247*	0.0026*	0.0001*	0.9943	0.025*	0.2547
Correlation									
CO2	1								
CHAL	0.5302	1							
COAGRAPROD	0.9289	0.5219	1						
COCOBE	0.6565	0.1578	0.5961	1					
FRUPROD	0.9577	0.4239	0.9167	0.7631	1				
LIVEHEC	0.9163	0.3318	0.8568	0.7791	0.9592	1			
PULPROD	0.6990	0.2136	0.7050	0.4151	0.7294	0.7456	1		
RNTPROD	0.9659	0.4696	0.9565	0.7206	0.9644	0.9220	0.6557	1	
VEGPROD	0.7941	0.6111	0.8265	0.4636	0.7413	0.6813	0.5891	0.7824	1

*Rejection of the null hypothesis at 5 % *p* value

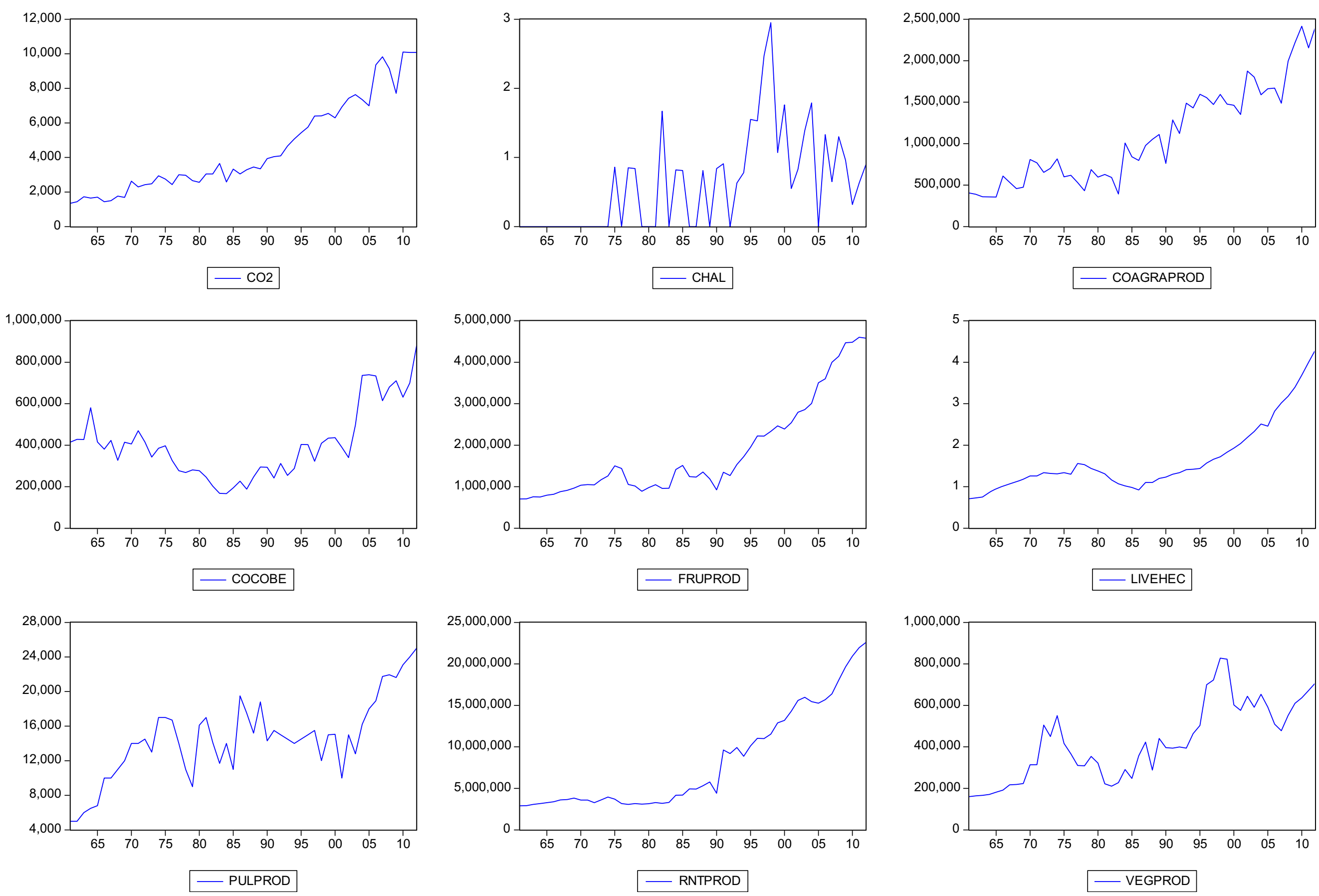

Fig. 1 Trend of endogenous variables

Table 2 Unit root testing

Level individual intercept		Unit test method			
Method	Levin, Lin and Chu t	Breitung t-stat	Im, Pesaran and Shin W-stat	ADF—Fisher Chi-square	PP—Fisher Chi-square
Statistic	7.52987	–	6.36604	6.95122	17.7264
Prob.**	0.9994	–	1.0000	0.9905	0.4738
Level individual intercept and trend					
Statistic	3.24334	4.1874	3.21326	11.7706	34.7347
Prob.**	0.9994	0.9994	0.9993	0.8589	0.0102
1st diff individual intercept					
Statistic	−9.0765	–	−13.4168	193.944	315.553
Prob.**	0.0000	–	0.0000	0.0000	0.0000
1st diff individual intercept and trend					
Statistic	−10.605	−4.94109	−13.7597	183.171	853.607
Prob.**	0.0000	0.0000	0.0000	0.0000	0.0000

**Probabilities for Fisher tests are computed using an asymptotic Chi-square distribution. All other tests assume asymptotic normality. The null hypothesis is rejected at 5 % *p* value

cause CO_2, COAGRAPROD does not Granger cause CO_2, COCOBE does not Granger cause CO_2, FRUPROD does not Granger cause CO_2, LIVEHEC does not Granger cause CO_2, PULPROD does not Granger cause CO_2, RNTPROD does not Granger cause CO_2 is rejected at the 5 % significance level. In other words, only VEGPROD does not Granger cause CO_2 emissions.

Another evidence from the analysis shows that CO_2 emissions Granger cause CHAL, COAGRAPROD, COCOBE, FRUPROD, LIVEHEC, and VEGPROD (see Table 6).

ARDL cointegration test, long-run and model selection

In this section, the study estimates the ARDL model since no evidence of long-run causality was established by the VEC model. As proposed by Pesaran et al. (2001), ARDL has desirable small sample properties and provide unbiased long-run estimation, even when some endogenous variables behave as regressors (Adom and Bekoe 2012). The ARDL cointegration test based on one equation is expressed as:

$$\begin{aligned}\text{Cointeq} = \text{CO2}- \Big(&1598.7198 \times \text{CHAL} + 0.0013 \times \text{COAGRAPROD} + 0.0074 \times \text{COCOBE} - 0.0003\\ &\times \mathit{FRUPROD} - 788.5518 \times \text{LIVEHEC} + 0.2659 \times \text{PULPROD} + 0.0003 \times \text{RNTPROD}\\ &- 0.0024 \times \text{VEGPROD} - 3524.0628\Big)\end{aligned} \tag{7}$$

Table 7 presents a summary of ARDL cointegration and long-run coefficient estimation. Based on 5 % significance level, the null hypothesis of no existence of cointegration is rejected.

Table 3 Lag order selection criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−4217.62		2.46E + 65	176.1091	176.4599	176.2417
1	−3917.85	474.6252	2.86E + 61	166.9939	170.5024	168.3198
2	−3835.17	99.90504	3.81E + 61	166.9239	173.5901	169.4431
3	−3701.68	111.2473	1.29E + 61	164.7366	174.5604	168.449
4	−3426.2	126.2595*	7.93E + 58*	156.6334*	169.6149*	161.5391*

LR sequential modified LR test statistic (each test at 5 % level), *FPE* final prediction error, *AIC* Akaike information criterion, *SC* Schwarz information criterion, *HQ* Hannan-Quinn information criterion

*Indicates lag order selected by the criterion

Table 4 Summary of Johansen co-integrated test by max-eigenvalue and trace methods

No. of CE(s)	Eigenvalue	Trace statistic	Critical value	Prob.**	Eigenvalue	Max-eigen statistic	Critical value	Prob.**
None	0.9952	642.1057	197.3709	0.0001*	0.9952	256.4677	58.4335	0.0000*
At most 1	0.9390	385.6380	159.5297	0.0000*	0.9390	134.2252	52.3626	0.0000*
At most 2	0.8590	251.4128	125.6154	0.0000*	0.8590	94.0378	46.2314	0.0000*
At most 3	0.7570	157.3750	95.7537	0.0000*	0.7570	67.9021	40.0776	0.0000*
At most 4	0.5229	89.4729	69.8189	0.0006*	0.5229	35.5169	33.8769	0.0316*
At most 5	0.4245	53.9560	47.8561	0.0120*	0.4245	26.5234	27.5843	0.0679
At most 6	0.2742	27.4326	29.7971	0.0915	0.2742	15.3817	21.1316	0.2630
At most 7	0.2220	12.0509	15.4947	0.1545	0.2220	12.0506	14.2646	0.1088
At most 8	0.0000	0.0003	3.8415	0.9881	0.0000	0.0003	3.8415	0.9881

Trace test indicates six cointegrating eqn(s) at the 0.05 level while max-eigenvalue test indicates five cointegrating eqn(s) at the 0.05 level

*Denotes rejection of the hypothesis at the 0.05 level; **MacKinnon-Haug-Michelis (1999) *p* values

With the existence of cointegration, the next step is to select the optimal model for the long-run equilibrium relationship estimation. In Fig. 2, the Akaike information criterion model selection is given. Akaike information criterion was used to select the best model with the specification: ARDL (4, 4, 3, 4, 4, 4, 4, 4, 4). From ARDL (4, 4, 3, 4, 4, 4, 4, 4, 4) model, the long-run equilibrium relationships were estimated using ARDL bounds test. ARDL bounds test for long-run estimation is presented in Table 8. The bounds cointegration test shows that the estimated *F*-statistic lies above the upper bound at 10, 5, and 2.5 % significance levels. Based on 5 % significance level, the null hypothesis of no long-run equilibrium relationship between variables is rejected.

Diagnostic test for VECM and ARDL model

In order to avoid misleading statistical inferences, the study verified and validated the model through diagnostic and stability checks. VECM was subjected to several diagnostic tests as presented in Table 10. VEC Residual Serial Correlation was tested using Lagrange-multiplier test based on Null Hypothesis: no serial correlation at lag order h. Results from the test shows that the null hypothesis cannot be rejected at the 5 % significance level, meaning that no serial correlation exists at lag order h. VEC Residual Normality was tested using Jarque-Bera test based on Null Hypothesis: residuals are multivariate normal. Results from the test shows that the null hypothesis cannot be rejected at the 5 % significance level, meaning that residuals are multivariate normally distributed.

In the same vein, ARDL was subjected to several diagnostic tests as presented in Table 9. Results from the test shows that the null hypothesis cannot be rejected at the 5 % significance level, meaning that no autocorrelation at lag order exists in the model (Breusch-Pagan-Godfrey Test), the equations are in their correct functional form (Ramsey RESET Test), no serial correlation exists at lag order h in the model (Lagrange-multiplier test), and residuals are multivariate normally distributed (Jarque-Bera test).

Robustness of VECM and ARDL model

As mentioned, checking the stability of the model is also beneficial before making statistical inferences. Figure 3 shows the roots characteristic polynomial. The root characteristics polynomial is used to check the stability of the short run causality among endogenous variables in VECM (Table 10). VEC specification imposes one unit root and VAR stability condition check does not present a root outside the unit circle (the eigenvalues of the respective matrix are exactly one or less) besides the first unit root of 1. Therefore, since the model satisfies VAR stability conditions, the VEC model is acceptable in a statistical sense to make inferences.

Figure 4 shows the CUSUM of Squares, CUSUM, and Recursive Residuals tests for the parameter instability from ARDL model. The CUSUM of Squares, CUSUM, and Recursive Residuals tests are used to ascertain the parameter instability of the equation employed in the ARDL model. Since the plots in the CUSUM of Squares, CUSUM, and Recursive Residuals tests lie within the 5 % significance level or ±2 S.E, the parameter of the equation is stable enough to estimate the long-run and short-run causality in the study.

Conclusion and policy recommendation

In this paper, the relationship between carbon dioxide and agriculture was investigated in Ghana by comparing a VECM and ARDL model using a time series data spanning from 1961 to 2012. Ten variables that constitute the majority of Ghana's agricultural sector were used in the study, which include the following: livestock, annual change of agricultural area, roots and tubers, total primary vegetable production,

Table 5 Long-run multivariate causality of the error correction model

Error correction	D(CO2)	D(CHAL)	D(COAGRAPROD)	D(COCOBE)	D(FRUPROD)	D(LIVEHEC)	D(PULPROD)	D(RNTPROD)	D(VEGPROD)
CointEq1	−0.4393	0.0004	67.2037	−62.1631	323.0504	−0.0002	4.8425	371.3803	12.4760
Std. error	−0.3774	−0.0005	−186.7290	−39.8512	−84.7524	−0.0001	−1.5137	−1148	−61.5081
t-statistic	−1.1640	0.8095	0.3599	−1.5599	3.8117	−2.3233	3.1991	0.3233	0.2028
$P>\|z\|$	0.2639	0.4318	0.7243	0.1411	0.0019*	0.0357*	0.0064*	0.7512	0.8422
CointEq2	663	−0.9895	−42355	−110871	−348899	−0.0905	−6942	5048	−13,014
Std. error	−419	−0.5867	−207,596	−44,304	−94,223	−0.0716	−1682	−1,276,990	−68,381
t-statistic	1.5809	−1.6865	−0.2040	−2.5025	−3.7029	−1.2652	−4.1258	0.0040	−0.1903
$P>\|z\|$	0.1362	0.1138	0.8413	0.0253*	0.0024*	0.2265	0.0010*	0.9969	0.8518
CointEq3	0.0038	0.0000	−0.4123	−0.8350	−1.2704	0.0000	−0.0097	−0.1195	0.3115
Std. error	−0.0020	0.0000	−1.0062	−0.2147	−0.4567	0.0000	−0.0082	−6.1892	−0.3314
t-statistic	1.8547	1.9831	−0.4098	−3.8885	−2.7818	0.4503	−1.1923	−0.0193	0.9399
$P>\|z\|$	0.0848	0.0673	0.6881	0.0016*	0.0147*	0.6594	0.2530	0.9849	0.3632
CointEq4	0.0054	0.0000	−0.7888	−1.3404	−0.7261	0.0000	−0.0495	5.7796	−0.2264
Std. error	−0.0027	0.0000	−1.3211	−0.2819	−0.5996	0.0000	−0.0107	−8.1263	−0.4352
t-statistic	2.0273	0.3219	−0.5971	−4.7542	−1.2110	0.6564	−4.6214	0.7112	−0.5203
$P>\|z\|$	0.0621	0.7523	0.5600	0.0003*	0.2459	0.5222	0.0004*	0.4886	0.6110
CointEq5	−0.0010	0.0000	−0.2833	0.0324	−0.4843	0.0000	0.0017	−1.5000	−0.0224
Std. error	−0.0007	0.0000	−0.3674	−0.0784	−0.1667	0.0000	−0.0030	−2.2598	−0.1210
t-statistic	−1.4003	−1.4355	−0.7713	0.4128	−2.9044	2.5050	0.5696	−0.6638	−0.1851
$P>\|z\|$	0.1832	0.1731	0.4534	0.6860	0.0115*	0.0252*	0.5779	0.5176	0.8558
CointEq6	102	1.0809	124300	37187	−166399	−0.2474	6841	−1,052,947	122,747
Std. error	−715	−1.0005	−354,010	−75,551	−160,677	−0.1220	−2869	−2,177,630	−116,610
t-statistic	0.1427	1.0804	0.3511	0.4922	−1.0356	−2.0269	2.3841	−0.4835	1.0526
$P>\|z\|$	0.8886	0.2982	0.7307	0.6302	0.3179	0.0622	0.0318*	0.6362	0.3103

*Significant at 5 % *p* value

Table 6 Summary of a pairwise Granger causality Wald tests

Dependent	Independent	chi2	df	Prob>chi2
CO2	CHAL	14.200	4	0.0070*
CO2	COAGRAPROD	31.928	4	0.0000*
CO2	COCOBE	20.687	4	0.0000*
CO2	FRUPROD	11.074	4	0.0260*
CO2	LIVEHEC	12.770	4	0.0120*
CO2	PULPROD	6.0475	4	0.1960
CO2	RNTPROD	1.0036	4	0.9090
CO2	VEGPROD	19.303	4	0.0010*
CO2	ALL	249.01	32	0.0000*
CHAL	*CO2*	*11.653*	*4*	*0.0200**
CHAL	COAGRAPROD	16.697	4	0.0020*
CHAL	COCOBE	19.956	4	0.0010*
CHAL	FRUPROD	19.879	4	0.0010*
CHAL	LIVEHEC	34.616	4	0.0000*
CHAL	PULPROD	40.507	4	0.0000*
CHAL	RNTPROD	37.492	4	0.0000*
CHAL	VEGPROD	7.9873	4	0.0920
CHAL	ALL	190.13	32	0.0000*
COAGRAPROD	*CO2*	*13.682*	*4*	*0.0080**
COAGRAPROD	CHAL	18.063	4	0.0010*
COAGRAPROD	COCOBE	9.8365	4	0.0430*
COAGRAPROD	FRUPROD	8.1717	4	0.0850*
COAGRAPROD	LIVEHEC	4.4001	4	0.3550
COAGRAPROD	PULPROD	17.370	4	0.0020*
COAGRAPROD	RNTPROD	14.329	4	0.0060*
COAGRAPROD	VEGPROD	17.235	4	0.0020*
COAGRAPROD	ALL	172.71	32	0.0000*
COCOBE	*CO2*	*24.612*	*4*	*0.0000**
COCOBE	CHAL	47.742	4	0.0000*
COCOBE	COAGRAPROD	63.548	4	0.0000*
COCOBE	FRUPROD	15.833	4	0.0030*
COCOBE	LIVEHEC	6.7030	4	0.1520
COCOBE	PULPROD	8.4783	4	0.0760
COCOBE	RNTPROD	77.069	4	0.0000*
COCOBE	VEGPROD	81.140	4	0.0000*
COCOBE	ALL	615.45	32	0.0000*
FRUPROD	*CO2*	*173.78*	*4*	*0.0000**
FRUPROD	CHAL	70.633	4	0.0000*
FRUPROD	COAGRAPROD	30.054	4	0.0000*
FRUPROD	COCOBE	42.614	4	0.0000*
FRUPROD	LIVEHEC	49.571	4	0.0000*
FRUPROD	PULPROD	43.923	4	0.0000*
FRUPROD	RNTPROD	99.038	4	0.0000*
FRUPROD	VEGPROD	50.463	4	0.0000*
FRUPROD	ALL	711.79	32	0.0000*
LIVEHEC	*CO2*	*16.607*	*4*	*0.0020**
LIVEHEC	CHAL	8.6783	4	0.0700*
LIVEHEC	COAGRAPROD	13.618	4	0.0090*
LIVEHEC	COCOBE	6.8334	4	0.1450
LIVEHEC	FRUPROD	62.244	4	0.0000*
LIVEHEC	PULPROD	5.0669	4	0.2810
LIVEHEC	RNTPROD	8.1877	4	0.0850
LIVEHEC	VEGPROD	4.6244	4	0.3280
LIVEHEC	ALL	262.21	32	0.0000*
PULPROD	*CO2*	*115.00*	*4*	*0.0000**
PULPROD	CHAL	98.649	4	0.0000*
PULPROD	COAGRAPROD	14.282	4	0.0060*
PULPROD	COCOBE	85.029	4	0.0000*
PULPROD	FRUPROD	105.45	4	0.0000*
PULPROD	LIVEHEC	112.85	4	0.0000*
PULPROD	RNTPROD	35.836	4	0.0000*
PULPROD	VEGPROD	54.826	4	0.0000*
PULPROD	ALL	520.24	32	0.0000*
RNTPROD	*CO2*	*11.600*	*4*	*0.0210**
RNTPROD	CHAL	9.6898	4	0.0460*
RNTPROD	COAGRAPROD	6.1751	4	0.1860
RNTPROD	COCOBE	9.6749	4	0.0460*
RNTPROD	FRUPROD	8.4719	4	0.0760
RNTPROD	LIVEHEC	12.738	4	0.0130*
RNTPROD	PULPROD	4.1052	4	0.3920
RNTPROD	VEGPROD	9.3527	4	0.0530
RNTPROD	ALL	90.531	32	0.0000*
VEGPROD	*CO2*	*3.5456*	*4*	*0.4710*
VEGPROD	CHAL	6.8709	4	0.1430
VEGPROD	COAGRAPROD	10.079	4	0.0390
VEGPROD	COCOBE	19.122	4	0.0010*
VEGPROD	FRUPROD	31.349	4	0.0000*
VEGPROD	LIVEHEC	17.736	4	0.0010*
VEGPROD	PULPROD	33.535	4	0.0000*
VEGPROD	RNTPROD	16.259	4	0.0030*
VEGPROD	ALL	230.75	32	0.0000*

*Denotes rejection of the hypothesis at 5 %

Table 7 Summary of ARDL cointegration and long-run coefficient estimation

Variable	Coefficient	Std. error	*t*-statistic	Prob.
CHAL	1598.7198	260.8435	6.1290	0.0036*
COAGRAPROD	0.0013	0.0010	1.2943	0.2652
COCOBE	0.0074	0.0019	3.9029	0.0175*
FRUPROD	−0.0003	0.0003	−1.11553	0.3271
LIVEHEC	−788.5518	249.7341	−3.1576	0.0343*
PULPROD	0.2659	0.0383	6.9442	0.0023*
RNTPROD	0.0003	0.0001	2.7587	0.0509
VEGPROD	−0.0024	0.0006	−4.1615	0.0141*
C	−3524.0628	746.1006	−4.7233	0.0091*
ECT(−1)	−3.8006	1.1059	−3.4368	0.0264*

*Denotes rejection of the hypothesis at 5 %

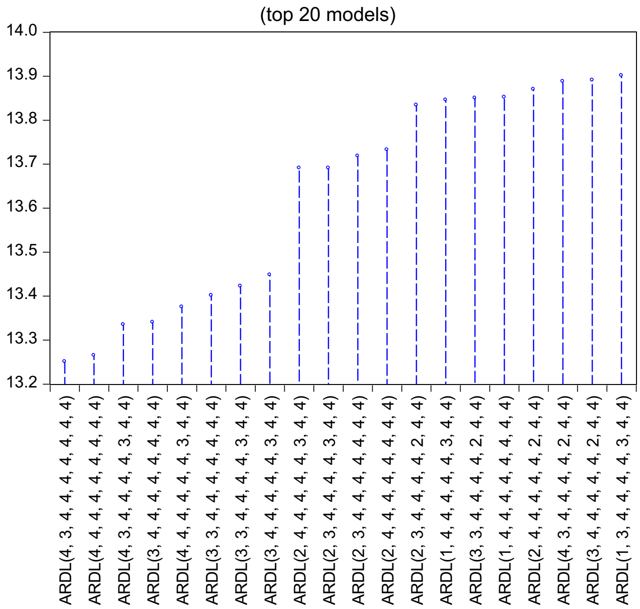

Fig. 2 Akaike information criterion model selection

total pulses production, total fruit production excluding melons, total coarse grain production, and cocoa bean production.

Results from the study shows that carbon dioxide emissions affect the percentage annual change of agricultural area, coarse grain production, cocoa bean production, fruit production, vegetable production, and the total livestock per hectare of the agricultural area. It is widely assumed that atmospheric carbon dioxide will increase crop production; nevertheless, in Figs. 5 and 6, the majority of the cointegration relation in VECM and ARDL model shows that the relationship between carbon dioxide emissions and agriculture in Ghana decreases periodically which may die over-time. The evidence provided in study confirms a study by Chang (2013) whose analysis shows that Ghana has an excess carbon dioxide emissions of −67.97 million metric tons.

Moreover, all the time series variables (total livestock per hectare of agricultural area, annual change of Agricultural area, total roots and tuber production, total pulses production, total fruit production excluding melons, total coarse grain production, and cocoa bean production) except total primary vegetables production lead to carbon dioxide emissions. This may be due to poor agricultural practices to meet the growing food demand in Ghana.

Table 8 Summary of ARDL bounds testing

Test statistic	Value	*k*
F-statistic	4.08*	8
Critical value bounds		
Significance	I0 bound	I1 bound
10 %	1.95	3.06
5 %	2.22	3.39
2.50 %	2.48	3.7
1 %	2.79	4.1

*indicates statistical significance at the 5 % level

Table 9 Diagnostics of ARDL model

Heteroskedasticity Test: Breusch-Pagan-Godfrey			
F-statistic	0.8273	Prob. *F*(43,4)	0.6790
Obs*R-squared	43.1484	Prob. chi-square(43)	0.4650
Scaled explained SS	0.1863	Prob. chi-square(43)	1.0000
Ramsey RESET test			
	Value	df	Probability
t-statistic	0.5403	3	0.6265
F-statistic	0.292	(1, 3)	0.6265
Residual Serial Correlation LM Tests			
F-statistic	17.6452	Prob. *F*(2,2)	0.0536
Obs*R-squared	45.4256	Prob. chi-square(2)	0.0000
Jarque-Bera test			
Component	Jarque-Bera	df	Prob.
1	4.4462	2	0.1083
2	2.9145	2	0.2329
3	0.8978	2	0.6383
4	0.6871	2	0.7092
5	2.7714	2	0.2502
6	0.5902	2	0.7445
7	1.0559	2	0.5898
8	3.1898	2	0.2029
9	0.0090	2	0.9955

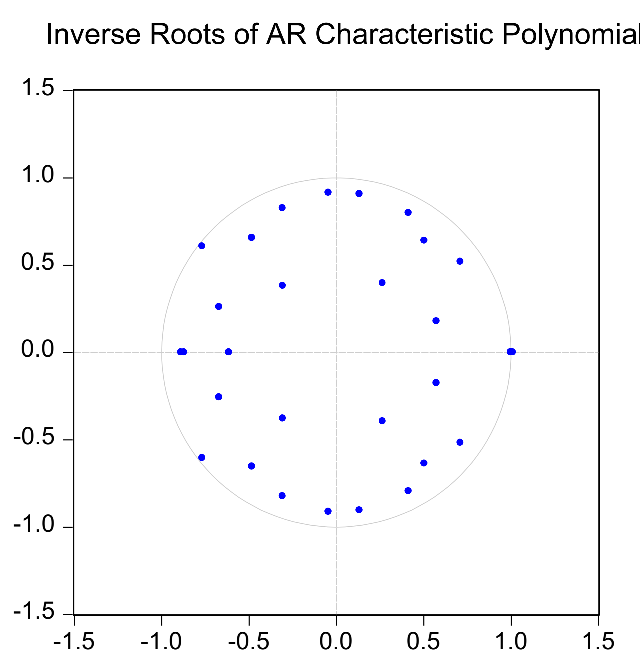

Fig. 3 Checking the stability of VAR

Table 10 Diagnostics of VECM

VEC Residual Serial Correlation LM tests		
Lags	LM-Stat	Prob
1	64.6551	0.4536
2	59.5471	0.6345
3	71.0526	0.2545
4	62.6091	0.5258
Jarque-Bera test		
Component	Jarque-Bera	Prob.
1	0.5251	0.7691
2	0.9063	0.6356
3	1.2096	0.5462
4	0.8645	0.6490
5	2.9921	0.2240
6	0.410164	0.8146
7	0.1483	0.9285
8	0.1429	0.9310
9	1.0221	0.5999

VECM analysis provides evidence of a short-run causality running from cocoa bean production, total fruit production excluding melons, livestock total per hectare of agricultural area, annual change of Agricultural area, and total pulses production of carbon dioxide emissions. But in contrast to *no evidence* of long-run relationship with the VEC model, ARDL bounds test cointegration analysis shows evidence of a long-run equilibrium relationship between the percentage annual change of agricultural area, cocoa bean production, livestock total per hectare of agricultural area, total pulses production, total primary vegetable production, and carbon dioxide emissions. Nevertheless, since ARDL bound testing method of cointegration is superior to other modern econometric techniques in small sample size, the results from ARDL model is unbiased and can be accepted since it meets diagnostic and stability conditions. Based on the results from the ARDL model, the following policy recommendations are made:

- It is important to end hunger and ensure people have access to safe and nutritious food, especially the poor, orphans, pregnant women, and children under-5 years in order to reduce maternal and infant mortalities. Nevertheless, it is also important that the Government of Ghana institutes agricultural policies that focus on promoting a sustainable agriculture using environmental friendly agricultural practices.
- Increasing agricultural investment in Ghana through enhanced international cooperation will help reduce the use

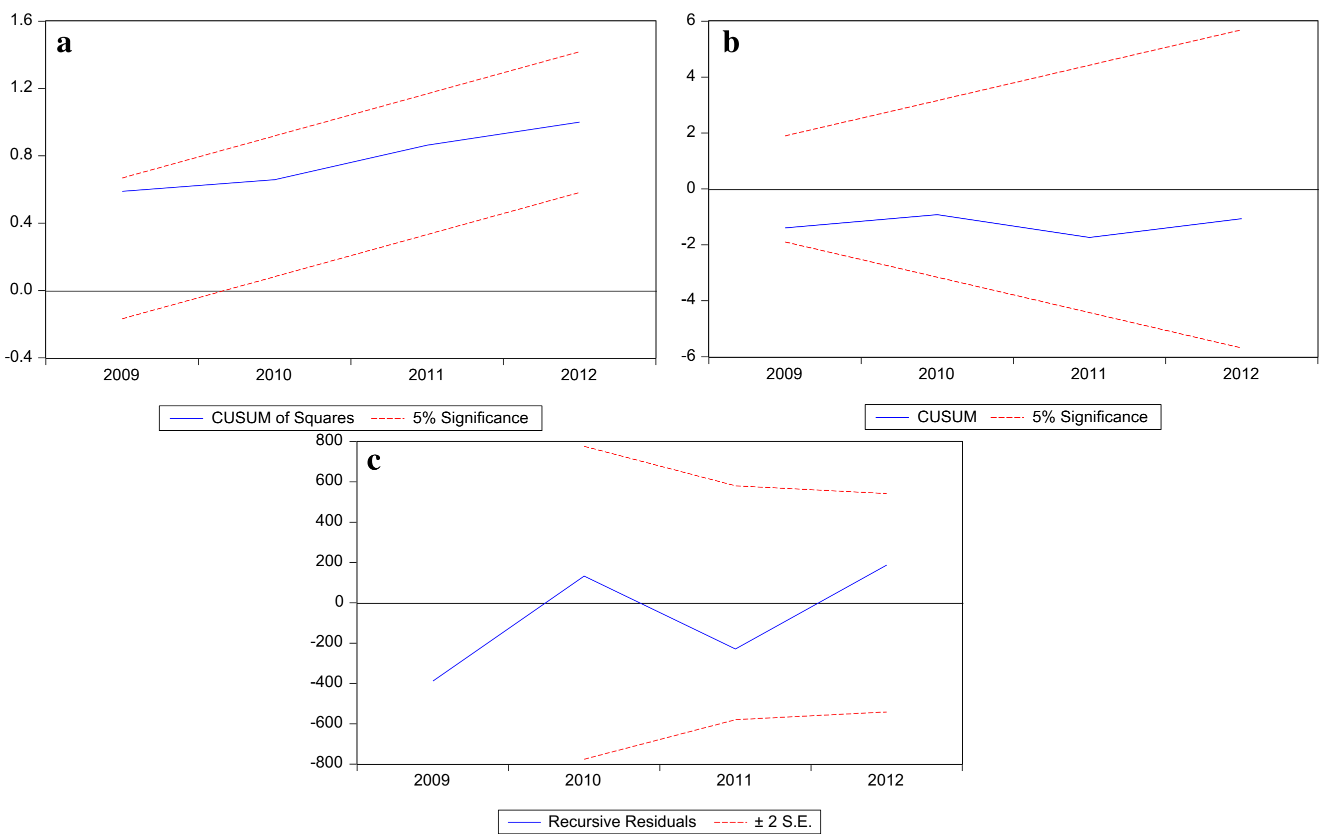

Fig. 4 **a** CUSUM of squares; **b** CUSUM; and **c** recursive residuals tests for the parameter stability from ARDL model

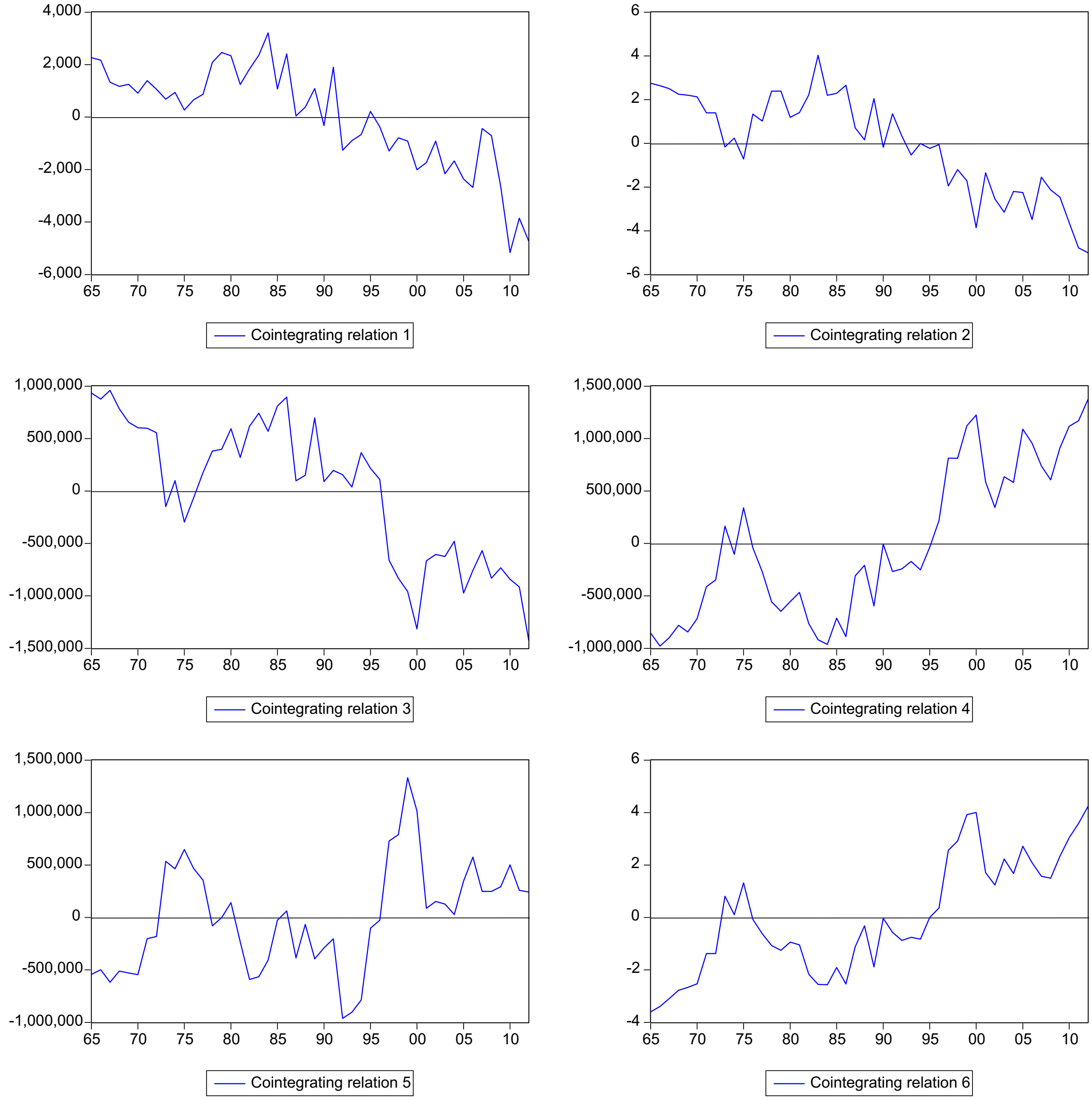

Fig. 5 Cointegration relation of carbon dioxide and exogenous variables using VECM

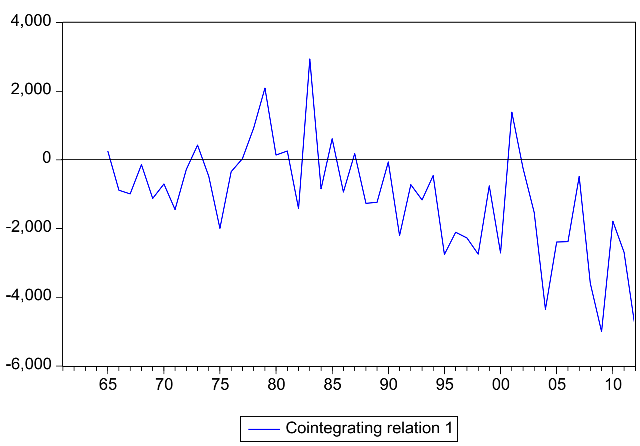

Fig. 6 Cointegration relation of carbon dioxide and exogenous variables using ARDL

of crude and indigenous agricultural methods that are detrimental to the ecosystem and agricultural productivity.

- There should be introduction of measures that ensure proper running of agricultural commodity markets and the timely access to agricultural output reserves in order to prevent extreme agricultural output price volatility.
- There should be an improvement in education, awareness-raising and institutional capacity building on early warning signs, climate change reduction, and adaptations.

Finally, the Government of Ghana should integrate climate change measures into the national strategies, policies, and planning in order to strengthen the country's effort to achieving a sustainable ecosystem. Future research should examine the percentage contribution of the causal relationship between carbon dioxide emissions and other agricultural commodities.

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