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

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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 and Distributed Lag (ARDL) Model. Ten study variables spanning from 1961 to 2012 were employed from the Food and 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 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

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

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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 have been skewed toward the energy and industrial sector. Burney et al. (2010) argue 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 accounts 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.
software. Their study concluded that the cultivation of saffron emits 2325.5 kg CO₂eq. ha⁻¹ greenhouse gas emissions.

Roth et al. (2014) investigated methane (CH₄) and nitrous oxide (N₂O) emissions from pig farming under tropical climate. They concluded that N₂O emissions were related to nitrate composition while CH₄ 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 CO₂ emissions in China from 1994 to 2011 by using the logarithmic mean divisia index as a decomposition technique. They concluded that economic development contributed immensely towards CO₂ 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 2016a, b), 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 using EViews 7 software for the computations. 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: CO₂—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), FRUPTPROD—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):

\[ \text{CO}_2 = f(\text{CHAL}_t, \text{COAGRAPROD}_t, \text{COCOBE}_t, \text{FRUPROD}_t, \text{LIVEHEC}_t, \text{PULPROD}_t, \text{RNTPROD}_t, \text{VEGPROD}_t) \quad (1) \]

Where \( y_t = \alpha_0 + \alpha_1 x_t \) is the long-run cointegrating relation existing between two variables of interest and, \( \lambda_x \) and \( \lambda_y \) 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), Fuihanas and Marques (2012), Kankal et al. (2011), and Ozturk and Acaravci (2011), ARDL Cointegration regression form of ARDL model can be expressed as:

\[ \Delta \text{CO}_2 = \alpha_0 + \delta_1 \text{CO}_2_{t-1} + \delta_2 \Delta \text{CHAL}_{t-1} + \delta_3 \Delta \text{COAGRAPROD}_{t-1} + \delta_4 \Delta \text{COCOBE}_{t-1} + \delta_5 \Delta \text{FRUPROD}_{t-1} + \delta_6 \Delta \text{LIVEHEC}_{t-1} + \sum_{i=0}^{p} \beta_{1i} \Delta \text{CO}_2_{t-i} + \sum_{i=0}^{p} \beta_{2i} \Delta \text{CHAL}_{t-i} + \sum_{i=0}^{p} \beta_{3i} \Delta \text{COAGRAPROD}_{t-i} + \sum_{i=0}^{p} \beta_{4i} \Delta \text{COCOBE}_{t-i} + \sum_{i=0}^{p} \beta_{5i} \Delta \text{FRUPROD}_{t-i} + \sum_{i=0}^{p} \beta_{6i} \Delta \text{LIVEHEC}_{t-i} + \sum_{i=0}^{p} \beta_{7i} \Delta \text{PULPROD}_{t-i} + \sum_{i=0}^{p} \beta_{8i} \Delta \text{RNTPROD}_{t-i} + \sum_{i=0}^{p} \beta_{9i} \Delta \text{VEGPROD}_{t-i} + \varepsilon_{1t} \quad (6) \]

Where \( \alpha \) is the intercept, \( p \) is the lag order, \( \varepsilon_t \) is the error term, and \( \Delta \) 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 $H_0: \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = \delta_7 = \delta_8 = 0$ against the alternative hypothesis $H_1: \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq \delta_6 \neq \delta_7 \neq \delta_8 \neq 0$.

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).

### 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 CO2 and the other endogenous variables. However, short-run causality exists running from COCOBE, FRUPROD, LIVEHEC, and PULPROD to CO2. However, since there was no evidence of long-run multivariate causality, it is realistic to ascertain the direction of the causal relationships between CO2 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  |

*Rejection of the null hypothesis at 5 % p value

**Fig. 1** Trend of endogenous variables

(Springer)
cause CO₂, COAGRAPROD does not Granger cause CO₂, COCOBE does not Granger cause CO₂, FRUPROD does not Granger cause CO₂, COAGRAPROD does not Granger cause CO₂, LIVEHEC does not Granger cause CO₂, PULPROD does not Granger cause CO₂, RNTPROD does not Granger cause CO₂ is rejected at the 5 % significance level. In other words, only VEGPROD does not Granger cause CO₂ emissions.

Another evidence from the analysis shows that CO₂ emissions Granger cause CHAL, COAGRAPROD, COCOBE, FRUPROD, LIVEHEC, and VEGPROD (see Table 6).

\[
\text{Cointeq} = \text{CO}_2 - \left(1598.7198 \times \text{CHAL} + 0.0013 \times \text{COAGRAPROD} + 0.0074 \times \text{COCOBE} - 0.0003 \\
\times \text{FRUPROD} - 788.5518 \times \text{LIVEHEC} + 0.2659 \times \text{PULPROD} + 0.0003 \times \text{RNTPROD} \\
- 0.0024 \times \text{VEGPROD} - 3524.0628\right)
\]

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 | 2.86E + 61 | 166.9939 | 170.5024 | 168.3198 |
| 2 | -3835.17 | 3.81E + 61 | 166.9239 | 173.5901 | 169.4431 |
| 3 | -3701.68 | 1.29E + 61 | 164.7366 | 174.5604 | 168.449 |
| 4 | -3426.2 | 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     | 3.8415              | 0.9881         | 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, 4). From ARDL (4, 4, 3, 4, 4, 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      | -1276990    | -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      | 2.0723 | 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 (continued)

| Dependent     | Independent     | chi2  | df   | Prob>|chi2 |
|---------------|-----------------|-------|------|-----|------|
| LIVEHEC       | RNTPROD         | 8.1877| 4    | 0.0850*  |
| LIVEHEC       | VEGPROD         | 4.6244| 4    | 0.3280*  |
| LIVEHEC       | ALL             | 262.21| 32   | 0.0000*  |
| PULPROD       | CO2             | 115   | 4    | 0.0000*  |
| PULPROD       | CHAL            | 98.649| 4    | 0.0000*  |
| PULPROD       | COAGRAPROD      | 14.232| 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*  |
| RNTPROD       | CO2             | 11.6  | 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   |
| VEGPROD       | CO2             | 9.3527| 4    | 0.0530   |
| VEGPROD       | ALL             | 90.531| 32   | 0.0000*  |
| VEGPROD       | COAGRAPROD      | 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

| Variable | Coefficient | Std. error | t-statistic | Prob. |
|----------|-------------|------------|-------------|-------|
| CHAL     | 1598.719788 | 260.8435   | 6.129038    | 0.0036*  |
| COAGRAPROD| 0.001253  | 0.000968   | 1.294321    | 0.2652  |
| COCOBE   | 0.007401   | 0.001896   | 3.902878    | 0.0175*  |
| FRUPROD  | −0.000338  | 0.000303   | −1.11553    | 0.3271  |
| LIVEHEC  | −788.551777| 249.7341   | −3.15757    | 0.0343*  |
| PULPROD  | 0.265884   | 0.038289   | 6.944175    | 0.0023*  |
| RNTPROD  | 0.000334   | 0.000121   | 2.758728    | 0.0509  |
| VEGPROD  | −0.002386  | 0.000573   | −4.16152    | 0.0141*  |
| C        | −3524.062756| 746.1000  | −4.72331    | 0.0091*  |
| CointEq(−1)| −3.80061   | 1.105852   | −3.43682    | 0.0264*  |

*Denotes rejection of the hypothesis at 5%
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 bound testing

| Test statistic | Value  | k |
|----------------|--------|---|
| F-statistic    | 4.08*  | 8 |
| Critical value bounds |
| Significance 10 bound | 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
VEC 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

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**Table 10** Diagnostics of VECM

| Lags | LM-Stat | Prob   |
|------|---------|--------|
| 1    | 64.65506 | 0.4536 |
| 2    | 59.54709 | 0.6345 |
| 3    | 71.05257 | 0.2545 |
| 4    | 62.60911 | 0.5258 |

Each of the 8 components of the Jarque-Bera test implies normality at the 5% significance level.

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

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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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