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The causal relationship between agricultural production, economic growth, and energy consumption in Ghana

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ABSTRACT
Relevance. Transition to a low-carbon economy in order to effectively and efficiently exploit the natural resource base of a country is a daunting task, especially for developing countries due to their over-reliance on climate factors. This study focuses on the case of Ghana and assesses the impact of several indicators – agricultural production, economic growth and energy consumption – on the environment. **Research objectives.** The aim of the study is to describe the causal relationship between agriculture production, economic growth, energy consumption and environmental degradation. **Data and Methods.** Using time-series data from 1975 to 2014, the study employed the ARDL model to achieve its objectives. **Results.** The empirical results from the bounds test provide evidence of a long-run association when the covariates are regressed on environmental degradation. The significance of the error correction term at 1% level of significance confirms this assertion. The result further shows that there is evidence of a unidirectional short-run Granger causality and a bidirectional Granger causality among the variables. There was, however, no evidence of Granger causality between economic growth, livestock production index, crop production index and environmental degradation. **Conclusion.** It is recommended that policy makers should prioritize the adoption of environmentally friendly technologies both in the crop and livestock sub-sectors to ensure that while the food needs of citizens are met, environmental quality is not compromised. Moreover, it is important to ensure energy use efficiency in production.

KEYWORDS
environmental degradation; economic growth; agricultural productivity; energy consumption; ARDL tests

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Причинная взаимосвязь между сельскохозяйственным производством, экономическим ростом и потреблением энергии в Гане

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АННОТАЦИЯ
Актуальность. Переход к низкоуглеродной экономике с целью эффективного и действенного использования базы природных ресурсов страны является сложной задачей, особенно для развивающихся стран из-за их чрезмерной зависимости от климатических факторов. В данном исследовании основное внимание уделяется примеру Ганы и оценивается влияние нескольких показателей – сельскохозяйственного производства, экономического роста и потребления энергии – на окружающую среду. **Цель исследования:** описать причинно-следственную связь между сельскохозяйственным производством, экономическим ростом, потреблением энергии и состоянием окружающей среды. **Данные и методы.** Используя данные временных рядов с 1975 по 2014 г., в исследовании применялась модель ARDL для достижения поставленных целей. **Результаты**. Эмпирические результаты теста границ доказывают долгосрочную связь, когда ковариаты влияют на ухудшение окружающей среды. Значимость ошибки модели на уровне значимости 1% подтверждает это утверждение. Результат также показывает, что есть свидетельства однонаправленной краткосрочной

КЛЮЧЕВЫЕ СЛОВА
деградация окружающей среды; экономический рост; продуктивность сельского хозяйства; потребление энергии; ARDL тесты

причинности Грейнджера и двунаправленной причинности Грейнджера среди переменных. При этом не было получено доказательств наличия причинно-следственной связи Грейнджера между экономическим ростом, индексом животноводства, индексом растениеводства и ухудшением состояния окружающей среды. **Выводы**. Рекомендуется, чтобы правительственные органы уделяли приоритетное внимание внедрению экологически безопасных технологий как в подсекторах растениеводства, так и в животноводстве, чтобы гарантировать, что при удовлетворении пищевых потребностей граждан качество окружающей среды не будет ухудшено. Кроме того, важно обеспечить эффективное использование энергии в производстве.

ДЛЯ ЦИТИРОВАНИЯ
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Introduction

Following the exponential growth of economies worldwide, the emergence of global concerns about finding lasting solutions to the continuous decline of environmental quality caused by the emission of greenhouse gases is critical. Over the last two decades or more, policymakers have focused their attention on assessing the global impact of the negative ramifications of greenhouse gas (GHG) emissions such as global warming on the world's environmental quality. Environmental degradation is mostly human induced – people are responsible for the emission of carbon dioxide into the atmosphere (Bogdanov et al., 2016; Petrova, 2011). According to the Intergovernmental Panel on Climate Change (IPCC) (2007), global temperatures and sea levels are expected to increase by 2100 from 1.1°C and 16.5cm to 6.4°C and 53.8 cm respectively.

In other to remedy the situation, global bodies such as the United Nations Framework Convention on Climate Change (UNFCCC) in recent past led developed and developing countries to sign global agreements such as the Kyoto Protocol and the most recent Paris Agreement. These agreements seek to reduce the effect of anthropogenic activities on the environment. In light of this, Ghana entered the Paris agreement on December 12, 2015. This agreement among other things finds ways of reducing the effect of climate change globally. For instance, Article 2 of the Paris agreement aims to forestall the rising trend in average global temperature from reaching 2°C above pre-industrial levels while also ensuring global efforts to reduce temperature increase to 1.5°C above pre-industrial levels.

As reported by the United Nations Development Programme (UNDP, 2018), Ghana is the highest-ranked West African country within the medium human development category – it currently ranks 140th globally (see Table 1). Furthermore, the country attained the middle-income status in 2011, which means that it is making progress in achieving economic growth and eradication of poverty. The country's sustained economic progress to a large extent depends on the agricultural sector because agriculture and related activities primarily serve as the source of direct income and livelihood for many people in Ghana (Ministry of Food and Agriculture [MOFA], 2017).

Table 1

Ranking positions of African countries in the medium human development category

World Rank	Countries	Human Development Index (Value)	Location
113	South Africa	0.699	Southern Africa
115	Egypt	0.696	North Africa
123	Morocco	0.667	North Africa
129	Namibia	0.647	Southern Africa
137	Congo	0.606	Central Africa
140	Ghana	0.592	West Africa
142	Kenya	0.590	East Africa
144	Zambia	0.588	Southern Africa
147	Angola	0.582	Southern Africa
151	Cameroon	0.556	West Africa

Source: UNDP (2018).

According to Liu et al. (2017) and the Food and Agriculture Organization (FAO, 2016), inorganic fertilizers, agricultural mechanization and the burning of biomass are the main determinants of the agricultural sector's emissions globally. Agriculture accounts for about 21% of the total global emissions of GHGs. MESTI and EPA (2015) documented that agriculture, forest and other land use (AFOLU) were the main sources of GHG emissions in Ghana, between 1990 and 2012. This can be attributed to the increase in animal population, conversion of forest lands for agricultural purposes, biomass burning via wildfires, etc. This trend is, however, expected to continue in the country's next national greenhouse gas inventory report since the majority of Ghanaians are (self-) employed in the AFOLU sector. Even though GHG emissions in Ghana are far lower compared to global levels (see Table 2), their impact on the environment cannot be underestimated.

Table 2

Net greenhouse gas emission from selected major emitters

Country	Total Emissions $MtCO_2e$		Percentage change, %
	1990	2016	
China	2305.425	10432.751	352.530
South Africa	268.333	390.558	45.550
Brazil	215.804	462.995	114.544
Russia	2379.433	1661.899	–30.156
Nigeria	69.062	82.634	19.652
*Ghana	3.132	14.470	362.005

Source: Janssens-Maenhout et al. (2017).

Therefore, it is necessary to examine the causal nexus which includes CO_2 emissions (henceforth 'environmental degradation'), agricultural production (which is segregated into the livestock and crop production index, GDP per capita (henceforth 'economic growth'), and agricultural energy consumption in Ghana. It is important that Ghana should promote energy use efficiency and develop an agricultural system that is resilient to the externalities of climate change. Very few studies such as Appiah et al. (2017) have delved into the GDP-CO_2 emissions nexus in Ghana. However, this study to the best of the authors' knowledge is the first of its kind to be conducted in Ghana that seeks to deal with the causal nexus including environmental degradation, agricultural production, economic growth, and energy consumption by applying the autoregression distributed lag (ARDL) model. In light of this, this study would contribute to the existing literature by adding agricultural production which would be disintegrated into the crop and livestock index and energy consumption as covariates. The aim is to identify the exact source of the causal relationship between agriculture production, economic growth, energy consumption and environmental degradation. Ghana's interest in working out and implementing a low-carbon economy due to the country's participation in international agreements presents an important platform for both local and international investors in the fields of sustainable agriculture and renewable energy.

Review of research literature

A number of studies in the recent past have investigated the causal relationship between macroeconomic and human-induced indicators of environmental degradation using different econometric techniques such as the Statistically Inspired Modification of Partial Squares (SIMPLS) regression model, Ordinary Least Square (OLS), Markov-switching dynamic regression, NIPALS regression, Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS). However, these models have weaknesses such as multicollinearity (Sarkodie et al., 2019; Appiah et al., 2018; Asumadu-Sarkodie and Owusu, 2017).

Saidi et al. (2019) applied the ARDL model to examine the effect of crude oil prices on economic growth in South East Sulawesi, Indonesia. Their study found no long-run relationship between crude oil prices and economic growth, however, they found evidence of short-run associations between the variables.

Li et al. (2018) investigated the interrelationship of carbon emission intensity, economic development and energy factors in 19 out of the G20 countries, using a panel heterogeneity data from 1990 to 2015. By conducting panel cointegration using the three-panel root test, they found the existence of long-run equilibrium among the variables. They further employed the DOLS and FMOLS to examine the long-term elasticity among the variables and the D-H panel causality to ascertain the direction of causality if there was any. Their findings revealed a bi-directional effect between energy factors and development mode while the development level significantly influenced energy factors and development mode.

Tang and Tan (2015) explored the relationship of CO_2 emissions, energy consumption, foreign direct investment, and economic growth in Vietnam using data spanning 1976 to 2009 and found a long-run association among the variables. Their findings also supported the Environmental Kuznets Curve (EKZ) hypothesis. The study recommended the adoption of clean technologies by foreign investment to deal with CO_2 emissions.

Gosh (2010) studied the carbon emissions and economic growth nexus in India by using the multivariate cointegration approach while using a time series data set from 1971 to 2006. No evidence was found of the long-run causality between the two variables, although the empirical findings showed the existence of unidirectional short-run causality from economic growth to energy supply and energy supply to carbon emissions.

Sakyi (2011) applied the ARDL bound test approach to examine trade openness, foreign aid and economic growth in post-liberalization Ghana. The results indicate that in as much as trade openness and foreign aid positively impacted economic growth both in the short and long run, the impact is reduced by their interactive term. However, they both have been of significant benefit to economic growth in Ghana.

In an attempt to establish the long run and causal nexus between economic growth and carbon dioxide in Malaysia using data from 1980 to 2009 in light of the EKC, Saboori et al. (2012) found a long-run relationship between per capita CO_2 emissions and real GDP when CO_2 is made the dependent variable. The study also found evidence of the inverted U-shape between CO_2 emissions and GDP indicating the existence of the EKC in Malaysia. However, while the study found no short-run causality between the two variables, it demonstrated the existence of unidirectional causality from GDP to CO_2 emissions in the long-run.

African countries are highly exposed to climate change and variability. EPA (2008) noted that at the rate of desertification of 20,000 hectares per annum, about 35% of Ghana's total land area has been converted to desert lands due to anthropogenic activities mainly in the AFOLU sector, leading to the increase in greenhouse gas emissions. Activities such as outmoded farming practices, which have proven to be unfriendly to the environment, and the growing population have significantly contributed to desertification as forest areas are converted into farmlands and residential areas. Similarly, several recent studies have found that agricultural production has a negative impact on the environment. For example, Luo et al. (2017) and Ben Jebli and Ben Youssef (2017) found that agricultural production significantly contributed to CO_2 emissions in China and Tunisia respectively.

However, the evidence from the World Bank (2010) indicates that the negative impact of climate change on the Ghanaian economy will only get more severe. The report predicts a temperature increase between 2.1 to 2.4°C from 2010 to 2050 across the country. This could have an adverse effect on the agricultural sector as rainfall patterns would be seriously affected. The net effect of this situation would be the challenge of meeting the population's food and nutrition needs due to the overreliance of the Ghanaian agricultural sector on rainfall.

According to Asumadu-Sarkodie and Owusu (2016, 2017), good and effective energy policies should support the creation of new and alternative energy technologies that would meet the energy demand of the populace while at the same time meeting the sustainable environment needs of the energy sector. Furthermore, Asumadu-Sarkodie and Owusu (2016) and Jørgensen (2005) noted that an efficient energy sector among other things aims at the stabilization of energy supply, reduction of environmental effects from energy production and utilization, introduction of efficient energy utilization; and the development of alternative renewable energy. In Ghana, most energy consumed is biomass (Asumadu-Sarkodie and Owusu (2016)), accounting for about 60% of the country's total energy supply with its resources covering about 20.8 million hectares of land (Ghana Energy Commission (2013)). In spite of the volume of degraded landmass due to the overexploitation of the country's natural resources, Sustainable Development Action Plan (2015) shows that these lands still have the potential for cultivating crops that have significant value for the production of solid and liquid biofuels.

Recent literature has been inconclusive on the relationship between environmental degradation and energy consumption. While some studies observe that energy consumption adds to environmental degradation, others have found no relationship between the two.

Materials and methods

This study assesses the connection between agricultural production, economic growth, environmental degradation, and energy consumption by using the autoregression distributed lag (ARDL) bounds testing approach. The data employed for this study covers the period from 1975 to 2014 and these data were taken from the World Bank and FAOSTAT database. Predictor variables used in the study include agriculture production proxied as the crop production index and livestock production index, economic growth (proxied as GDP per capita), agricultural energy consumption, and environmental degradation (proxied as CO_2 emissions). Following Appiah et al. (2018); Adom and Amankwa (2018); Amuakwa-Mensah and Adom (2017), we used the CO_2 equivalent, which represents potential CO_2 emissions. It presents a better alternative in terms of model efficiency and also elasticities of variables in the long run compared to the actual CO_2 measured in kt. Details of the data can be found in Table 3.

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Table 3

Data source and definition of variables

Codes	Variable Names	Proxy	Unit of measurement
CPI	Crop Production	Crop production Index	(2004–2006 = 100)
LPI	Animal Production	Livestock Production Index	(2004–2006 = 100)
GDP	Economic growth	Gross domestic product per capita	GDP per capita (Current US $)
EC	Agricultural Energy Consumption		Kilogram of oil equivalent per capita
EVD	Environmental degradation	Carbon dioxide emissions	Gigagram

Results

Stationarity Test

Before running any time series to ascertain causality, we need to first run a unit root test to confirm whether variables are stationary or not and to find out whether the variables are integrated of the first order or not. The bounds test for cointegration is more flexible compared to other techniques, that is, it allows selected variables to be integrated of both the first order or order zero. As such it would not have been necessary to conduct a unit root test, however, we need to conduct the unit root test to eliminate any I(2) variable. If this is the case, we will be running spurious regressions. In light of this, we employ the ADF test by (Maddala et al., 1999), the Phillips-Perron (PP) as suggested by (Phillips and Perron, 1988) and Im-Persaran-Shin (IPS) by (Im et al., 2003).

Table 4 shows that in performing the unit root test, two regressions were estimated; the first had only an intercept and the second had both an intercept and a trend term so as to enable us to compare results. Three tests as mentioned earlier were applied to both the level form and after taking the first difference. The result clearly indicates that the variables at level were non-stationary. However, when the first difference was taken, the variables were all stationary indicating that they were all of I(1) series and not of I(2).

Test for Cointegration

This study employs the ARDL bound testing approach to examine the nexus among the variables in the long run. This technique was first introduced by Pesaran et al. (2001; 1999). The cointegration technique has several advantages over other methods due to its flexibility (Nkoro and Uko, 2016; Belloumi, 2014; Odhiambo, 2009).

Table 4

Unit Root Test

Test	Variable	At Level		At First difference	
		Intercept	Intercept + trend	Intercept	Intercept + Trend
ADF	ln*EVD*	0.799	–2.061	–6.068^{a}	–6.336^{a}
	ln*LPI*	–0.816	–1.589	–3.714^{a}	–3.725^{b}
	ln*CPI*	0.814	–2.495	–4.643^{a}	–4.992^{a}
	ln*EC*	–1.736	–2.153	–4.352^{b}	–4.292^{a}
	ln*EG*	0.129	–0.907	–3.939^{a}	–4.128^{b}
PP	ln*EVD*	0.617	–3.087	–10.094^{a}	–10.553^{a}
	ln*LPI*	–1.151	–1.770^{a}	–6.027^{a}	–5.984^{a}
	ln*CPI*	0.701	–2.614	–8.272^{a}	–8.664^{a}
	ln*EC*	–1.698	–2.133	–5.960^{a}	–5.885^{a}
	ln*EG*	0.49	–0.91	–5.776^{a}	–5.841^{a}
IPS	ln*EVD*	2.8428	0.521	–4.277^{a}	–4.669^{a}
	ln*LPI*	0.792	0.718	–2.457^{a}	–1.880^{b}
	ln*CPI*	2.62	–0.386	–3.498	–3.42
	ln*EC*	–0.24	0.031	–3.172^{a}	–2.569^{a}
	ln*EG*	1.852	1.549	–2.710^{a}	–2.370^{a}

Source: Authors' computations

For the purpose of this study, we specify the ARDL model as shown below:

$$\begin{aligned}\Delta\ln(EVD_t) = {} & \propto_{01} + \beta_{11}\ln(EVD_{t-1}) + \beta_{21}\ln(LPI_{t-1}) + \beta_{31}\ln(CPI_{t-1}) + \beta_{41}\ln(EC_{t-1}) \\ & + \beta_{51}\ln(EG_{t-1}) + \sum_{i=1}^{n}\propto_{1i}\Delta\ln(EVD_{t-1}) + \sum_{i=1}^{n}\propto_{2i}\Delta\ln(LPI_{t-1}) \\ & + \sum_{i=1}^{n}\propto_{3i}\Delta\ln(CPI_{t-1}) + \sum_{i=1}^{n}\propto_{4i}\Delta\ln(EC_{t-1}) \\ & + \sum_{i=1}^{n}\propto_{5i}\Delta\ln(EG_{t-1}) + \mu_{1t}\end{aligned} \quad (1)$$

$$\begin{aligned}\Delta\ln(LPI_t) = {} & \propto_{02} + \beta_{12}\ln(EVD_{t-1}) + \beta_{22}\ln(LPI_{t-1}) + \beta_{32}\ln(CPI_{t-1}) + \beta_{42}\ln(EC_{t-1}) \\ & + \beta_{52}\ln(EG_{t-1}) + \sum_{i=1}^{n}\propto_{1i}\Delta\ln(LPI_{t-1}) + \sum_{i=1}^{n}\propto_{2i}\Delta\ln(EVD_{t-1}) \\ & + \sum_{i=1}^{n}\propto_{3i}\Delta\ln(CPI_{t-1}) + \sum_{i=1}^{n}\propto_{4i}\Delta\ln(EC_{t-1}) \\ & + \sum_{i=1}^{n}\propto_{5i}\Delta\ln(EG_{t-1}) + \mu_{2t}\end{aligned} \quad (2)$$

$$\begin{aligned}\Delta\ln(CPI_t) = {} & \propto_{03} + \beta_{13}\ln(EVD_{t-1}) + \beta_{23}\ln(LPI_{t-1}) + \beta_{33}\ln(CPI_{t-1}) + \beta_{43}\ln(EC_{t-1}) \\ & + \beta_{53}\ln(EG_{t-1}) + \sum_{i=1}^{n}\propto_{1i}\Delta\ln(LPI_{t-1}) + \sum_{i=1}^{n}\propto_{2i}\Delta\ln(EVD_{t-1}) \\ & + \sum_{i=1}^{n}\propto_{3i}\Delta\ln(CPI_{t-1}) + \sum_{i=1}^{n}\propto_{4i}\Delta\ln(EC_{t-1}) \\ & + \sum_{i=1}^{n}\propto_{5i}\Delta\ln(EG_{t-1}) + \mu_{3t}\end{aligned} \quad (3)$$

$$\begin{aligned}\ln(CPI_t) = {} & \propto_{04} + \beta_{14}\ln(EVD_{t-1}) + \beta_{24}\ln(LPI_{t-1}) + \beta_{34}\ln(CPI_{t-1}) + \beta_{44}\ln(EC_{t-1}) \\ & + \beta_{54}\ln(EG_{t-1}) + \sum_{i=1}^{n}\propto_{1i}\Delta\ln(LPI_{t-1}) + \sum_{i=1}^{n}\propto_{2i}\Delta\ln(EVD_{t-1}) \\ & + \sum_{i=1}^{n}\propto_{3i}\Delta\ln(CPI_{t-1}) + \sum_{i=1}^{n}\propto_{4i}\Delta\ln(EC_{t-1}) \\ & + \sum_{i=1}^{n}\propto_{5i}\Delta\ln(EG_{t-1}) + \mu_{4t}\end{aligned} \quad (4)$$

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$$\begin{aligned}\ln(CPI_t) = {} & \propto_{05} + \beta_{15}\ln(EVD_{t-1}) + \beta_{25}\ln(LPI_{t-1}) + \beta_{35}\ln(CPI_{t-1}) + \beta_{45}\ln(EC_{t-1}) \\ & + \beta_{55}\ln(EG_{t-1}) + \sum_{i=1}^{n}\propto_{1i}\Delta\ln(v) + \sum_{i=1}^{n}\propto_{2i}\Delta\ln(EVD_{t-1}) \\ & + \sum_{i=1}^{n}\propto_{3i}\Delta\ln(CPI_{t-1}) + \sum_{i=1}^{n}\propto_{4i}\Delta\ln(EC_{t-1}) \\ & + \sum_{i=1}^{n}\propto_{5i}\Delta\ln(EG_{t-1}) + \mu_{5t}\end{aligned} \tag{5}$$

Where the meaning of variables as already defined in Table 3 apply, ln is the log form of the variables, Δ stands for the 1^{st} difference of variables and μ_t is the error term.

To determine the existence of cointegration among the variables under study, the bounds test was employed with the underlying statistic being the joint F or Wald statistic. It does not really matter whether the variables under study are of I(0) or I(1) order, the null hypothesis always gives an indication of no cointegration. Pesaran et al. (2001) provide two pairs of asymptotic critical values for determining the significant levels of variables under study. Whereas the first pair operates on the assumption that all variables are of I(I) series, the second assumes they are all of the I(0) series. The rule of thumb is that firstly, if the F-statistic is greater than that of the I(1) bound, then the null hypothesis of no cointegration is rejected and concluded that there is cointegration among the regressors. Secondly, if the I(0) bound is greater than the estimated statistic, we fail to reject the null hypothesis and conclude that indeed there is no evidence of cointegration among the regressors. Finally, an inconclusive result is when the estimated statistic falls between the I(0) and I(1) bounds.

To apply the above rules and assumptions to this current study, we need to first estimate equations 1 to 5 using the OLS model to test the hypotheses as described above, we, therefore, specified the null and alternative hypotheses for this study as follows:

$$H_0 : \beta_{1i} = \beta_{2i} = \beta_{3i} = \beta_{4i} = \beta_{5i} = 0$$

$$H_1 : \beta_{1i} \neq \beta_{2i} = \beta_{3i} \neq \beta_{4i} \neq \beta_{5i} \neq 0$$

Where i = 1, 2, 3, 4, 5

Before examining the long-run relationship using the bounds test, we first obtained the optimum lag using the SBIC test. Table 5 indicates that the best lag length for Equation 1 was 2 lags while that for Equation 1 to 4 was 1 lag.

Results of the ARDL bounds test are found in Table 5. As specified in Equation 1 to 5, each variable was considered as a dependent variable. It can be observed that with the exception of Equation 1, which showed evidence of cointegration indicating that there is a long-run nexus among the variables, the others (Equation 1 to 4) showed no evidence of cointegration. This means that using ln*LPI*, ln*CPI*, ln*EC* and ln*EG* as dependent variables in Equation 1 to 4 will produce no long-run interaction among the variables. Critical values of lower and upper bounds were taken from (Pesaran et al., 2001).

Table 5

Bounds Test Cointegration

Dependent Variable	SBIC lags	*F*-statistic	Decision rule
$F_{CO_2}(EVD/LPI, CPI, EC, EG)$	2	7.320	Cointegration
$F_{LPI}(LPI/EVD, CPI, EC, EG)$	1	3.172	No Cointegration
$F_{CPI}(CPI/EVD, LPI, EC, EG)$	1	1.342	No Cointegration
$F_{EC}(EC/EVD, LVI, CPI, EG)$	1	2.870	No Cointegration
$F_{GDP}(EG/LVI, CPI, EC, EVD)$	1	1.495	No Cointegration
Lower-Bound at 1%	3.74		
Upper-Bound at 1%	5.06		

Source: Authors' Computations

Granger Causality Test

After establishing the presence of cointegration among the variables under study, we then proceeded to ascertain the short and long-run causality between variables. Given that cointegration was found in Equation 1, we estimate the long-run model as follows:

$$\begin{aligned}\ln EVD_t = {} & \gamma_0 + \sum_{i=1}^{n_1}\gamma_1\ln(EVD_{t-i}) + \\ & + \sum_{i=1}^{r}\gamma_{i-0}\ln(LPI_{t-i}) + \sum_{i=1}^{n_2}\gamma_{i-1}\ln(CPI_{t-i}) + \\ & + \sum_{i=1}^{n_3}\gamma_{i-1}\ln(EC_{t-i}) + \sum_{i=1}^{n_4}\gamma_{i-1}\ln(GDP_{t-i}) + \mu_t.\end{aligned} \tag{6}$$

The meaning of the variables (i.e. *EVD*, *LPI*, *CPI*, *EC*, and *GDP*) is defined in Table 3. Please refer to Odhiambo (2009) for Granger's definition of causality and how it operates.

Table 6 presents the results obtained after the normalization of EVD in the long run. It is observed that all regressors in the model were significant and positive at 1% level of significance. The positive sign of the livestock production index (*FPI*) and the crop production index (*CPI*) as major contributing factors to environmental degradation (*EVD*) is an indication of the growing animal population and the country's overreliance on the agricultural sector for livelihood sources. Although this signifies the country's potential to meet the food and protein needs of its citizens, the lack of demarcated areas such as grazing fields for animals and the expansion of farmlands into forest zones means that forest areas are being encroached on by farmers in their agricultural activities hence leading to the degradation of forest in the country. The positive relationship between economic growth (*EG*) and environmental degradation is indicative of the on-going structural economic transformation agenda of the country, which has led to relatively sustained growth and expansion of the economy. The country's increasingly growing transportation sector could also account for this relationship. Energy consumption from the agricultural sector (*EC*) also has a positive influence on environmental degradation.

Table 6

Long-Run Estimates

Variables	Coefficient	*t*-statistic
Constant	–1.236	–1.12
ln*LPI*	0.4625***	3.75
ln*CPI*	0.5170***	3.83
ln*EC*	0.9292**	2.74
ln*EG*	0.3723***	3.77
R-squared	0.9784	-
F-statistic	192.78***	-
Durbin-Watson Statistic	2.5015	-

Note: *** denotes the significance level at 1%.

Source: Authors' computations

To estimate the short-run causality, we include a dynamic error-correction term linked to the long-run dynamic estimates in our specification. This is to reintroduce the long-run component that is lost as a result of taking the difference of the variables (Odhiambo, 2009). We, therefore, specify the vector error correction model as:

$$\begin{aligned}\Delta\ln(EVD_t) = \propto_0 &+ \sum_{i=1}^{n} \propto_{1i} \Delta\ln(EVD_{t-1}) + \sum_{i=1}^{n} \propto_{2i} \Delta\ln(LPI_{t-1}) \\ &+ \sum_{i=1}^{n} \propto_{3i} \Delta\ln(CPI_{t-1}) + \sum_{i=1}^{n} \propto_{4i} \Delta\ln(EC_{t-1}) \\ &+ \sum_{i=1}^{n} \propto_{5i} \Delta\ln(EG_{t-1}) + \gamma ECT_{t-1} + \mu_{1t}\end{aligned} \tag{7}$$

$$\begin{aligned}\Delta\ln(LPI_t) = \propto_0 &+ \sum_{i=1}^{n} \propto_{1i} \Delta\ln(EVD_{t-1}) + \sum_{i=1}^{n} \propto_{2i} \Delta\ln(LPI_{t-1}) \\ &+ \sum_{i=1}^{n} \propto_{3i} \Delta\ln(CPI_{t-1}) + \sum_{i=1}^{n} \propto_{4i} \Delta\ln(EC_{t-1}) \\ &+ \sum_{i=1}^{n} \propto_{5i} \Delta\ln(EG_{t-1}) + \gamma ECT_{t-1} + \mu_{1t}\end{aligned} \tag{8}$$

$$\begin{aligned}\Delta\ln(CPI_t) = \propto_0 &+ \sum_{i=1}^{n} \propto_{1i} \Delta\ln(EVD_{t-1}) + \sum_{i=1}^{n} \propto_{2i} \Delta\ln(LPI_{t-1}) \\ &+ \sum_{i=1}^{n} \propto_{3i} \Delta\ln(CPI_{t-1}) + \sum_{i=1}^{n} \propto_{4i} \Delta\ln(EC_{t-1}) \\ &+ \sum_{i=1}^{n} \propto_{5i} \Delta\ln(EG_{t-1}) + \gamma ECT_{t-1} + \mu_{1t}\end{aligned} \tag{9}$$

$$\begin{aligned}\Delta\ln(EC_t) = \propto_0 &+ \sum_{i=1}^{n} \propto_{1i} \Delta\ln(EVD_{t-1}) + \sum_{i=1}^{n} \propto_{2i} \Delta\ln(LPI_{t-1}) \\ &+ \sum_{i=1}^{n} \propto_{3i} \Delta\ln(CPI_{t-1}) + \sum_{i=1}^{n} \propto_{4i} \Delta\ln(EC_{t-1}) \\ &+ \sum_{i=1}^{n} \propto_{5i} \Delta\ln(EG_{t-1}) + \gamma ECT_{t-1} + \mu_{1t}\end{aligned} \tag{10}$$

$$\begin{aligned}\Delta\ln(GDP_t) = \propto_0 &+ \sum_{i=1}^{n} \propto_{1i} \Delta\ln(EVD_{t-1}) + \sum_{i=1}^{n} \propto_{2i} \Delta\ln(LPI_{t-1}) \\ &+ \sum_{i=1}^{n} \propto_{3i} \Delta\ln(CPI_{t-1}) + \sum_{i=1}^{n} \propto_{4i} \Delta\ln(EC_{t-1}) \\ &+ \sum_{i=1}^{n} \propto_{5i} \Delta\ln(EG_{t-1}) + \gamma ECT_{t-1} + \mu_{1t}\end{aligned} \tag{11}$$

where $\propto_{1i}, \propto_{2i}, \propto_{3i}, \propto_{4i}$, and $\propto_{5i}$ represent the short-term coefficients, γ is the speed of adjustment.

Giving that we found no evidence of cointegration among variables in Equation 2 to 5 and although the lagged ECT has been included in Equation 7 to 11, we only proceed to estimate Equation 7 by way of OLS (Odhiambo, 2009). Testing for the Granger causality between the variables in Equation 7 requires that we examine the significance level of the lagged ECT and the joint significance of the lagged differences of the explanatory variables using *F*-statistic (Belloumi, 2014; Odhiambo, 2009). The results are presented in Table 7 and 8.

Table 7

ARDL model based on the SBIC criterion

Variables	Coefficient	*t*-statistic
Constant	0.0435	1.53
lagged Error Correction (ECM-1)	–1.4043***	–9.14
Δln*LPI*	0.4065	0.59
Δln*CPI*	0.0454	0.25
Δln*EC*	0.8698**	2.72
Δln*EG*	0.2698**	2.43
F-statistic	3.23***	
R-squared	0.7976	
Durbin-Watson Statistic	1.9807	

Source: Authors' computations

From Table 7 it is evident that long-run Granger causality runs from the livestock production index, crop production index, agricultural energy consumption, and economic growth to environmental degradation at 1% level of significance, which is supported by the coefficient of the lagged error (ECT) term, which has a negative sign. The negative sign is a clear indication that there is going to be a long run convergence among the variables and an indication that previous errors will be corrected in the current period.

Table 8

Diagnostic tests

Tests	Chi-square	Probability	Decision
Bruesch-Godfrey Serial correlation	0.129	0.9375	Serial correlation
Jarque-Bera	2.041	.3605	Normality
White Heteroskedasticity	42.00	0.4274	Homoskedastic

Source: Authors' computations

The short-run Granger causality result in Table 9 clearly shows evidence of a unidirectional causality between the livestock production index and environmental degradation at 1% significance level and between the crop production index and economic growth at 5% level of significance. The result also shows evidence of a bi-directional Granger causality between economic growth and environmental degradation, between the crop production index and environmental degradation and between economic growth and energy consumption. The short-run causality of the livestock production index and crop production index on environmental degradation can be attributed to the fact that agricultural sector in Ghana is a major source of income and livelihood for more than a half of the Ghanaian population (Ghana Statistical Service (GSS, 2014)), who heavily rely on unsustainable agriculture to increase productivity. This also could be linked to the increasing demand for fossil fuels and the continuous application of inorganic fertilizers. The focus on industrialization in the recent past could account for the causal relationship between economic growth and environmental degradation.

We subjected our model to some diagnostic tests to ascertain its fitness against heteroskedasticity, serial correlation and the normality test. Test results presented in Table 8 indicate that the null hypothesis of no serial correlation is rejected in favour of the alternate. In the Jarque-Bera test for normality, we fail to reject the null hypothesis of normality. The White heteroskedasticity test also gives evidence of homoskedasticity.

Conclusion

The purpose of this study was to investigate the exact source of the causal relationship between agriculture production, economic growth, energy consumption and environmental degradation in Ghana from 1971 to 2014. The study employed the autoregression distributed lag (ARDL) model to examine whether there was evidence of a long-run relationship among the variables under study as well the direction of causality using the Granger causality test. Although a number of studies examined the causal relationship among environmental degradation, economic growth, and energy consumption in developing economies in the past, very few have focused on African economies. In Ghana, few studies have investigated economic growth and carbon dioxide emissions ne-xus using the Ordinary Least square (OLS) while also testing for evidence of the environmental Kuznet curve relationship between variables. In light of this and to the best of our knowledge, we believe that this study is the first of its kind to

Table 9

Granger causality Test

Dependent variables	*F*-statistics					
	Δln*EVD*	Δln*LPI*	Δln*CPI*	Δln*EC*	Δln*EG*	Causality
ΔlnEVD		7.580***	22.307***	3.688*	0.143	*LPI* → *EVD*; *CPI* → *EVD*; *EC* → *EVD*
ΔlnLPI	1.896		1.049	0.549	1.779	
ΔlnCPI	6.424**	0.812		1.322	1.595	*EVD* → *CPI*
ΔlnEC	7.374***	0.287	4.055**		4.054**	*EVD* → *EC*; *CPI* → *EC*; *EG* → *EC*
ΔlnEG	0.325	0.062	0.057	10.469***		*EC* → *EG*

Note: *** and ** denote the 1% and 5% level of significance respectively.

Source: Authors' computations

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be conducted in Ghana to investigate the variables by using the ARDL model. The fact that agricultural productivity was segregated into the crop and livestock production index allowed us to examine the source of environmental degradation in the sector while also helping us estimate the direction of causality. Findings from the ARDL bounds test of cointegration give evidence of cointegration among the variables when environmental degradation is made the dependent variable. This is an indication that there is a distinctive causal nexus among the variables both in the short and long-run. Findings from the Granger causality test also indicate that both the livestock production index and crop production index cause environmental degradation both in the long and short run. It is therefore imperative for policies makers to prioritize the adoption of environmentally friendly technologies both in the crop and livestock sub-sectors to ensure that while the food needs of citizens are met, environmental quality is not compromised. Given that the study found a positive relationship between economic growth and environmental degradation, it is important to ensure energy use efficiency in production. We believe that Ghana should start to explore the full potential of switching to solar energy since it is an excellent source of renewable energy.

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