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Article

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Research paper

Industrial growth and emissions of CO₂ in Ghana: The role of financial development and fossil fuel consumption



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ABSTRACT

The rapid rise in greenhouse gas emissions have become a global concern catching the attention of policy makers and researchers all over the world. Fossil fuel combustion has been named as the major source of greenhouse gas emissions, meanwhile, studies focusing on fossil fuel impact on CO₂ emissions are rare for developing countries including Ghana. This study employed the ARDL procedure with structural breaks and the Bayer–Hanck joint cointegration approach to examine the validity of the EKC hypothesis in the dynamic linkage between industrial growth and emissions of carbon dioxide (CO₂) in Ghana, capturing the role of fossil fuel consumption and financial development. The variables are found to be cointegrated and both the short-run and the long-run parameters showed evidence of a U-shaped relationship between industrial growth and CO₂ emissions which was further confirmed by the Lind and Mehlum U-test. The short-run causality revealed a uni-directional causality running from fossil fuel consumption to emissions of CO₂. For policy purposes, the study advocates for efficient and low carbon emission technologies.

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1. Introduction

Climate change and environmental degradation are two (2) of the key development-related challenges in the course to achieve sustainable global output growth (United Nations, 2016). The need to safeguard environmental quality has therefore taken the center stage in both national and international development discourse in the last three decades in the quest to promote sustainable development globally (United Nations, 2013). Global warming and air pollution have been identified as some of the key causes of climate change; and CO₂ emissions have been generally considered in literature as a significant contributor to these problems (Ali et al., 2016). Stocker et al. (2013) reported that CO₂ emissions is a key contributing factor to the high emissions of green-house gases (GHG) globally. The report further emphasized that 76.7% of GHG emissions emanate from emissions of CO₂ mainly coming from developing countries such as Ghana in the effort to accelerate economic growth and increase income levels with little or no recourse to environmental provisions.

Several attempts have been made through international conventions and intergovernmental agreements to minimize the destructive effects of global warming by advocating for the reduction of global emissions by both developed and developing countries. Notable among these international environmental agreements are the Paris convention (2015) and the Kyoto protocol, which was adopted in 1997 under the United Nations Framework Convention on Climate Change (UNFCCC) with the underpinning aim of reducing GHG concentration in the atmosphere in order to minimize the pace of climate change (Ali et al., 2016). Ghana is a signatory to the climate change convention (2015) and has also ratified the Kyoto Protocol aimed at minimizing climate change and promoting sustainable development globally. In this regard, the Environmental Protection Agency (EPA), acting on behalf of the government developed a national climate change policy in 2012 to mitigate climate change through the promotion of sustainable smart investments in all sectors of Ghana's economy. Nonetheless, environmental pollution and degradation of the environment is very rampant and continues to pose a big challenge to the sustainable development of the country. CO₂ emissions in Ghana increased by close to 100% from 12.2Mt to 23.9Mt between 2000 and 2010 (Twerefou et al., 2015).

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List of abbreviations

| | |
|-------|---|
| ADF | Augmented Dickey–Fuller |
| ARDL | Autoregressive distributed lag |
| ECT | Error Correction Term |
| EKC | Environmental Kuznets Curve |
| EPA | Environmental protection agency |
| FDI | Foreign direct investment |
| GFEVD | Generalized forecast error variance decomposition |
| GHG | Greenhouse gas |
| OLS | Ordinary least squares |
| PP | Phillips Perron |
| SIC | Schwarz information criterion |
| VECM | Vector error correction model |
| WDI | World Development Indicators |

Fossil fuels supply more than 87% of the energy used globally (Lyman, 2016). In Ghana, petroleum and other fossil fuels are the main sources of energy in the transport industry and also in electric power generation.

The diagram in Fig. 2 shows that the consumption of fossil fuel is becoming increasingly important than the other types of energy in Ghana. Fossil fuel consumption which accounted for 22% of total energy in 1971 increased significantly to 52% of total energy consumption in 2014 as shown in Fig. 1. Beginning 2009, fossil fuel consumption has taken the first position in Ghana's energy consumption mix and continue to rise while the consumption of other types of energy (Alternative and nuclear energy & Combustible renewables and waste) decline on the average (WDI, 2017).

Ghana is acclaimed as one of the fast-growing economies in Sub-Saharan Africa, having achieved an annual average GDP growth rate of above 5% in the last three decades (IMF, 2016). Consistent with the sustained output growth, Ghana's industrial sector has expanded tremendously and accounted for 23.68% of the country's GDP in 2017 (GSS, 2018). A point worth noting is the fact that, an important catalyst required to catapult the rising output levels and to sustain the continuous expansion of the industrial sector is energy. In 2011, Ghana's oil import bill comprising of crude oil and other petroleum products rose significantly by about 50% from its 2010 level to catapult the historical growth rate of 15% the country achieved (CEPA, 2012). Expanding industrial output, which thrives on fossil fuel consumption to power industrial machines and reduced carbon sink resulting from forest depletion have been touted as key contributing factors to the persistent rise in CO₂ emission levels in Ghana from 3817.35kt in 1990 to 14466.32kt in 2014 (WDI, 2017).

Grossman and Krueger (1995) assert that there exists an inverted U-shape relationship between growth in income and environmental degradation. In the literature, this relationship has been termed the Environmental Kuznets Curve (EKC) hypothesis. The fundamental principle of the EKC is that as an economy expands, the benefits of increasing output are so large at the early stages of the growth process such that they dominate the increased demands for environmental quality caused by a rising income and thus, increase in output comes with more environmental degradation. A number of theoretical explanations have been advanced to rationalize the EKC hypothesis. Israel and Levinson (2004, p.2) assert that 'the inverted U-shaped pollution-income path reflects the natural progression of economic development from clean agrarian economies to dirty industrial economies to clean service economies'. Gangadharan and Valenzuela (2001)

point out that clean environment is a typical example of luxurious goods, whose demand rises only after individuals or a country have achieved economic prosperity to a level where they no longer have economic struggles. In line with this idea, Inglehart (1997) in his post-materialism hypothesis also postulate that people pay attention to post materialist values such as environmental quality only after becoming sufficiently affluent to the point that they have no serious material needs. On this premise, Bruneau and Echevarria (2009) argue that the demand for environmental improvement would be low in developing countries with low levels of income, because the poor are 'too poor to green'. The Pollution Haven Hypothesis also asserts that governments in most developing nations are hesitant to place strict environmental standards on their firms in order to boost the competitiveness of local firms in the global market (Busse, 2004). The Environmental Kuznets Curve and the Pollution Haven Hypothesis are the basis for the assertion in the literature that, increased output to meet the needs of high and rising human population (which requires high consumption of fossil fuels) will most likely lead to high emissions of GHGs such as CO₂ and general environmental degradation in a developing country such as Ghana, where environmental regulations are usually not strictly enforced (Antweiler et al., 2001).

In the literature, available studies on the EKC have mostly focused on the nexus between energy consumption in general and CO₂ emissions (Sarkodie and Strezov, 2018; Aboagye, 2017; Asumadu-Sarkodie and Owusu, 2016; Twerefou et al., 2016; Begum et al., 2015; Gökmenoğlu and Taspınar, 2015; Kwakwa et al., 2014; Omisakin, 2009). Bilgili et al. (2016) uses a panel data set of 17 OECD countries from 1977–2010, employing the panel FMOLS and panel DOLS estimation techniques to analyze the validity of the EKC hypothesis focusing on renewable energy consumption and environmental quality nexus. The findings of their study give credence to the EKC hypothesis for the countries studied and indicate that the validity of EKC is not dependent on the levels of income of the sample countries. This paper is similar to the present study in the use of CO₂ emissions as dependent variable. The key point of divergence between this paper and the present study has to do with the independent variables employed. While they use renewable energy, the present study uses fossil fuels (non-renewable energy) as the key dependent variable of interest. Sarkodie and Strezov (2018, 2019) examines the Environmental Sustainability and the Environmental Kuznets curve hypotheses for Australia, China, Ghana and the USA for the period 1971–2013. The study reveals that the consumption of electric power is the main factor that determines energy intensity in the countries studied. The authors argue that enhancing energy efficiency in Ghana and the other selected countries will enhance energy security and minimize the adverse impacts of economic activities on the environment. Koçak and Şarkgüneşi (2018a) uses the EKC model to analyze the potential effect of FDI on CO₂ emission in Turkey from 1974–2013. The authors report that there exists a long-run nexus between FDI, economic growth, energy usage, and CO₂ emission. Increase in FDI inflows thus lead to a rise in CO₂ emissions in Turkey. More so, the results of this study points to the prevalence of the EKC hypothesis in Turkey. The main difference between this study and the current study is the use of different independent variables in the estimation. Whereas the authors use economic growth as the key independent variable to test for the validity of the EKC, we use industrial growth as a proxy for income growth in the present study.

In a recent study, Sarkodie and Strezov (2019) employs the traditional review method to undertake a systematic review of the EKC hypothesis by tracking the historical trends of findings in relation to the EKC hypothesis. The authors report that among the studies that support the EKC hypothesis, the turning point of

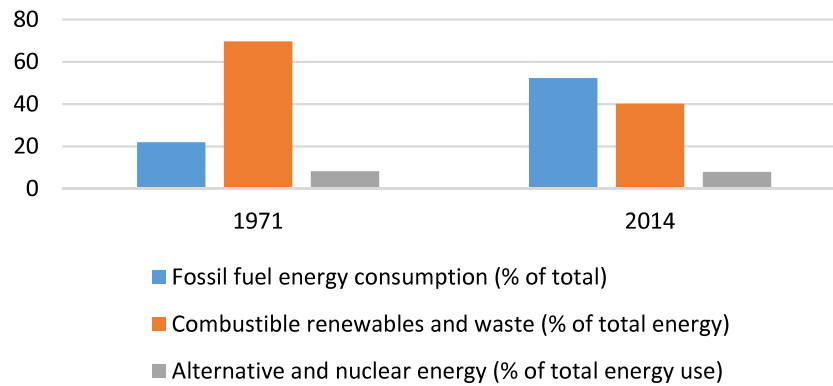


Fig. 1. Energy consumption.
Source: Data Source: WDI (2017).

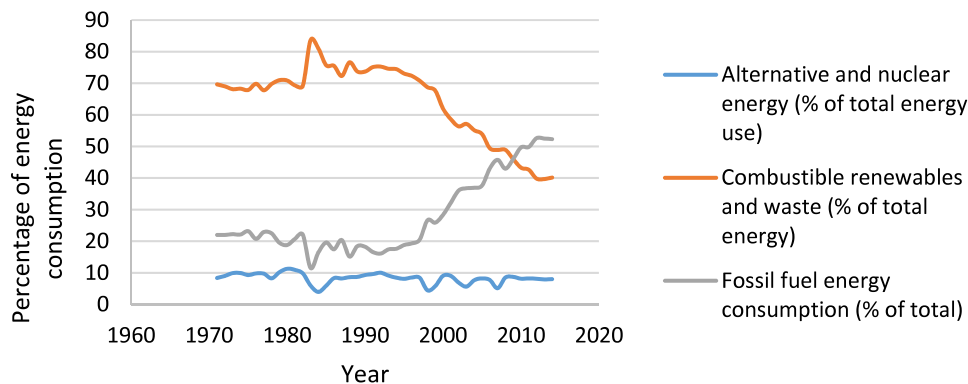


Fig. 2. Energy consumption.
Source: Data Source: WDI (2017).

average annual income level is US\$8910. This finding implies that a developing country like Ghana with an average income level far below the reported turning point is likely to experience increased environmental degradation with increased growth. The present study is different from the study by Sarkodie and Strezov (2019) in its use of empirical data to test the EKC hypothesis rather than undertaking a review of past studies. In another related study, Asumadu-Sarkodie and Owusu (2016) employs the VECM and the ARDL models to analyze the empirical nexus between CO₂ emissions, GDP, energy use, and population growth in Ghana from 1971 to 2013. The authors performed Johansen's multivariate co-integration and a variance decomposition analysis using Cholesky's technique before testing for Granger causality based on VECM. The variance decomposition revealed that 21% of future shocks in CO₂ emissions are caused by fluctuations in energy use, 8% result from fluctuations in GDP, and 6% of shocks result from fluctuations in population. The authors further report the existence of bidirectional causality from energy use to GDP and a unidirectional causality from carbon dioxide emissions to energy use, carbon dioxide emissions to GDP both in the long-run and short-run. Adom et al. (2012) investigates both the short-run and long-run nexus among CO₂ emissions, GDP growth, technical efficiency, and industrial structure for Ghana, Senegal and Morocco. Their bounds test cointegration results point to the existence of a multiple long-run equilibrium nexus in the case of Ghana and Senegal but a one-way long-run equilibrium relationship in the case of Morocco. More so, the variance decomposition analysis show that economic growth significantly contributes to variations in CO₂ emissions in Senegal and Morocco whereas in the case of Ghana, technical efficiency account for a greater part of the

future variations in CO₂ emissions. Kwakwa and Alhassan (2018) analyzes the impact of urbanization and energy consumption on CO₂ emissions in Ghana in the framework of the EKC model using data for the period 1971–2013. Estimation with the FMOL affirm the existence of the EKC hypothesis in Ghana. The results further show that production of electricity from fossil fuels, industrialization and urbanization result in a rise in CO₂ emissions in Ghana.

A number of both theoretical and empirical studies in the literature have analyzed the effect of financial development on the quality of the natural environment. Frankel and Romer (1999) theorized that financial sector development enhances growth in output. Birdsall and Wheeler (1993) assert that financial sector development usually precedes the adoption of improved and environmentally-friendly technology through increased supply of financial credit to purchase such technology. On the other hand, Islam et al. (2013) argue that the development of the financial sector could enhance the level of energy consumption in an economy, and as a result lead to a rise in GHG emissions such as CO₂ especially in countries where fossil fuels are used in energy production. Financial sector development attracts FDI and advanced technology that have minimal adverse impact on the environment (Ali et al., 2016). Hence the development of a country's financial sector is expected to cause a reduction in the emissions of GHGs such as CO₂ through the use of environmentally-friendly technology. From the foregoing, development of the financial sector could have a favorable or adverse effect on the environment. In theory, financial development impacts the environment via technology, income, improved regulations as well as capitalization (Yuxiang and Chen, 2011). Using econometric techniques

and employing a provincial panel data from China, [Yuxiang and Chen \(2011\)](#) report that there is an empirical linkage between financial sector development and industrial pollution discharges. The authors observe that financial development has led to a significant improvement in environmental performance of China in recent times. [Jalil and Feridun \(2011\)](#) uses time series data from 1953 to 2006 on China and the ARDL bounds testing technique to analyze the long-run relationship between financial development and environmental pollution. The results of the analysis point to fact that financial development has resulted in a decline in environmental pollution in China. The authors conclude that CO₂ emissions in China in the long term are caused mainly by GDP growth, increased consumption of energy and increased trade openness. More so, their findings give credence to the validity of the Environmental Kuznets Curve in China. [Zhang \(2011\)](#) uses data from China and econometric techniques (cointegration theory, Granger causality test, variance decomposition, etc.), to examine the effect of financial sector development on CO₂ emissions. The authors report that financial development is a crucial driver for high CO₂ emissions. Their results further show that, FDI has the least influence on variations of carbon emissions among the list of financial development indicators in China owing to its relatively smaller volume in relation to GDP

Ghana has seen a drastic development in its financial sector since adopting financial sector deregulation as part of the Structural Adjustment Program (SAP) in 1986 and the establishment of the Ghana Stock Exchange in 1989. The number of commercial banks currently stands at about 25 alongside a large number of savings and loans and microfinance institutions. The number of companies listed on the Ghana stock exchange rose significantly from 11 in 1994 to more than 40 in 2016 with market capitalization of GHc56,120.08 as at 7th July, 2018 ([GSE, 2018](#)). In response to the development of the country's financial sector, net FDI inflows increased significantly from \$15.6million in 1980 to \$3,485.333 million in 2016 ([GIPC, 2017](#)). There is a general consensus in the literature that, financial sector development as witnessed in Ghana in the last three decades facilitates domestic investment, minimizes financial risk as well as enhances the capital accumulation process; and thereby attract more FDI inflows and modern environmentally-friendly technologies which help to minimize environmental pollution.

From the forgoing, understanding the dynamic relationships between fossil fuel consumption, industrial growth, financial development and CO₂ emissions in a developing country such as Ghana is of great importance for policy-makers. Based on the review of the earlier studies relating to output growth and the environment within the framework of the EKC hypothesis, this study is the first of its kind covering the relationship between fossil fuel consumption, industrial output growth, financial sector development and CO₂ emissions in Ghana. The proposed study is unique in its focus on fossil fuel consumption which is a principal source of carbon dioxide emissions globally as noted by [US EPA \(2016\)](#) instead of energy in general as used by most of the previous studies on Ghana ([Sarkodie and Strezov, 2018](#); [Aboagye, 2017](#); [Asumadu-Sarkodie and Owusu, 2016](#); [Twerefou et al., 2016](#); [Kwakwa et al., 2014](#)) with the exception of [Kwakwa and Alhassan \(2018\)](#) who also used fossil fuel in their study. However, instead of Fully Modified OLS used in [Kwakwa and Alhassan \(2018\)](#), we employed the ARDL technique which produces more efficient results in small samples. Another uniqueness of the paper lies in the method of analysis employed, making provision for structural breaks in the time series variables, contrary to previous studies on Ghana. The study used two cointegration techniques to ascertain the robustness of the long-run nexus among the variables. These techniques include the [Bayer and Hanck \(2013\)](#) joint cointegration approach and the ARDL cointegration approach in

the presence of structural breaks. Unlike [Asumadu-Sarkodie and Owusu \(2016\)](#), the study goes further to test for the validity of the environmental Kuznets curve hypothesis in the case of Ghana. While the previous studies mostly relied on only the necessary condition to verify the EKC hypothesis, a procedure which has been described as “flawed” by [Lind and Mehlum \(2010\)](#), the present study conducted the [Lind and Mehlum \(2010\)](#) U-test which provides both the necessary and sufficient conditions for the existence of a U-shaped or inverted U-shaped relationship. In order to check the robustness of the causal relationships among the variables, the study conducted both the error correction term (ECT) augmented Granger-causality test and the generalized forecast variance decomposition. Finally, the focus on the nexus between development of the financial sector and environmental pollution is one more interesting dimension of this study. Thus, in a more specific terms, the proposed study makes the following five contributions to literature. First, we examine the role of financial development and fossil fuel consumption in the industrial growth–CO₂ emissions nexus within the framework of the EKC hypothesis for Ghana. Second, the method of analysis employed makes provision for structural breaks in the variables as shown in the ARDL approach applied in the presence of structural breaks. Third, the EKC hypothesis is tested on industrial growth and CO₂ emissions. Fourth, the sufficient condition for the existence of a U-shaped relationship between industrial growth and CO₂ emissions is checked via the Lind and Mehlum U-test. Finally, the causal relationships between the variables are ascertained by conducting both the ECT augmented Granger-causality test and the generalized forecast variance decomposition to check the robustness of the causal relationships between the variables.

The remaining part of the study has been structured as follows: section two is used to describe the data and the econometric methodology to be employed in the study. In section three, we present and discuss the empirical results. Section four will cover conclusions and policy implications emanating from the findings.

2. Data source and methodology

2.1. Data and model specification

This study used annual time series data covering the period 1971–2014 from [WDI \(2017\)](#) version. This period was used since data on emissions of CO₂ in Ghana was available for only the period under study. Data was collected on variables of interest such as CO₂ emissions (metric tons per capita), Fossil fuel energy consumption (% of total) and transformed to fossil fuel as a ratio of total energy, Domestic credit provided by financial sector (% of GDP) and transformed into domestic credit provided by financial sector as a ratio of GDP (used to proxy financial development). Data was also collected on Industry value added (current LCU) due to missing values on the real versions of Industry value added in WDI. The Industry value added (current LCU) was transformed into industrial sector real value added using 2010 base year CPI.

In this study, the relationship between financial development, industrial growth, fossil fuel consumption and carbon dioxide emission in Ghana was examined. In Ghana, fossil fuel consumption alone accounts for more than half of the total energy consumption. Fossil fuel consumption as a percentage of total energy consumed rose from around 22% in 1971 to about 52% in 2017 ([WDI, 2017](#)). Meanwhile, according to [US EPA \(2016\)](#), fossil fuel consumption is the primary source of emissions of CO₂ globally. The impact of Fossil fuel consumption on emissions of CO₂ is also supported empirically ([Kwakwa and Alhassan, 2018](#); [Nnaji et al., 2013](#)). On financial development and CO₂ emissions, a study by [Yuxiang and Chen \(2011\)](#) for China found that there exists a

linkage between financial development and industrial pollution. Financial development has been shown in some studies to impact CO2 emissions positively while others showed negative relationship (Ali et al., 2016; Başarir and Çakir, 2015; Zhang, 2011; Jalil and Feridun, 2011). This is due to the fact that, it can either lead to the adoption of energy efficient technologies or encourage increased consumption of energy. Financial development may increase the allocation of financial resources to domestic firms, making them able to purchase technologies which are friendly to the environment. Financial development can also lead to degradation of the environment. When financial resources are allocated to domestic firms, they are able to increase their scale of production which may also raise the demand for certain types of energy which are not environmentally friendly.

Generally, the activities of the industrial sector impact environmental degradation especially in developing countries where output increases and decreases with environmental pollution due to the inefficient technologies used. The impact of industrialization on CO2 emissions is also recorded in literature (Kwakwa and Alhassan, 2018; Shahbaz et al., 2014).

The proposed study derives the empirical model from the constant returns to scale Cobb–Douglas production function written as follows:

$$Y_t = f(A_t, K_t, L_t) \quad (1)$$

where Y is GDP, A is technology, K is capital and L is labor.

In theory, economic activities are the major causes of environmental degradation, therefore CO2 emissions (CE) is written as a function of economic activities (proxied by GDP) as follows:

$$CE_t = Y_t = f(A_t, K_t, L_t) \quad (2)$$

Advancement in technology can be achieved through research and development and the latter is aided by financial development. Therefore, technology is replaced with financial development (FD) as done in Ali et al. (2016). The use of capital in production can be put into two categories, namely, polluting capital and non-polluting capital. Where polluting capital is the one that emits CO2 in production while non-emitting capital does not emit CO2. Examples of emitting capital include burning of coal and gas (fossil fuels) in production. Therefore, total capital used in production is written as follows:

$$K_t = K_{em} + K_{ne} \quad (3)$$

where K_{em} is the emitting capital and K_{ne} is the non-emitting capital. Thus, the environmental degradation arising from the use of capital in production emanates from the polluting capital. Therefore, we replace capital in Eq. (2) with fossil fuel (emitting capital) similar to Ali et al. (2016) and Begum et al. (2015) where emitting capital was replaced with energy consumption for Malaysia. Next, since labor activities can be considered as economic activities but the proposed study focuses on industrial growth, we replaced labor with industrial output (I) similar to Ali et al. (2016) who replaced labor with GDP. From the foregoing, our CO2 emissions function is stated as:

$$CE_t = Y_t = f(FD_t, F_t, I_t) \quad (4)$$

In order to make interpretation easier by obtaining elasticity values, we applied natural logarithm to transform the variables to their natural log forms. Eq. (4) is written as follows:

$$\ln CE_t = \alpha_0 + \alpha_1 \ln F_t + \alpha_2 \ln I_t + \alpha_3 \ln FD_t + u_t \quad (5)$$

where $\ln CE$ is the emissions of CO2 (in metric tons per capita) expressed in natural log, $\ln F$ is fossil fuel energy consumption as a ratio of total energy expressed in natural log, $\ln FD$ is the ratio of domestic credit by financial sector to GDP in natural log, a proxy

for financial development. $\ln I$ is the natural log of real industrial value added (a proxy for industrial growth), α_0 is the intercept and u_t is the disturbance term.

The EKC hypothesis which describes an inverted U-shaped relationship between environmental quality and economic development was introduced and made popular by the writings of Grossman and Krueger (1991) and the World Bank Report (Shafik and Bandyopadhyay, 1992; World Bank, 1992). Following Grossman and Krueger (1995), we tested the EKC hypothesis on CO2 emissions and industrial growth for Ghana by including the squared term of the natural log of real industrial value added $(\ln I)^2$ in the regression as shown below:

$$\ln CE_t = \alpha_0 + \alpha_1 \ln F_t + \alpha_2 \ln I_t + \alpha_3 (\ln I_t)^2 + \alpha_4 \ln FD_t + u_t \quad (6)$$

The expected sign of α_1 is positive since increase in fossil fuel consumption leads to a rise in emissions of CO2. From existing literature, α_4 can be either positive or negative because if increased credit to the private sector results in expansion and increased output of the industrial sector without change in technology, there will be more pollution. On the other hand, if the increased credit to the private sector leads to the adoption of improved and energy efficient technologies, pollution or CO2 emissions may reduce. Given the non-linear relationship between CO2 emissions and industrial growth in Eq. (1), α_2 has been suggested in literature to be either negative or positive depending on whether the relationship is U-shape or inverted U-shape. Provided there exists a U-shaped non-linear relationship between carbon and industrial growth, α_2 is expected to be negative and α_3 positive. In case of inverted U-shaped relationship, α_2 is positive and α_3 is negative. Thus, if the EKC holds (the case of the inverted U-shape), then $\alpha_2 > 0$ and $\alpha_3 < 0$. If instead of the EKC hypothesis, we have a U-shape, then $\alpha_2 < 0$ and $\alpha_3 > 0$. In each case, α_2 and α_3 must be statistically significant. If these conditions hold, then a turning point will exist for the U-shaped or inverted U-shaped relationship between carbon dioxide and industrial growth. By taking the first derivative of the natural logarithm of CO2 emissions ($\ln CE$) with respect to the natural logarithm of industrial growth ($\ln I$) and setting it to zero we are able to obtain the turning point when we solve for $\ln I$. This gives:

$$\ln I^* = \frac{-\alpha_2}{2\alpha_3} \quad (7)$$

If the EKC hypothesis holds, then this turning point implies that at the initial growth stages, pollution increases but at a diminishing rate up to a threshold beyond which further growth leads to improvement in the environment. In case of a U-shaped relationship, the reverse is expected, where the environment improves in the initial stages of growth up to a turning point or threshold and then begins to deteriorate beyond this point for any further attained growth. While the EKC hypothesis augers well for sustainable development assumptions, the U-shaped relationship does not favor these assumptions as high growth and development also translates into increased pollution to the environment.

This study examines the EKC assumptions for Ghana both in the long-run and short-run using econometric techniques outlined. However, it must be stated that the ARDL short-run and long-run results only provide the necessary conditions for the existence of a U-shaped or inverted U-shaped relationship between carbon dioxide emission and industrial growth as implied by Lind and Mehlum (2010). To confirm the existence of a U-shaped or inverted U-shaped relationship between industrial growth and CO2 emissions, the study goes further to conduct the Lind and Mehlum (2010) test for a U-shape or inverted U-shape.

2.2. Bayer–Hanck combined approach to cointegration

The unit root properties of the variables were determined by employing both the Augmented Dickey–Fuller (ADF) and the Phillips Perron (PP) tests before proceeding to check for long-run cointegration relationship. However, these traditional unit root testing procedures are not appropriate in the presence of structural break since the break in the series is interpreted as unit root by these conventional unit root tests. In view of this, the study employed the Zivot and Andrews (2002) approach to test for unit root in the presence of structural break.

There exist many cointegration approaches in literature employed to examine long-run relationship among variables which are $I(1)$. One of these popular cointegration techniques extensively used in literature is Engle and Granger (1987). Later, Johansen (1991) cointegration approach which was more appropriate and preferred was introduced. Other popular cointegration tests include Phillips and Ouliaris (1990) cointegration test, Boswijk (1994) Structural Error Correction Model (ECM) and then Banerjee et al. (1998) t-test cointegration approach. Despite the popularity and extensive use of these cointegration techniques, they have come under severe criticisms. The explanatory power properties of these traditional cointegration techniques could lead to ambiguous empirical results (Shahbaz et al., 2018). A combined cointegration approach was later developed by Bayer and Hanck (2013) in order to overcome the weakness of these cointegration techniques which tends to cause bias in empirical results rendering it unreliable. In this newly developed cointegration technique, Bayer and Hanck used a combined cointegration approach where the results of Engle and Granger (1987), Johansen (1991), Boswijk (1994) and Banerjee et al. (1998) were combined to increase the power of the test. To employ this newly developed combined cointegration, variables must be $I(1)$. This technique produces the Fisher F-statistics which are compared with the critical values in order to make a more accurate and reliable decision of the cointegration status of the variables. The null hypothesis which suggests no cointegration is rejected if the computed F-statistic is greater than the critical value. The null is not rejected if the reverse is true. The Fisher's formulae was employed by Bayer and Hanck (2013) to provide a combined p-values for the four cointegration tests in the equations below. Many studies in literature (Saint Akadiri et al., 2019; Shahbaz et al., 2015a,b; Rafindadi, 2015; Farhani et al., 2014) also employed the Bayer and Hanck (2013) combined cointegration in investigating the long-run relationship between variables. The proposed study employs the joint Bayer and Hanck cointegration approach due to its superiority over the traditional cointegration techniques.

$$EG - JOH = -2[\ln(P_{EG}) + \ln(P_{JOH})] \tag{8}$$

$$EG - JOH - BO - BDM = -2\ln[(P_{EG}) + (P_{JOH}) + (P_{BO}) + (P_{BDM})] \tag{9}$$

where P_{EG} is the p -value of Engle and Granger (1987), P_{JOH} is the p -value of Johansen (1991), P_{BO} is the p -value of Boswijk (1994) and P_{BDM} is the p -value of Banerjee et al. (1998). Depending on the value of the Fisher F-statistic, long-run cointegration relationship will exist if the computed F-statistic is greater than the critical value and no long-run cointegration relationship if computed F-statistic is less than the critical value.

2.3. ARDL approach to cointegration

In order to check the robustness of the cointegration result, the study employed the ARDL bound test cointegration approach in the presence of structural break to find the long-run relationship among the variables. This approach was chosen over the

traditional cointegration techniques because it produces efficient and consistent result for small sample data. It is also appropriate for a mixture of $I(0)$ and $I(1)$ variables or mutually cointegrated variables. The unrestricted error correction model is stated as follows:

$$\begin{aligned} \Delta \ln CE_t &= \delta_1 + D_{CE} + \gamma_1 \ln CE_{t-1} + \gamma_2 \ln F_{t-1} + \gamma_3 \ln I_{t-1} \\ &+ \gamma_4(\ln I_{t-1})^2 + \gamma_5 \ln FD_{t-1} \\ &+ \sum_{i=1}^n \lambda_{1i} \Delta \ln CE_{t-i} + \sum_{i=0}^n \lambda_{2i} \Delta \ln F_{t-i} + \sum_{i=0}^n \lambda_{3i} \Delta \ln I_{t-i} \\ &+ \sum_{i=0}^n \lambda_{4i} \Delta(\ln I_{t-i})^2 \\ &+ \sum_{i=0}^n \lambda_{5i} \Delta \ln FD_{t-i} + \varepsilon_{1t} \end{aligned} \tag{10}$$

$$\begin{aligned} \Delta \ln F_t &= \delta_2 + D_{FOS} + \gamma_6 \ln CE_{t-1} + \gamma_7 \ln F_{t-1} + \gamma_8 \ln I_{t-1} \\ &+ \gamma_9(\ln I_{t-1})^2 + \gamma_{10} \ln FD_{t-1} \\ &+ \sum_{i=0}^n \lambda_{6i} \Delta \ln CE_{t-i} + \sum_{i=1}^n \lambda_{7i} \Delta \ln F_{t-i} + \sum_{i=0}^n \lambda_{8i} \Delta \ln I_{t-i} \\ &+ \sum_{i=0}^n \lambda_{9i} \Delta(\ln I_{t-i})^2 \\ &+ \sum_{i=0}^n \lambda_{10i} \Delta \ln FD_{t-i} + \varepsilon_{2t} \end{aligned} \tag{11}$$

$$\begin{aligned} \Delta \ln I_t &= \delta_3 + D_{IND} + \gamma_{11} \ln CE_{t-1} + \gamma_{12} \ln F_{t-1} + \gamma_{13} \ln I_{t-1} \\ &+ \gamma_{14}(\ln I_{t-1})^2 + \gamma_{15} \ln FD_{t-1} \\ &+ \sum_{i=0}^n \lambda_{11i} \Delta \ln CE_{t-i} + \sum_{i=0}^n \lambda_{12i} \Delta \ln F_{t-i} + \sum_{i=1}^n \lambda_{13i} \Delta \ln I_{t-i} \\ &+ \sum_{i=0}^n \lambda_{14i} \Delta(\ln I_{t-i})^2 \\ &+ \sum_{i=0}^n \lambda_{15i} \Delta \ln FD_{t-i} + \varepsilon_{3t} \end{aligned} \tag{12}$$

$$\begin{aligned} \Delta(\ln I_t)^2 &= \delta_4 + D_{INDSQ} + \gamma_{16} \ln CE_{t-1} + \gamma_{17} \ln F_{t-1} + \gamma_{18} \ln I_{t-1} \\ &+ \gamma_{19}(\ln I_{t-1})^2 + \gamma_{20} \ln FD_{t-1} \\ &+ \sum_{i=0}^n \lambda_{16i} \Delta \ln CE_{t-i} + \sum_{i=0}^n \lambda_{17i} \Delta \ln F_{t-i} + \sum_{i=0}^n \lambda_{18i} \Delta \ln I_{t-i} \\ &+ \sum_{i=1}^n \lambda_{19i} \Delta(\ln I_{t-i})^2 \\ &+ \sum_{i=0}^n \lambda_{20i} \Delta \ln FD_{t-i} + \varepsilon_{4t} \end{aligned} \tag{13}$$

$$\begin{aligned} \Delta \ln FD_t &= \delta_5 + D_{FDT} + \gamma_{21} \ln CE_{t-1} + \gamma_{22} \ln F_{t-1} + \gamma_{23} \ln I_{t-1} \\ &+ \gamma_{24}(\ln I_{t-1})^2 + \gamma_{25} \ln FD_{t-1} \\ &+ \sum_{i=0}^n \lambda_{21i} \Delta \ln CE_{t-i} + \sum_{i=0}^n \lambda_{22i} \Delta \ln F_{t-i} + \sum_{i=0}^n \lambda_{23i} \Delta \ln I_{t-i} \\ &+ \sum_{i=0}^n \lambda_{24i} \Delta(\ln I_{t-i})^2 \end{aligned}$$

$$+ \sum_{i=0}^n \lambda_{25i} \Delta \ln FD_{t-i} + \varepsilon_{5t} \tag{14}$$

where the D_{CE} , D_{FOS} , D_{IND} , D_{INDSQ} and D_{FDT} are dummy variables which capture structural breaks. δ_0 denotes the intercept and ε_t is the error term. The long-run and short-run parameters are γ_i and λ_i respectively while Δ is the change parameter.

The study estimated equation (10) to investigate the long-run relationship among the variables. We employed the Ordinary Least Square (OLS) technique in the estimation after which the F-test for joint significance was computed. The null hypothesis, which implies no cointegration, is stated as $\gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = \gamma_5 = 0$ while the alternative hypothesis implying the existence of cointegration is written as $\gamma_1 \neq \gamma_2 \neq \gamma_3 \neq \gamma_4 \neq \gamma_5 \neq 0$. The same procedure was followed to test for long-run cointegration among the variables in Eqs. (11)–(14). The study compared the value of the F-statistic computed with the bounds of Pesaran et al. (2001) critical values. If the F-statistic computed exceeds the upper critical value, the null hypothesis of no cointegration is rejected implying the existence of long-run relationship among the variables. On the other hand, we fail to reject the null hypothesis provided the computed F-statistic is lower than the lower critical bound which in this case suggests the variables are not cointegrated. We would have inconclusive result if the F-statistic is within the upper and lower critical values. Since evidence of cointegration is found to exist among the variables, the study proceeded to estimate both the long-run and short-run parameters.

2.4. Lind and Mehlum test for a U-shaped or inverted U-shaped relationship

Since the ARDL approach provides only the necessary condition for the existence of a U-shaped or inverted U-shaped relationship but without the sufficient condition, the study proceeds to conduct the Lind and Mehlum (2010) U-shaped test. Lind and Mehlum (2010) built on the work of Sasabuchi (1980) to develop a test that overcomes the problem of misinterpreting the actual non-linear relationship existing between two variables in conventional non-linear econometric models. In these models, U-shaped or inverted U-shaped relationships are examined by looking at the different signs and the statistical significance of the original variable and its squared term. According to Lind and Mehlum (2010), this conventional method of testing for a non-linear relationship is inappropriate. Lind–Mehlum test ensures that the necessary and sufficient conditions for the existence of a U-shape are provided on some interval values where the relationship decreases at the left side of the interval and increases at the right. To conduct this test, we first estimated the equation below by OLS:

$$\ln CE_t = \alpha_0 + D_{CE} + \alpha_1 \ln F_t + \alpha_2 \ln I_t + \alpha_3 (\ln I_t)^2 + \alpha_4 \ln FD_t + u_t \tag{15}$$

Next, the following condition was tested:

$$\alpha_2 + \alpha_3 \ln I_{\min} < 0 < \alpha_2 + \alpha_3 \ln I_{\max}$$

This condition examines whether industrial growth is declining at the left side of the interval values and rising at the right side of the interval values to ascertain the exact non-linear relationship (either U-shape or inverted U-shape) between carbon dioxide emission and industrial growth in Ghana. Begum et al. (2015) also employed the Lind and Mehlum (2010) U shaped test to confirm the existence of a U-shaped relationship GDP growth and CO2 emissions in Malaysia.

Table 1
Descriptive statistics and correlation matrix.

| | $\ln CE_t$ | $\ln F_t$ | $\ln I_t$ | $\ln FD_t$ |
|-------------|------------|-----------|-----------|------------|
| Mean | -1.1658 | -1.3705 | 21.6413 | -1.3573 |
| Median | -1.1888 | -1.5100 | 21.6591 | -1.3190 |
| Maximum | -0.5889 | -0.6422 | 23.6655 | -0.9340 |
| Minimum | -1.5621 | -2.1603 | 19.6369 | -1.8089 |
| Std. Dev. | 0.2273 | 0.4082 | 0.9812 | 0.2332 |
| Jarque–Bera | 2.9600 | 3.3134 | 0.2299 | 1.8397 |
| Probability | 0.2276 | 0.1908 | 0.8914 | 0.3986 |
| $\ln CE_t$ | 1.0000 | | | |
| $\ln F_t$ | 0.8302 | 1.0000 | | |
| $\ln I_t$ | 0.8327 | 0.8542 | 1.0000 | |
| $\ln FD_t$ | 0.4224 | 0.5876 | 0.4560 | 1.0000 |

2.5. Granger-causality approach

According to Engle and Granger (1987), the existence of cointegration between the variables implies that there exists causality in at least one direction. In order to ascertain the direction of causality between the variables, the proposed study applied the modified Granger-causality test. Engle and Granger (1987) notes that, if the variables are all $I(1)$ and cointegrated, then specifying the Vector Error Correction Model (VECM) is appropriate. Therefore with evidence of cointegration in the $I(1)$ series used in this study, we go further to investigate the direction of causality among the variables using the Error Correction Term (ECT) augmented Granger-causality test. This approach involves setting up a multivariate VECM of p th order as given below:

$$(1-L) \begin{bmatrix} \ln CE_t \\ \ln F_t \\ \ln I_t \\ (\ln I_t)^2 \\ \ln FD_t \end{bmatrix} = \begin{bmatrix} \theta_1 \\ \theta_2 \\ \theta_3 \\ \theta_4 \\ \theta_5 \end{bmatrix} + \begin{bmatrix} D_{CE} \\ D_{FOS} \\ D_{IND} \\ D_{INDSQ} \\ D_{FDT} \end{bmatrix} + \sum_{i=1}^p (1-L) \begin{bmatrix} \omega_{11i} & \omega_{12i} & \omega_{13i} & \omega_{14i} & \omega_{15i} \\ \omega_{21i} & \omega_{22i} & \omega_{23i} & \omega_{24i} & \omega_{25i} \\ \omega_{31i} & \omega_{32i} & \omega_{33i} & \omega_{34i} & \omega_{35i} \\ \omega_{41i} & \omega_{42i} & \omega_{43i} & \omega_{44i} & \omega_{45i} \\ \omega_{51i} & \omega_{52i} & \omega_{53i} & \omega_{54i} & \omega_{55i} \end{bmatrix} \begin{bmatrix} \ln CE_{t-i} \\ \ln F_{t-i} \\ \ln I_{t-i} \\ (\ln I_{t-i})^2 \\ \ln FD_{t-i} \end{bmatrix} + \begin{bmatrix} \varphi_1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} [ECT_{t-1}] + \begin{bmatrix} u_{1t} \\ u_{2t} \\ u_{3t} \\ u_{4t} \\ u_{5t} \end{bmatrix} \tag{16}$$

where $(1-L)$ in the above VECM is the lag operator, the lagged error correction term is ECT_{t-1} derived from the long-run relationship while u_{1t} , u_{2t} , u_{3t} , u_{4t} and u_{5t} are the error terms which are expected to be serially uncorrelated with zero mean. The appropriate lag length p was selected based on SIC information criteria. The specification of the VECM helps to ascertain causal relationships among the variables in the long-run as well as the short-run. The significance of the t-statistic associated with the term ECT_{t-1} indicates causality in the long-run while the significance of the F-statistics associated with the lagged differences of the regressors indicate short-run Granger causality.

3. Results and discussion

Information presented in Table 1 include descriptive statistics of all the variables as well as their correlation matrix.

The Jarque–Bera statistics show that each of the variables is normally distributed with a mean of zero and a constant variance. The results of the correlation matrix indicate that the variables under study are positively related. Thus, Fossil fuel consumption,

Table 2
ADF and PP unit root tests.

| Variable | ADF | | PP | |
|---------------|-------------|----------------|---------------|----------------|
| | Level form | 1st difference | Level form | 1st difference |
| | t-Statistic | t-Statistic | Adj. t-Stat | t-Statistic |
| $\ln CE_t$ | -0.0008(1) | -9.5149(0)* | -0.5065[2.96] | -9.6387[1.02]* |
| $\ln F_t$ | 0.6880(2) | -9.0686(0)* | -0.0128[3.13] | -9.2627[1.35]* |
| $\ln I_t$ | 0.2249(2) | -4.3750(1)* | 0.1328[5.31] | -3.4813[2.4]** |
| $(\ln I_t)^2$ | 0.3408(2) | -4.2936(1)* | 0.2975[5.19] | -3.4936[2.3]** |
| $\ln FD_t$ | -2.0135(0) | -6.4657(0)* | -2.1046[1.15] | -6.4657[0.17]* |

The optimal lags for ADF() was selected using SIC.

Whiles the band widths for the PP[] was selected using Andrews automatic.

*Statistically significant at 1%.

**Statistically significant at 5%.

Table 3
Zivot-Andrews unit root test in the presence of structural breaks.

| Variable | Level form | Break year | 1st diff | Break year |
|---------------|------------|------------|------------|------------|
| | t-Stat | | t-Stat | |
| $\ln CE_t$ | -3.745(1) | 1984 | -6.430(2)* | 1999 |
| $\ln F_t$ | -3.311(2) | 1983 | -8.115(1)* | 1994 |
| $\ln I_t$ | -3.292(2) | 1979 | -6.675(1)* | 1984 |
| $(\ln I_t)^2$ | -3.144(2) | 1979 | -6.529(1)* | 1984 |
| $\ln FD_t$ | -3.565(0) | 1997 | -6.895(0)* | 2001 |

*Statistically significant at 1%.

industrial growth and financial development have positive association with emissions of CO₂. Industrial growth and financial development are also positively related with fossil fuel consumption. Finally, industrial growth and financial development are correlated positively.

Unit root test

Prior to testing for the existence of cointegration, we first tested for the order of integration of the variables to ensure none of the series used in the study is $I(2)$. This is because the ARDL cointegration approach used in the study is invalid when $I(2)$ time series variables are introduced. Moreover, the Bayer–Hanck cointegration technique also require all variables to be $I(1)$.

To investigate the unit root properties of the variables, the study employed the Augmented Dickey–Fuller (ADF) and the Phillip–Perron tests which are conventional approaches for unit root testing. However, as discussed earlier, these tests are inappropriate in the presence of structural breaks, therefore the Zivot and Andrews (2002) unit root test was employed to test for the stationarity properties of the series in the presence of structural breaks. Tables 2 and 3 report the stationarity properties of the variables which suggest they are $I(1)$ and therefore suitable for ARDL and the Bayer–Hanck cointegration approaches employed in the study.

After determining the maximum lag length using Schwarz information criterion, the study proceeded to employ two cointegration techniques namely, the ARDL bound test and Bayer–Hanck cointegration to ensure robustness. In order to avoid weak cointegration relationship, the significance level was set at 5% for both cointegration procedures.

The result of the Bayer–Hanck combined cointegration is reported in Table 4. The result indicates that the Fisher-statistics associated with EG-JOH and EG-JOH-BO-BDM are greater than the critical values at 5% level of significance only when emissions of CO₂ is the dependent variable. Thus, using the other variables as the dependent variable failed to give evidence of cointegration suggesting the existence of only one cointegration relationship between the variables.

For the ARDL bounds test approach, we tested for cointegration among the variables by computing the F-test to examine

the joint significance of the lagged level time series variables. Before computing the F-test, the AIC information criterion was first used to select the optimal lag so as to avoid under fitting the model. From Table 5 where the result of the bound test is reported, we found the existence of cointegration only in one case, when carbon dioxide emissions is the dependent variable. Using the other variables as dependent variable produced no evidence of cointegration and thus confirming the existence of only one cointegration relationship between the variables.

The break dates were selected by forming AR(1) process of the series in levels and applying (Bai and Perron, 1998) sequential test to select structural break dates which are relatively the most significant. The selected break dates for emissions of CO₂, fossil fuel consumption, industrial growth, the squared term of industrial growth and financial development are 1993, 1998, 1983, 1983 and 1996 respectively. The selected breakpoint of 1983 marks the Economic Recovery Program initiated by the government of Ghana to overcome the economic decline that confronted the country at the time. The other estimated break dates are close to 1992 and 1996 which are very important in the political and economic history of Ghana. Ghana took a decisive step to return to democratic rule in 1992 after a long period of military rule. According to Leite et al. (2000), the period 1992 saw significant changes in both monetary and exchange rate policies. Since both 1992 and 1996 were election years in Ghana, Leite et al. (2000) noted that huge cost was imposed on the economy of Ghana due to excess spending in an effort to capture election victory.

After finding evidence of cointegration, the study analyzed the long-run impact of the other variables on emissions of CO₂. The result, which is illustrated in Table 6, suggests fossil fuel consumption and financial development impact emissions of CO₂ positively. The positive sign found on the impact of fossil fuel consumption on CO₂ emissions is consistent with other studies on Ghana such as Kwakwa and Alhassan (2018) and Twerefou et al. (2016) though the latter used energy in general. The positive sign of fossil fuel is also in line with other studies (Begum et al., 2015; Ozturk and Acaravci, 2010; Park and Lee, 2011) which found positive impact of energy consumption on air pollution for Malaysia, Turkey and Republic of Korea respectfully. However, the coefficient is insignificant. Thus, given the sample period under study, there is no enough evidence to suggest that fossil consumption impact CO₂ emissions positively in Ghana. This could be due to the different energy variable (fossil fuel) used in this study. The proposed study used fossil fuel consumption which is just a component of total energy consumption, contrary to Twerefou et al. (2016) where energy in general was used. The difference in control variables and time period used in the proposed study could also account for the insignificant impact fossil fuel consumption has on CO₂ emissions. Similarly, the insignificant impact of financial development on CO₂ emissions could also be attributed to the same reasons such as the difference in variables used to measure financial development, the control variables, the methodology and the difference in time periods used in the analysis. For instance, while the proposed study measured financial development as the ratio of domestic credit by financial sector to GDP, Ali et al. (2016) and Başarir and Çakir (2015) measured financial development as broad money supply and the time periods used in their studies are 1985–2012 and 1995–2010 respectively compared to 1971–2014 in the proposed study. The positive sign is consistent with Başarir and Çakir (2015) for Turkey and (Zhang, 2011) for China but contradicts Ali et al. (2016) and Jalil and Feridun (2011) which found financial development to reduce CO₂ emissions for Malaysia and China respectively.

The signs of the industrial growth and its squared term which are both significant at 1% give evidence of a U-shaped relationship between industrial growth and emissions of CO₂ in Ghana. The

Table 4
Bayer and Hanck cointegration analysis.

| Dependent variable | SBC lag | EG-JOH | EG-JOH-BO-BDM | Cointeg. |
|---|---------|---------|---------------|----------|
| $\ln CE_t = f[\ln F_t, \ln I_t, (\ln I_t)^2, \ln FD_t]$ | 2 | 17.6729 | 28.9426** | YES |
| $\ln F_t = f[\ln CE_t, \ln I_t, (\ln I_t)^2, \ln FD_t]$ | 1 | 7.4116 | 13.9419 | NO |
| $\ln I_t = f[\ln CE_t, \ln F_t, (\ln I_t)^2, \ln FD_t]$ | 1 | 7.1938 | 21.5303 | NO |
| $(\ln I_t)^2 = f[\ln CE_t, \ln F_t, \ln I_t, \ln FD_t]$ | 1 | 7.1942 | 21.4808 | NO |
| $\ln FD_t = f[\ln CE_t, \ln F_t, \ln I_t, (\ln I_t)^2]$ | 1 | 8.3650 | 11.9941 | NO |
| EG-J: critical value at 5% | 10.576 | | | |
| EG-J-Ba-Bo: critical value at 5% | 20.143 | | | |

**Statistically significant at 5%.

Table 5
ARDL bounds test cointegration analysis.

| Dependent variable | SBC | Optimal lag | Break year | F-stat | Cointeg. |
|---|-----|-------------|------------|---------|----------|
| $\ln CE_t = f[\ln F_t, \ln I_t, (\ln I_t)^2, \ln FD_t]$ | 2 | 1,2,0,2,2 | 1993 | 9.6661* | YES |
| $\ln F_t = f[\ln CE_t, \ln I_t, (\ln I_t)^2, \ln FD_t]$ | 1 | 1,0,0,0,0 | 1998 | 4.4360 | NO |
| $\ln I_t = f[\ln CE_t, \ln F_t, (\ln I_t)^2, \ln FD_t]$ | 1 | 1,1,1,1,0 | 1983 | 3.8431 | NO |
| $(\ln I_t)^2 = f[\ln CE_t, \ln F_t, \ln I_t, \ln FD_t]$ | 1 | 1,1,1,1,0 | 1983 | 3.8340 | NO |
| $\ln FD_t = f[\ln CE_t, \ln F_t, \ln I_t, (\ln I_t)^2]$ | 1 | 1,0,0,1,1 | 1996 | 1.9641 | NO |
| Lower-bound critical value at 5% | | | | | |
| Upper-bound critical value at 5% | | | | | |

| Diagnostic tests | DW | R ² | Adj-R ² | χ^2_{ARCH} | χ^2_{SERIAL} |
|---|------|----------------|--------------------|-----------------|-------------------|
| $\ln CE_t = f[\ln F_t, \ln I_t, (\ln I_t)^2, \ln FD_t]$ | 2.22 | 0.722 | 0.607 | 0.6113 (0.5480) | 1.4677 (0.2483) |
| $\ln F_t = f[\ln CE_t, \ln I_t, (\ln I_t)^2, \ln FD_t]$ | 2.40 | 0.403 | 0.304 | 2.1168 (0.1535) | 1.9029 (0.1765) |
| $\ln I_t = f[\ln CE_t, \ln F_t, (\ln I_t)^2, \ln FD_t]$ | 1.48 | 0.999 | 0.998 | 2.3457 (0.1335) | 4.1464 (0.0501) |
| $(\ln I_t)^2 = f[\ln CE_t, \ln F_t, \ln I_t, \ln FD_t]$ | 1.51 | 0.999 | 0.998 | 2.4109 (0.1284) | 3.7250 (0.0625) |
| $\ln FD_t = f[\ln CE_t, \ln F_t, \ln I_t, (\ln I_t)^2]$ | 1.95 | 0.275 | 0.104 | 0.3113 (0.5800) | 0.5530 (0.4624) |

Figures in parenthesis represents probabilities.

*Statistically significant at 1%.

negative coefficient of industrial growth and the positive sign of the squared term indicate that emissions of CO₂ decline at the initial stage of growth in industrial output and increases after a threshold point of industrial output growth is reached. One possible reason accounting for this phenomenon could be attributed to the use of obsolete and inefficient equipment by the industrial sector (Energy Commission, 2006). Growth of the industrial sector exacerbates the air pollution problem due to the high carbon technologies used in this sector which makes the growth of the industrial sector occur at the cost of environmental quality. The U-shaped relationship found for Ghana contradicts other studies (Kwakwa and Alhassan, 2018; Aboagye, 2017; Kwakwa et al., 2014) which found an inverted U-shaped relationship for Ghana. The difference could be due to the different growth variables used, the methodologies employed, the time periods used in the studies and the control variables. Whiles Aboagye (2017) used aggregate growth variable, the proposed study focused on a single sector (industrial growth). Kwakwa and Alhassan (2018) and Kwakwa et al. (2014) employed Fully Modified OLS and Johansen cointegration techniques respectively on small sample sizes and therefore their results are relatively less efficient to the ARDL technique employed in this study. More so, these studies only tested the necessary conditions for the existence of an inverted U-shaped relationship by looking at the signs of the growth variable and its squared term and thus failing to examine the sufficient condition which can be performed in Lind and Mehlum U-shape test. Notwithstanding, the detected U-shaped relationship is consistent with studies such as Twerefou et al. (2016) for Ghana, Begum et al. (2015) for Malaysia and Omisakin (2009) for Nigeria. This is not surprising since most developing countries tend to use high carbon technologies in production and therefore emissions of CO₂ increase with the output of the firms. The U-shaped relationship between emissions of CO₂ and industrial growth discovered for Ghana does not auger well for sustainable development assumptions. The U-shape implies

increased environmental pollution at higher level of industrial growth which may eventually lead to deterioration of health and welfare. This finding implies that air pollution has been a major challenge for the government of Ghana as the economy continues to grow and firms expand. As part of the efforts to curb the amount of environmental damage produced by firms in their production activities, the Environmental Protection Agency (EPA) was set up in December 1994. It is the responsibility of the EPA to protect the environment by ensuring that firms conform to acceptable standards in terms of the pollution discharged into the environment from their production activities. Furthermore, the Environmental Assessment Regulations policy was also formulated in 1999 to promote the course of improving environmental quality by way of controlling pollution.

Table 7 presents the short-run elasticities. Again, we find a U-shaped relationship between emissions of CO₂ and industrial growth in the short-run. Contrary to the long-run, financial development impact emissions of CO₂ negatively but not statistically significant. Fossil fuel consumption still maintains a positive and insignificant impact on emissions of CO₂ in the short-run. The error correction term (ECT_{t-1}) value of -0.9674 which is significant at 1% implies about 97% of the deviations from equilibrium in the short-run are corrected towards the long-run equilibrium every year. This gives further evidence that the variables are cointegrated. The dummy variable which represents return to democracy showed positive and significant impact on emissions of CO₂ at 1% significance level. The positive impact is due to the increased economic activities which exist in a democratic system of governance compared to a military system since there is more peace and freedom in the former. The increased economic activities in the democratic system of Ghana also translates into increased pollution due to the obsolete and high carbon technologies used in production.

In Fig. 3 and Table 8 presents the diagnostic tests for the long-run ARDL estimates as well as the short-run. The results imply

Table 6
Long-run elasticities.

| Dependent variable: $\ln CE_t$ | | | |
|--------------------------------|----------|----------|--------|
| Variable | Coeff | Std. Err | t-stat |
| $\ln F_t$ | 0.0190 | 0.0915 | 0.21 |
| $\ln I_t$ | -2.1874* | 0.5600 | -3.91 |
| $(\ln I_t)^2$ | 0.0530* | 0.0131 | 4.04 |
| $\ln FD_t$ | 0.0511 | 0.0936 | 0.55 |

*Statistically significant at 1%.

Table 7
Short-run elasticities.

| Dependent variable: $\ln CE_t$ | | | |
|--------------------------------|----------|----------|--------|
| Variable | Coeff | Std. Err | t-stat |
| Constant | 20.6107* | 6.3009 | 3.27 |
| $\Delta \ln F_t$ | 0.0184 | 0.0889 | 0.21 |
| $\Delta \ln I_t$ | -2.1161* | 0.6002 | -3.53 |
| $\Delta(\ln I_t)^2$ | 0.0485* | 0.0141 | 3.43 |
| $\Delta \ln FD_t$ | -0.0175 | 0.1038 | -0.17 |
| D_{CE} | 0.1899* | 0.0532 | 3.57 |
| ECT_{t-1} | -0.9674* | 0.1531 | -6.32 |

*Statistically significant at 1%.

Table 8
Diagnostic tests.

| Tests | Probability | Chi-sq. |
|-------------------|-------------|---------|
| χ^2_{SERIAL} | 0.1154 | 2.479 |
| χ^2_{HETERO} | 0.5985 | 0.28 |
| χ^2_{ARCH} | 0.5811 | 0.304 |
| χ^2_{NORM} | 0.8062 | 0.4308 |
| | Probability | F-stat |
| χ^2_{RESET} | 0.1045 | 2.23 |
| DW | 2.2030 | |
| R^2 | 0.5760 | |
| $Adj - R^2$ | 0.4762 | |

that, the error terms have no problems of autocorrelation, heteroskedasticity and non-normality. The Ramsey test also shows the model is correctly specified. In order to check the stability of the parameters, the CUSUM and CUSUMsq tests were performed. Figs. 3 and 4 show the plot of both tests are within the critical bounds at 5% level of significance.

The relationship between CO2 emissions and industrial growth is shown in Figs. 5 and 6. The local polynomial smoothing of degree 2 and 3 were applied to smoothen the scatter plots in order to find the relationship between CO2 emissions and industrial growth. The two diagrams confirm the ARDL regression results of a U-shaped relationship between CO2 emissions and industrial growth in Ghana.

4. Robustness analysis

Lind and Mehlum test for U-shape

As mentioned earlier, the results obtained in the ARDL with the coefficients for industrial growth and its squared term showing negative and positive signs respectively, provided only a necessary condition that the relationship between carbon dioxide and industrial growth is U-shaped. According to Lind and Mehlum (2010), the confirmation that a U-shaped relationship exists involves performing Lind and Mehlum U-test. Table 9 reports the result of the test. The U-test result shows that both the lower bound and the upper bound slopes are significant at 1%. The lower bound slope has a negative sign, implying a negative slope while the upper bound slope shows a positive sign suggesting a positive slope. Thus, the result describes a U-shaped relationship

Table 9
Lind and Mehlum test for U-shape.

| | Carbon dioxide emissions |
|----------------------------|--------------------------|
| Lower bound slope | -0.1276* |
| t-stat | (-2.4708) |
| Upper bound slope | 0.2917* |
| t-stat | (4.4799) |
| Overall U-shape t-stat | 2.47 |
| p-value | 0.00904 |
| Turning point of $\ln I_t$ | 20.86315 |

*Statistically significant at 1%.

and the overall U-shaped test is also significant at 1% implying the rejection of the null hypothesis of monotone or inverse U shape.

From Table 9, the turning point of 20.86315 corresponds to 1,150,140,562 Ghana cedis worth of real industrial output after finding the anti-logarithm. For the selected sample size, we found the industrial sector output (in real values) exceeding the threshold value from the beginning (1971–1977) but drops below the threshold value for the period 1978–1990 and finally rises above the threshold for the rest of the selected sample period 1991–2014. This fluctuation in output of the industrial sector is expected since Ghana is a developing country with numerous economic and socio-economic challenges which have the tendency to affect the output of the industrial sector. For instance, the fluctuation of the exchange rate in Ghana affects the output of the industrial sector since the sector relies heavily on the import of raw materials to produce. The frequent power crisis which confronts the economy coupled with high levels of inflation all have some bearings on the output of the industrial sector.

Test:

H1: U shape

vs. H0: Monotone or Inverse U shape

5. Causality analysis

5.1. Granger causality analysis

The evidence of cointegration found in Tables 4 and 5 imply that Granger causality must exist in at least one direction but it fails to show the direction. We therefore employ the ECT augmented Granger causality to examine the direction of causality between the variables. Following Narayan and Smyth (2004), the ECT term which was obtained from the long-run relationship is only included when evidence of cointegration is found in the equation. Therefore, since we found cointegration for only one equation (when carbon dioxide is the regressand) the ECT which represents long-run causality is included only in the carbon dioxide equation. Thus, the ECT augmented granger causality provides information on both causality in the short-run and causality in the long-run which can provide a useful information to policy makers in designing appropriate policies on environmental pollution for different time periods.

The result of the ECT augmented causality test is reported in Table 10. The coefficient of ECT_{t-1} was found to be negative and significant at 1% as indicated by the t-statistic. This result has two implications: first, it gives confirmation to the long-run equilibrium relationship found between the variables in both the ARDL bounds test and the Bayer–Hanck cointegration. Second, it implies that, fossil fuel consumption, financial development and industrial growth Granger-cause emissions of CO2 in the long-run. In the short-run, the F-statistic shows that there is a unidirectional causality running from fossil fuel to emissions of CO2, from industrial growth to fossil fuel consumption and finally from carbon dioxide emission to financial development.

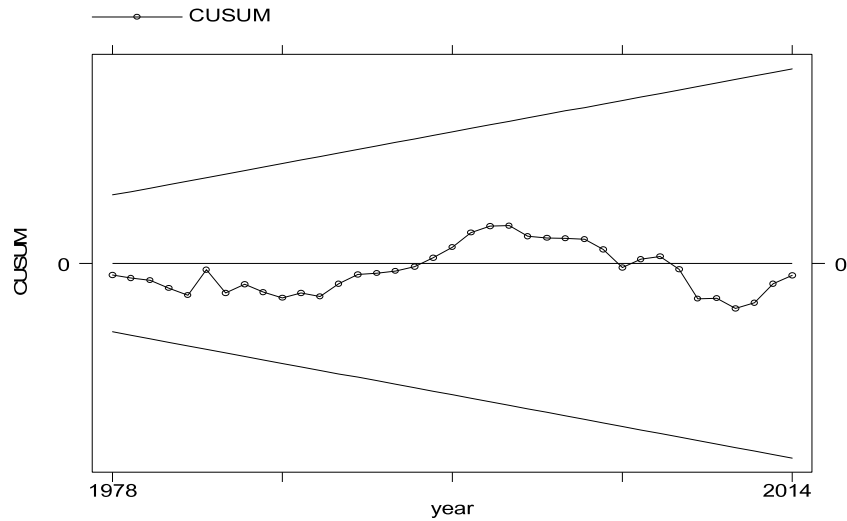


Fig. 3. Cumulative sum of recursive residuals. Straight lines indicate critical bounds at 5% level of significance.

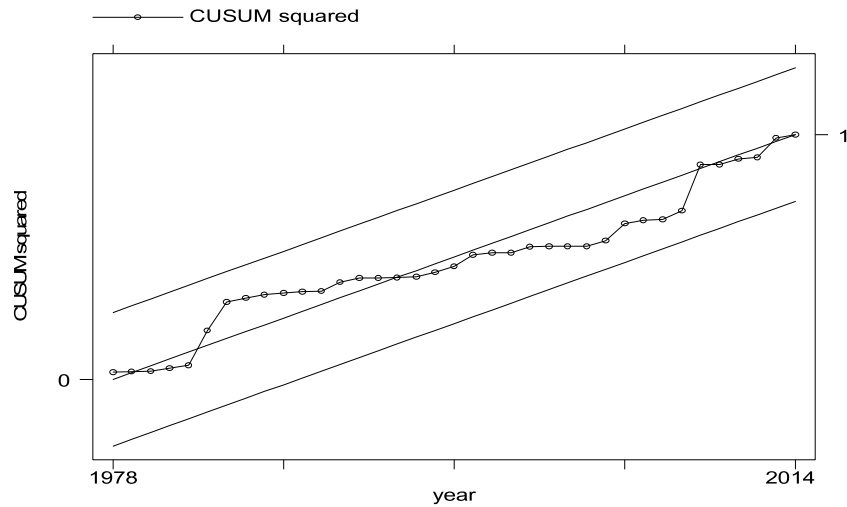


Fig. 4. Cumulative sum of squares of recursive residuals. Straight lines indicate critical bounds at 5% level of significance.

Table 10
Granger causality analysis.

| Dependent variable | | | | | | |
|----------------------|-------------------|------------------|------------------|----------------------|-------------------|-------------|
| | | | | Short-run | Long-run | |
| | $\Delta \ln CE_t$ | $\Delta \ln F_t$ | $\Delta \ln I_t$ | $(\Delta \ln I_t)^2$ | $\Delta \ln FD_t$ | ECT_{t-1} |
| $\Delta \ln CE_t$ | - | 3.8516** | 0.0828 | 0.0615 | 0.6803 | -0.8599* |
| $\Delta \ln F_t$ | 2.2522 | - | 9.5375* | 9.0068* | 0.4290 | - |
| $\Delta \ln I_t$ | 0.4057 | 0.6196 | - | - | 0.1014 | - |
| $(\Delta \ln I_t)^2$ | 0.4344 | 0.5590 | - | - | 0.0993 | - |
| $\Delta \ln FD_t$ | 2.6879*** | 0.1385 | 1.0154 | 0.9308 | - | - |

*Statistically significant at 1% level.
 **Statistically significant at 5% level.
 ***Statistically significant at 10% level.

5.2. Generalized forecast error variance decomposition

Whiles Granger causality can detect within-sample causal relationship between variables, it is not able to detect causal relationships beyond the sample period. An innovative accounting technique is applied in this study via generalized forecast error variance decomposition (GFEVD) proposed by Pesaran and Shin (1998) to measure the percentage of the forecast error variance of a particular variable resulting from shock to a variable in the system. According to Sims (1980), a variable is said to be

exogenous to other variables in the system if all of its forecast error variance decomposition is explained by own innovative shocks. One major advantage of using this approach is that it is insensitive to the ordering of the variables since the VAR system uniquely determines the order. However, it must be noted that the row sum of the elements of the GFEVD is not necessarily equal to one since the variables are not orthogonalized. Therefore, each entry of the generalized variance decomposition is normalized by the row sum.

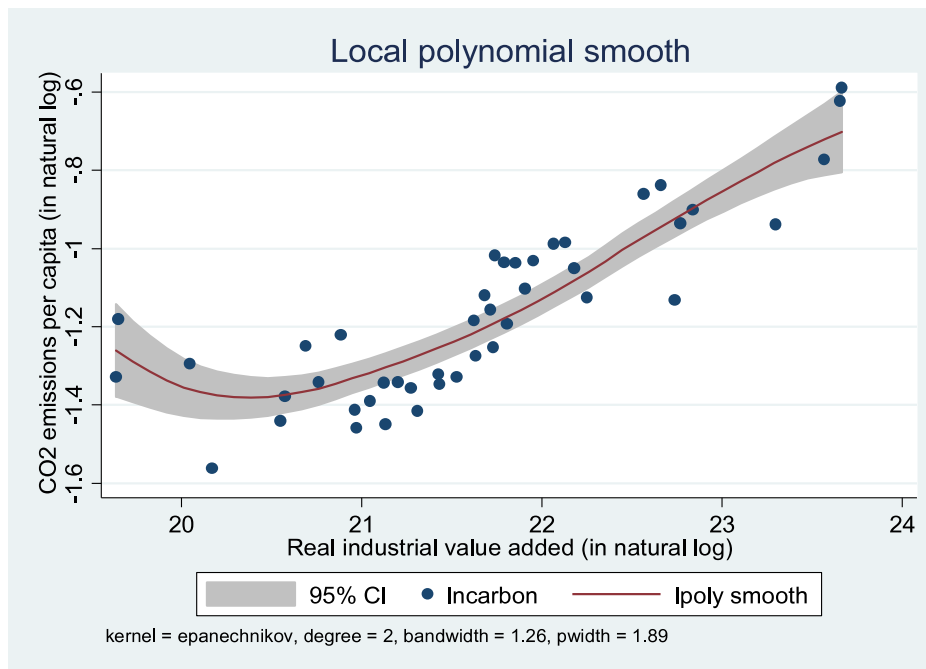


Fig. 5. CO2 emissions and industrial growth relationship.

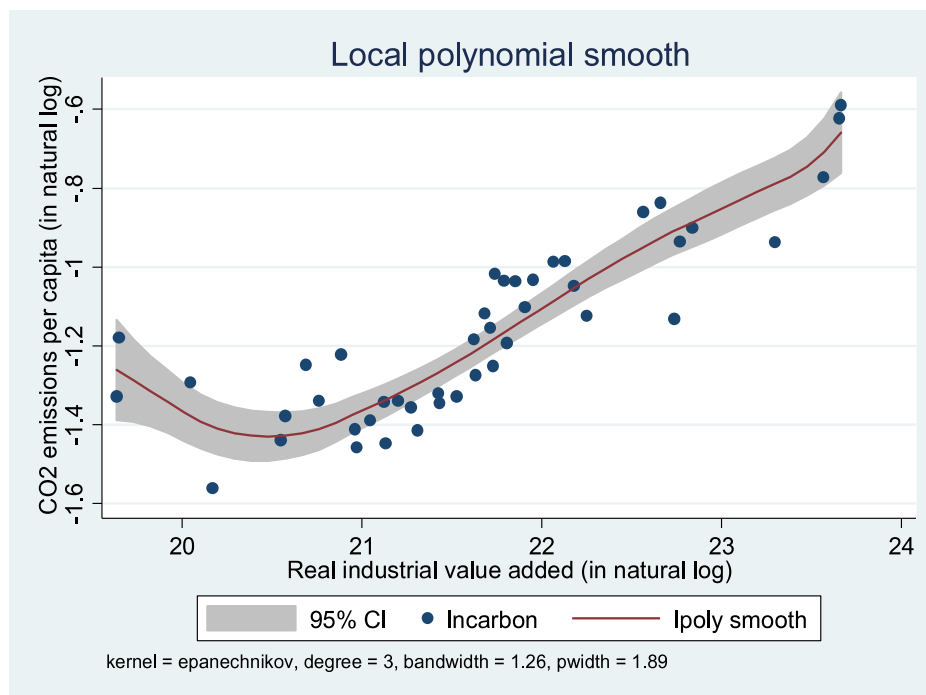


Fig. 6. CO2 emissions and industrial growth relationship.

Table 11 presents the result of the GFEVD which indicates that 25.95% of emissions of CO₂ is accounted for by own innovative shocks whiles innovative shocks in fossil fuel consumption, industrial growth and financial development account for 11.61%, 47.68% and 14.76% of emissions of CO₂ respectively at the end of the fifteen years. Thus, the most significant contributor to variations in emissions of CO₂ is industrial growth which is consistent with the ARDL estimates. Own innovative shocks to industrial growth alone explains 56.82% of industrial growth whiles emissions of CO₂, fossil fuel consumption and financial development

innovative shocks explain 15.12%, 12.24% and 15.82% respectively. This confirms the result of the Granger-causality about industrial growth being the most exogenous variable. This finding has important policy implications as it suggests that restricting the amount of fossil fuel consumption (the least important contributor to industrial sector output variations) would not have significant impact on CO₂ emissions. The output of the industrial sector could thrive on low carbon technologies for environmental sustainability. Emissions of CO₂, industrial growth, and financial development contributes 21.49%, 49.29% and 11.50% respectively to fossil fuel consumption whiles own shock contributes only

Table 11
Generalized forecast variance decomposition.

| Variance decomposition of $\ln CE_t$ | | | | | Variance decomposition of $\ln F_t$ | | | | |
|--------------------------------------|------------|-----------|-----------|------------|-------------------------------------|------------|-----------|-----------|------------|
| Horiz | $\ln CE_t$ | $\ln F_t$ | $\ln I_t$ | $\ln FD_t$ | Horiz | $\ln CE_t$ | $\ln F_t$ | $\ln I_t$ | $\ln FD_t$ |
| 0 | 0.9241 | 0.0093 | 0.0300 | 0.0365 | 0 | 0.0099 | 0.9786 | 0.0044 | 0.0071 |
| 1 | 0.7503 | 0.1617 | 0.0320 | 0.0560 | 1 | 0.0190 | 0.8492 | 0.1234 | 0.0084 |
| 2 | 0.6807 | 0.1304 | 0.1102 | 0.0787 | 2 | 0.0925 | 0.6977 | 0.2028 | 0.0070 |
| 3 | 0.6112 | 0.1204 | 0.1917 | 0.0768 | 3 | 0.1347 | 0.5930 | 0.2657 | 0.0066 |
| 4 | 0.5241 | 0.1032 | 0.2861 | 0.0865 | 4 | 0.1858 | 0.4833 | 0.3187 | 0.0121 |
| 5 | 0.4555 | 0.0896 | 0.3576 | 0.0973 | 5 | 0.2185 | 0.4086 | 0.3518 | 0.0211 |
| 6 | 0.4023 | 0.0852 | 0.4019 | 0.1107 | 6 | 0.2356 | 0.3489 | 0.3814 | 0.0341 |
| 7 | 0.3633 | 0.0833 | 0.4293 | 0.1241 | 7 | 0.2436 | 0.3032 | 0.4061 | 0.0471 |
| 8 | 0.3350 | 0.0856 | 0.4452 | 0.1342 | 8 | 0.2441 | 0.2687 | 0.4273 | 0.0599 |
| 9 | 0.3138 | 0.0894 | 0.4553 | 0.1415 | 9 | 0.2412 | 0.2417 | 0.4453 | 0.0718 |
| 10 | 0.2979 | 0.0939 | 0.4622 | 0.1460 | 10 | 0.2366 | 0.2215 | 0.4595 | 0.0824 |
| 11 | 0.2857 | 0.0989 | 0.4670 | 0.1484 | 11 | 0.2314 | 0.2064 | 0.4706 | 0.0916 |
| 12 | 0.2765 | 0.1038 | 0.4704 | 0.1492 | 12 | 0.2264 | 0.1952 | 0.4789 | 0.0994 |
| 13 | 0.2694 | 0.1083 | 0.4730 | 0.1493 | 13 | 0.2220 | 0.1871 | 0.4851 | 0.1058 |
| 14 | 0.2639 | 0.1125 | 0.4751 | 0.1486 | 14 | 0.2181 | 0.1813 | 0.4896 | 0.1109 |
| 15 | 0.2595 | 0.1161 | 0.4768 | 0.1476 | 15 | 0.2149 | 0.1772 | 0.4929 | 0.1150 |

| Variance decomposition of $\ln I_t$ | | | | | Variance decomposition of $\ln FD_t$ | | | | |
|-------------------------------------|------------|-----------|-----------|------------|--------------------------------------|------------|-----------|-----------|------------|
| Horiz | $\ln CE_t$ | $\ln F_t$ | $\ln I_t$ | $\ln FD_t$ | Horiz | $\ln CE_t$ | $\ln F_t$ | $\ln I_t$ | $\ln FD_t$ |
| 0 | 0.0296 | 0.0041 | 0.9099 | 0.0564 | 0 | 0.0356 | 0.0066 | 0.0559 | 0.9019 |
| 1 | 0.0453 | 0.002 | 0.8821 | 0.0702 | 1 | 0.0264 | 0.0051 | 0.0410 | 0.9276 |
| 2 | 0.0709 | 0.0101 | 0.8224 | 0.0966 | 2 | 0.0777 | 0.0052 | 0.0388 | 0.8783 |
| 3 | 0.0907 | 0.0226 | 0.7593 | 0.1273 | 3 | 0.1452 | 0.0076 | 0.0431 | 0.8041 |
| 4 | 0.1042 | 0.0366 | 0.7077 | 0.1515 | 4 | 0.2032 | 0.0073 | 0.0605 | 0.7290 |
| 5 | 0.1120 | 0.0509 | 0.6700 | 0.1672 | 5 | 0.2392 | 0.0077 | 0.0897 | 0.6634 |
| 6 | 0.1164 | 0.0639 | 0.6442 | 0.1755 | 6 | 0.2522 | 0.0079 | 0.1325 | 0.6074 |
| 7 | 0.1195 | 0.0755 | 0.6264 | 0.1786 | 7 | 0.2520 | 0.0084 | 0.1825 | 0.5571 |
| 8 | 0.1223 | 0.0857 | 0.6136 | 0.1784 | 8 | 0.2445 | 0.0100 | 0.2309 | 0.5146 |
| 9 | 0.1255 | 0.0944 | 0.6038 | 0.1763 | 9 | 0.2343 | 0.0130 | 0.2722 | 0.4806 |
| 10 | 0.1292 | 0.1018 | 0.5956 | 0.1734 | 10 | 0.2244 | 0.0172 | 0.3044 | 0.4540 |
| 11 | 0.1333 | 0.108 | 0.5886 | 0.1701 | 11 | 0.2157 | 0.0228 | 0.3283 | 0.4333 |
| 12 | 0.1378 | 0.113 | 0.5824 | 0.1668 | 12 | 0.2087 | 0.0291 | 0.3455 | 0.4166 |
| 13 | 0.1424 | 0.117 | 0.5769 | 0.1637 | 13 | 0.2033 | 0.0360 | 0.3581 | 0.4026 |
| 14 | 0.1469 | 0.1201 | 0.5722 | 0.1608 | 14 | 0.1994 | 0.0428 | 0.3674 | 0.3904 |
| 15 | 0.1512 | 0.1224 | 0.5682 | 0.1582 | 15 | 0.1968 | 0.0495 | 0.3745 | 0.3793 |

17.72%. Thus, consistent with the Granger-causality result, the GFEVD result suggests that fossil fuel consumption is endogenous with industrial sector output being the most important contributor to the variations in fossil fuel consumption. The highest contributor to financial development is own shock which explains 37.93% of financial development. Emissions of CO₂ contributes 19.68%, fossil fuel consumption contributes 4.95% and industrial growth contributes 37.45% to financial development. Thus, the GFEVD results suggest that the most exogenous variable in the system is industrial sector output followed by financial development.

6. Conclusion and policy recommendation

In this study, we investigated the dynamic linkage between fossil fuel consumption, industrial growth, financial development and CO₂ emissions in Ghana for the period 1971–2014. The study used the recently developed Bayer–Hanck combined cointegration technique and the ARDL bounds test with dummy variables included in the ARDL to take care of the structural breaks in the variables. Having found evidence that the variables are cointegrated, both the long-run parameters and the short-run parameters were computed which showed the existence of a U-shaped relationship between CO₂ emissions and industrial growth in both the long-run and short-run. The results suggest the EKC hypothesis is not valid for Ghana. This implies that the cost of output growth is environmental degradation and therefore calls for a surge in energy efficiency in firms' production technologies if sustainable economic development is to be achieved. This notwithstanding, the factors accounting for the U-shaped relationship were not investigated in the study. Future studies may consider other determinants of emissions of CO₂ such as

urbanization, cleaner production technologies, trade openness etc. which may affect the link between industrial growth and CO₂ emissions in Ghana. Another limitation of the study is that its findings cannot be generalized for other African or developing countries since it is a time series research on a single country, Ghana, and therefore for a more generalized findings and conclusions, a cross country analysis would be required in future. Also, instead of the real industrial sector output used in the present study, the per capita version of real industrial sector output could be considered in future studies. Fossil fuel consumption and financial development did not have significant impact on CO₂ emissions according to the ARDL parameters. Interestingly, the causality tests carried out via Granger-causality and variance decomposition suggest fossil fuel consumption and financial development have some significant relationship with CO₂ emissions. The difference in findings could be due to the difference in methodological background of each test. These tests serve different purposes and therefore their findings need not necessarily agree. For instance, whiles the estimated ARDL parameters would measure how much CO₂ emissions depend on the explanatory variables it does not necessarily imply causation. Granger-causality test is performed to detect only within sample causal relationships whiles out of sample relationship is ignored. Also, the exact magnitude of the feedback relationship between the variables cannot be provided in the Granger-causality procedure. Meanwhile, the GFEVD test is designed to detect the magnitude of feedback in a variable due to innovative shocks to another variable in the system over a given time horizon beyond the sample period. [Pesaran and Shin \(1998\)](#) rightly notes that the GFEVD method provides the proportional contributions in a variable resulting from innovative shocks from the other variables included in the model. Thus, since all three models apply different

methodologies in estimation and serve different purposes, their findings could differ.

The long-run and short-run causal relationships between the variables were examined by conducting ECT augmented Granger-causality test which showed the existence of long-run causality only when emissions of CO₂ is the regressand. The short-run causality showed the existence of a uni-directional causality between fossil fuel consumption and emissions of CO₂ where fossil fuel consumption Granger-causes emissions of CO₂. Industrial growth was also found to influence fossil fuel consumption but not the reverse. This suggests that policies which aim at reducing the consumption of fossil fuel will not harm industrial growth since other cleaner and energy efficient technologies can be adopted by firms to replace fossil fuel. This is crucial for environmental sustainability, as expansion in the output of the industrial sector could still be achieved in the presence of strict environmental policies which limit fossil fuel consumption. The causal relationships discovered are valid because as firms grow and expand their scale of production, the use of fossil fuel also increases. As mentioned earlier, the industrial sector in Ghana uses obsolete and inefficient energy consumption equipments and hence exacerbating the greenhouse gases problem. The short-run causality test further showed that emissions of CO₂ Granger-causes financial development.

This study recommends the adoption of energy efficient technologies and increase use of renewable energy whiles the consumption of fossil fuel is reduced. Government can achieve this by providing subsidies on these low carbon technologies to encourage its use whiles imposing or raising tariffs on fossil fuel consumption in Ghana especially beyond a certain threshold. This study further recommends that, as a way of curbing the increased pollution from firms' production activities, government should gradually migrate firms to renewable energy technologies starting from the largest firms (in terms of output size). Government should set targets in terms of the percentage of firms expected to migrate periodically from fossil fuel technologies to renewable energy. Relevant policies must be put in place to ensure that firms migrate to renewable energy use as their scale of production increase.

Government should also ban the importation of obsolete and energy inefficient machines which have the tendency to emit excess pollution as well as increase the sanctions of firms who exceed the acceptable levels of pollution to serve as deterrent to other firms.

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