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RESEARCH ARTICLE

The effects of urbanization, ICT, fertilizer usage, and foreign direct investment on carbon dioxide emissions in Ghana

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Abstract
Rising levels of carbon dioxide emissions in emerging countries has become a concern to all and there are calls for urgent action to curtail this. Ghana's government has in recent times sought to achieve higher economic growth at a lower carbon emission rate. With the current development of the country, this study analyzed the effect of urbanization, fertilizer usage, foreign direct investment (FDI), and ICT development on carbon dioxide emissions in Ghana. Time series data for 1971–2018 period was analyzed using autoregressive distributed lag regression approach within the environmental Kuznets curve (EKC) framework. From regression analysis, while the EKC hypothesis was not validated for aggregate carbon emissions, it was found that urbanization has a negative and significant impact on aggregate carbon emissions, whereas FDI and ICT infrastructure have positive impacts on the same in the both long run and short run. Fertilizer usage is seen to interact with urbanization to reduce carbon emissions at the aggregate and sectoral levels. It was found that although ICT helps reduce emissions at some sectoral levels, it was not enough to lower emissions at the aggregate level. Among other things, it is important for Ghana to take a critical assessment of its FDI sources and engagements to ensure that it does not become a sink for high toxic-emitting industries. Intensive education on efficient usage of fertilizer is also needed. It is important for policymakers to critically assess ways and means by which ICT development can be deployed to reduce overall carbon dioxide emissions in the country.

Keywords Fertilizer · ICT development · Carbon emissions · Urbanizations · Foreign direct investment

Introduction

Developing countries are faced with numerous challenges including low economic growth, infrastructural deficit, food insecurity, and urban slums due to growing urbanization. These have necessitated the implementation of several policies by many of such countries to unravel their challenges. For instance, to facilitate economic growth, some have opened their borders to international trade and embraced foreign direct investment (FDI) (Acquah and Ibrahim 2020). Mechanization and intensive farming have been adopted to improve food and nutrition security (Emami et al. 2018). Investment in infrastructural development to improve living conditions has also risen (Nketiah-Amponsah and Sarpong 2019).

The literature reveals that foreign direct investment spurs economic growth because in many cases it promotes industrial activities, and it is associated with transfer of technology, and capital formation (Malikane and Chitambara 2017; Moudatsou 2003; Sarker and Khan 2020). By mechanizing the agriculture sector crop yields increase, farms are

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expanded, more people are employed, and farm income increases. The effect is that food becomes readily available for all, while at the same time farmers and others employed because of farming activities earn more money to meet their food needs. Thus, food becomes readily available at less costs for all, while it generates more income for people to meet their food and non-food needs. Investing in infrastructural needs helps to improve the living conditions of people since basic amenities including water, electricity, health, and road are met (Nketiah-Amponsah and Sarpong 2019).

Ghana's economic policies have followed the above strategies aimed at addressing its developmental challenges. The Ghana Investment and Promotion Center has been set up to attract foreign investors into the country. Over the past 29 years, the country has attracted a net foreign direct investment of about US$ 41.4 billion. Specifically, in 1990, the net FDI was US$ 14.8 million which rose to US$ 165.9 million in 2000. Nineteen years later, Ghana received US$ 13.8 billion as net FDI. These amounts received over the said years translate into 0.25%, 3.3%, and 5.4% of GDP respectively (World Bank 2021). As a developing country, the agricultural sector has been the agenda of successive governments of Ghana in order to promote growth of the country (Kwakwa et al. 2022). Consequently, policies such as Food and Agricultural Sector Development Policy formulated in 2002 sought to modernize the agricultural sector and make it a catalyst for rural transformation. The planting for food and jobs was launched in 2017 with agricultural mechanization services (to intensify agricultural activities) as part of its defined five pillars. As part of the mechanization efforts, the Government has subsidized agricultural machines for farmers. The intensification of agricultural practices has led to the implementation of fertilizer subsidized program. The policy which started in 2008 aims at making it cheaper to access fertilizer and increase its usage. There are calls for government to continue with this policy which has led to increased food production, job opportunities, and welfare, to at least 2024 (Iddrisu et al. 2020).

Successive governments in the country have made effort to add on to the infrastructural facilities of the country. In recent times, areas such as education, transportation, and information telecommunication have received greater attention from the government. The digitalization agenda which is to digitalize economic activities in Ghana has necessitated in huge investment in information and communications technologies (ICT) infrastructure. The ICT sector in the country has become one of the fastest growing industries in the country (Oxford Business Group 2022). It is estimated that the sector is valued at $1 billion and by 2030 it may hit $5 billion (International Trade Administration 2022). In 2010, Ghana's population became urbanized when 50.7% of the population were identified to be residing in the urban towns. The current population census indicates that 57% of Ghanaians reside in urban areas. However, the slum conditions, congestion, and waste management in urban Ghana remain a major challenge (Alhassan et al. 2020; Kwakwa et al. 2018).

In all these, the government of Ghana is committed to having a low carbon economy by becoming signatory to many international protocols meant to halt carbon dioxide emissions in order to address the climate change menace. Thus, the commitment of the government forms part of the country's contribution to fighting the global problems of global warming and climate change whose effects have been witnessed in the country (Alhassan et al. 2019; Arku et al. 2017; Arku 2013). As contained in the Ministry of Environment Science, Technology and Innovation (2013) National Climate Change Policy, Ghana's target is to develop its economy within low carbon emissions rate. Notwithstanding, since 1990, Ghana's carbon dioxide emission has more than quadrupled to 16,110 kt in 2018 (World Bank 2021). Although this is a negligible portion of global emissions, the rising trend and effects cannot be overlooked. In fact, Ghana's carbon dioxide emission adds to compound the rising effects of higher emissions from developed and other developing countries.

The literature has documented the potential role of fertilizer usage, FDI, urbanization, and ICT development on carbon dioxide emissions. For instance, FDI through the pollution haven effect may positively affect (that is it increases) carbon dioxide emission because their activities are not environmentally friendly. On the other hand, it may help to reduce carbon dioxide emission through the pollution halo effect when their activities promote efficiency (Huang et al. 2022). The use of fertilizer can reduce carbon dioxide emission because it will reduce the land space cleared for farming. On the other hand, more fertilizer usage means more must be produced and transported through processes that require more energy, hence an increase carbon dioxide emissions (Yara 2022). The process of constructing ICT infrastructure has the capacity to increase carbon emissions when energy-efficient means are not employed (Chatti, 2020). After construction of these amenities, there may reduce carbon dioxide emission when they facilitate the research and development of energy-efficient technology, cheaper movement, and cheaper access to clean energy (Raheem et al. 2020). In the urban space, the congestion and waste management problems create a surge in carbon dioxide emissions. In some areas, the congestions promote economies of scale thereby helping to reduce carbon dioxide emission (Adom et al. 2018).

Based on the above and government of Ghana's effort of attaining low carbon economy, it becomes crucial to ascertain how fertilizer usage, FDI, urbanization, and ICT development affect the level of carbon dioxide emissions in the country. This is urgent because not much empirical analysis has been done in this regard on Ghana despite the growing interest of researchers on environmental quality in the country (Adom et al. 2018; Abokyi et al. 2019; Alhassan et al. 2022; Kwakwa 2021). In this regard, this study seeks to analyze the effect of urbanization, fertilizer usage, FDI, and ICT development on carbon dioxide emissions in Ghana. It is also hard to find the interactive effect of urbanization and fertilizer usage in the literature. Doing such interactive analysis is necessary since in some developing countries like Ghana, many of the rural areas where farming takes are not far from the urban centers. In fact, urban expansion has led to the situation where many rural areas have been swept by the urban activities. This has led to a reduction in the land space for farming. Consequently, the use of fertilizer is one of the panacea to increasing food yield.

Therefore, this is also considered in this study on the grounds that urbanization usually involves the clearance of forest cover for building purposes while with relatively reduced farm lands, available fertilizer usage may be intensified to get more yields instead of clearing more lands. In such cases, it can be said that fertilizer usage can trigger urbanization to reduce carbon dioxide emissions.

This study is novel by highlighting the effect of ICT development on carbon dioxide emissions in Ghana since previous studies have not investigated this despite the increased investment into the IT sector in the country. Also, the interaction effect of urbanization and fertilizer use on carbon dioxide emissions is examined. As urbanization is increasingly becoming a global phenomenon and increased fertilizer usage has been suggested towards food production, such interaction effect of the two on carbon emissions is necessary guide for policymakers in designing appropriate framework to handle these issues but little is known about this empirically. It also contributes to the literature by offering sectoral evidence of carbon emisisons in addition to the aggregate carbon emissions.

Literature review

Global climatic conditions continue to worsen over the years. The concentration of greenhouse gases such as carbon dioxide continue to rise. The concentration of carbon dioxide has increased by 148% over the pre-industrial level, reaching an all-time peak in 2019 with an averaged mole fractions at 410.5 ± 0.2 parts per million (ppm) (World Meteorological Organization, WMO 2021). Such increase poses threats to the global society, for instance, by making adverse exposures more frequent and long lasting (Jacobson et al. 2019). Considering its major threats on the global economy, several studies have been conducted to provide recommendations on minimizing its emissions and anticipated impacts (Rehman et al. 2021; Chatti and Majeed 2022; Chandio et al. 2021, 2019; Kwakwa 2020).

Effect of economic growth on carbon dioxide emissions

Earlier studies focused on the direction of relationship between carbon emissions and economic growth or the presence of environmental Kuznets curve (EKC) in a particular economy or a set of economies. The EKC theory states that economic growth shall in the long term help reduce environmental degradation although in the short term it may be the opposite. This occurs through three processes of scale effect, composition effect, and technique effect. First, a growing economy will initially increase extraction of environmental resources, as well as mass production to meet growing demand by the population. This increases environmental degradation (carbon emissions). Second, at a latter growth stage, consumption transits from agrarian goods to industrial and finally to service goods where environmental degradation begins to fall. Lastly, higher economic growth translates into acquisition of energy-efficient technologies for production and the implementation of cleaner environmental policies (Aboagye et al. 2020) thereby reducing environmental degradation. This results in an inverted U-shape relationship between income and environmental degradation. Studies by Olubusoye and Musa (2020) provided that the data of 79% of African countries supports the existence of EKC while that of the remaining 21% does not support the EKC hypothesis. For Olubusoye and Musa (2020), these later countries must take steps including carbon trading to ensure economic growth with lower emissions. Beyene and Kotosz (2019) estimated for East African economies a bell-shaped relationship between economic growth and carbon emissions, and argued for environmental and modern industrial policies to ensure economic activities are not detrimental to environmental quality. Ajanaku and Collins (2021) and Kwakwa and Adu (2016) confirmed the EKC hypothesis for sub-Saharan African countries.

Effect of foreign direct investment on carbon dioxide emissions

Also important in explaining carbon emissions or environmental quality is the level of FDI. This has been given broader attention in the literature (Duan et al. 2021; Dhrifi et al. 2020; Zhang et al. 2017; Ngonadi et al. 2020; Acheampong et al. 2019; Tang 2014). The effect of FDI on the environment is argued through the pollution haven effect and the pollution halo effect. The pollution haven effect posits that the environment of the host country gets polluted through investment into environmentally weak regulated energy-intensive sectors/economies. On the other hand, the pollution halo effect argues that carbon emissions are reduced through the transfer of energy-efficient technology to the host country. There have been mixed empirical results based on the location or time duration of the data used. For instance, Dhrifi et al. (2020) estimated that while there is a negative relationship between FDI and carbon emissions on African countries, there is a positive effect from Latin American countries and a U-shaped relationship in Asian countries. Even within the same country, Zhang et al. (2017) observed that there are different impacts based on the regional locations of China. Wang et al. (2021a, b) found an inverted U-shaped relationship between FDI and carbon dioxide emissions in China. For the South African economy, Ekwueme et al. (2021) found that FDI exerts positive effect on carbon dioxide emissions. In their study, Halliru et al. (2021) found both inverted U-shape and N-shape relations between FDI and carbon dioxide emissions in West Africa. The findings of these studies therefore suggest that in order to provide near workable policies on FDI, periodic and localized analysis is necessary.

Effect of ICT on carbon dioxide emissions

Infrastructural development effect on environmental degradation is gaining attention in the present literature (Müller et al. 2013; United Nations Office for Project Services 2021; Churchill et al. 2021). Without adequate infrastructure, life becomes unbearable, economic growth gets retard, and education and health of individuals are adversely affected. However, a report by United Nations Office for Project Services (2021) has shown that almost 80% of greenhouse gases emanate from infrastructure development. Consequently, there are calls for energy-efficient infrastructure to reduce carbon emissions. Provision of infrastructure is usually energy intensive and the construction process involves destruction of the immediate environment including forest thereby leading to higher carbon emissions. ICT infrastructure can enhance energy efficiency by improving production and facilitating the development of renewable energy technologies which will help in the reduction of carbon dioxide emission (Atsu et al. 2021). However, it can increase carbon dioxide emissions through the production process (where more raw materials are extracted for production), the transportation process (from the manufacturing company to local and international user) which requires more energy, operational emissions from usage and repairs, and end of life disposal (Freitag et al. 2021). Empirically, Chatti (2021) found a positive effect of ICT on carbon emissions of 43 countries. Atsu et al. (2021) reported that ICT increases carbon dioxide emissions in South Africa. Haini (2021) recorded a negative effect of ICT on carbon dioxide emissions for ASEAN economies. The author reported that ICT reduces carbon dioxide emissions for manufacturing, transport, and residential sectors of the economies. Wang et al. (2022) also reported that ICT agglomeration indirectly increases carbon dioxide emissions through economies of scale but reduces it through technological innovation. Raheem et al. (2020) observed that ICT infrastructure has a negative effect on carbon emissions, while Añón Higón et al. (2017) estimated that although there is an inverted U-shaped relationship between ICT and carbon emissions globally, the turning point for the developing countries is higher than that of developed countries. Thus, many developed countries already have developed ICT levels beyond which there is a reduction in carbon emissions. Churchill et al. (2021) recorded a positive effect of transport infrastructure on carbon dioxide emissions.

Effect of urbanization on carbon dioxide emissions

Another major consideration in the literature is the effect of urbanization on carbon emissions. The rapid economic development has contributed to the rapid urbanization in many economies. Urbanization is seen as an identifier for human and social development, and a reflection of moving the social production structure from primary to secondary or tertiary (Zhao et al. 2021). In the next couple of decades, the United Nations has projected that urban population is expected to reach 70% of the world's population. The consumption lifestyle of urban population has therefore raised concerns for its environmental effect including carbon dioxide emissions. Theories like urban compact theory calms nerves that rising urban population is not harmful to the environment because scarcity of resources translates into development of efficient system of production. On the other hand, ecological theory contends that urbanization increases traffic congestion and waste management problem (Kwakwa and Alhassan 2018). It is also mentioned that the effect of urbanization on carbon emissions is through its effects on economic growth, energy efficiency, and energy consumption structure (Wang et al. 2021a, b). Thus, urbanization can have both negative and positive effects on carbon emissions based on the process and time. On the negative impacts, the process of urbanization changes the production, consumption, and transportation characteristics of the economy, thereby reducing the carbon absorption of the environment while on the positive, the process can lead to technological advancement and diffusion including energy-efficient technologies that would reduce the level of carbon emissions (Zhao et al. 2021). This means that for urbanization to yield positive dividends on the economy, the process must be carefully guided. Based on factors such as the geographical data and duration, there are estimated diversity in findings on the relationship between urbanization and carbon emissions (Chikaraishi et al. 2015; Liu et al. 2018; Musah et al. 2021). While some studies reported urbanization increases carbon dioxide emissions (Hanif 2018; Erdoğan et al. 2022; Sun et al 2022), others had the opposite results (Balsalobre-Lorente et al. 2022) and Amin et al. (2020) established an insignificant effect of urbanization on carbon emissions.

Effect of fertilizer on carbon dioxide emissions

The changes in the agricultural production environment including declining soil fertilities amidst rapid population growth especially in the urban areas are a threat to global food security. This has necessitated the promotion of sustainable agricultural intensification measures, largely, the promotion of fertilizer usage. Since 1961, cereal production has increased by

240% due to increase in productivity and land expansion, and between 2007 and 2016, about 23% of anthropogenic greenhouse gas emissions are from the agriculture sector (IPCC 2019). This places agriculture in a central part to greenhouse gas emission levels. Phiri et al. (2021) concluded that the effect of agriculture on carbon emissions is due to poor agricultural activities and practices including deforestation, burning of vegetation, and use of conventional fertilizers. It is in this regard that fertilizer usage is expected to help reduce carbon dioxide emissions. However, as Yara (2022) argued more fertilizer usage means more must be produced and transported through processes that require more energy plus its inefficient application can increase carbon emissions. Empirically, Pant (2009), Wei et al. (2020), and Guo et al. (2022) confirmed fertilizer usage increases carbon dioxide emissions.

Summary of literature review

The review has revealed a mixture of evidence and arguments regarding the effect of FDI, ICT, urbanization, and fertilizer on carbon dioxide emissions. While the more researchers are devoting attention to the subject matter, little empirical evidence is known about the moderating effect of fertilizer usage on the urbanization-carbon emission nexus. Also not much is known about the effect of ICT on carbon emissions in Ghana. Sectoral analysis of carbon emissions is also found to be limited. These above gaps are addressed in this study.

Methods

Theoretical and empirical model

The theoretical framework that this work is related to are the environmental Kuznets curve, the compact city theory, the pollution haven/halo hypothesis, and the theory of green economics. According to the EKC hypothesis (Grossman and Krueger 1995), environmental degradation is a function of income and the square of income which is expressed mathematically as:

$$\text{Evnt} = \text{YPC}_t \times \text{YPC}^2{}_t \times \mu_t \tag{1}$$

where Evn denotes environmental degradation, YPC is the income, and YPC^2 is the income square. The square term of the variable YPC is included in the model to reflect the non-linear relationship between economic growth and environmental degradation as argued by the EKC hypothesis. According to the EKC theory, there is an inverted U-shaped relationship between economic growth and environmental degradation. The random error is denoted by μ and t represents time. Guided by previous studies, CO_2 emission is used as an indicator of environmental degradation (Balsalobre-Lorente et al. 2021; Kwakwa 2020; Liu et al 2018; Shahbaz et al. 2019) since it contributes heavily to the global greenhouse gases and climate change.

The pollution haven effect argues that through FDI, countries with weak environmental regulations attract dirty firms that lead to higher levels of environmental degradation. However, the pollution halo effect suggests that FDI is considered a major channel of transfer of efficient technology and hence influences both the economic and environmental structure of the host countries which leads to lower environmental degradation (Balsalobre-Lorente et al. 2019). However, investigation of the environmental effect of FDI is mixed based on the pollution haven hypothesis (Cole 2004), and the pollution halo effect (Mohr 2002). On the empirical front, studies have shown that uncontrolled and unplanned urbanization has adverse impact on the environment, especially on the ecosystem and biodiversity (Sadorsky 2014; Sheng and Guo 2016) due to forest clearance and traffic congestion (Kwakwa and Alhassan 2018). Contrarily, the theory of compact city implies that through economies of scale as a result of urbanization resource waste is reduced thereby leading to lower degradation (Sadorsky 2014; Yi et al. 2017).

Based on the theory of green economics (Cato 2012), it is important to ensure that the use of fertilizer and ICT do not degrade the environment so as not to inconvenience future generation. Although adoption of fertilizer in farming reduces the land space cleared for farming, it has the potential to increase carbon emission via increased energy consumption for more production and transportation (Yara 2022). It has also been argued that fertilizer usage can trigger urbanization effect to reduce carbon dioxide emissions. Motivated by this argument, the interactive effect of urbanization and fertilizer usage on carbon dioxide emissions needs to be also explored. The effect of ICT development on carbon dioxide emissions is inconclusive. With no uncertainty regarding the direction of the effect ICT development exerts on carbon dioxide emissions despite the increasing spate in Ghana, it is worth considering in the carbon emissions model.

Adopting the Cobb–Douglas production function and the above argument, the EKC model is extended to include the variables posited to influence carbon dioxide emissions in Ghana as:

$$\begin{aligned} CO_{2t} = {} & A \times YPC_t^{\beta 1} \times YPC_t^{2\ \beta 2} \times FDI_t^{\beta 3} \times FERT_t^{\beta 4} \\ & \times UBS_t^{\beta 5} \times ICT_t^{\beta 6} \times (FERT_t \times UBS_t)^{\beta 7} \times e^{\mu t} \end{aligned} \tag{2}$$

where A represents the technological change and β_1–β_7 represent the input elasticity for the covariates. FDI, FERT, UBS, ICT, and FERT × UBS are respectively, FDI, fertilizer, urbanization, information communication technology, and the urbanization-fertilizer interaction. Transforming all the variables into natural logarithm, Eq. (2) is modified and expressed as Eq. (3):

$$\mathrm{lnCO}_{2t} = \mathrm{lnA} + \beta_1 \mathrm{lnYPC}_t + \beta_2 \mathrm{lnYPC}^2{}_t + \beta_3 \mathrm{lnFDI}_t + \beta_4 \mathrm{lnFERT}_t + \beta_5 \mathrm{lnUBS}_t + \beta_6 \mathrm{lnICT}_t + \beta_7 \mathrm{lnFERT}_t \times \mathrm{lnUBS}_t + \mu_t \quad (3)$$

Data and estimation techniques

To examine the effect of urbanization, fertilizer use, ICT development, and foreign direct investment on carbon dioxide emissions in this study, four main steps were followed: (1) stationarity test, (2) cointegration test, (3) estimation of long- and short-run relationships, and (4) diagnostic test to establish the goodness of fit of the model. The Zivot and Andrews unit root test (Zivot and Andrews (ZA), 1992) was used to test for the stationarity properties of the selected variables. Testing for the stationarity properties is important because time series data are usually non-stationary at levels and may produce spurious regression when used in level or non-stationary form. Compare to the Dickey and Fuller (Dickey and Fuller 1979) test, the Zivot and Andrews unit root test produces efficient and unbiased inference in the presence of structural break in the level time series data. This motivated the use of the ZA unit root test.

After the unit root test, the bound testing approach proposed by Pesaran et al. (2001) within the autoregressive distributed lag (ARDL) framework was used to test for the existence of cointegration among the selected variables. The null hypothesis states that there is no cointegration among the variables while the alternative hypothesis is that there exists cointegration among variables. The next step is the estimation of the long- and short-run parameters using the ARDL regression model. The ARDL approach has several benefits over the Johensen and Juselius' cointegration technique (Johansen and Juselius 1990). The estimations from the ARDL model are robust and efficient and accommodate series with different orders of integration I(0), I(1), or I(0)/I(1). In addition, it accounts for potential problem of endogeneity among the selected variables and autocorrelation (Odhiambo 2011). Following Pesaran et al. (2001), the long-run model in the ARDL framework for Eq. (3) is expressed as in Eq. (4);

$$\begin{aligned} lnCO_{2t} = {} & \delta_0 + \sum\nolimits_{k=1} \rho_{1k} CO^2{}_{t-k} + \sum\nolimits_{k=0} \beta_{1k} lnYPC_{t-k} \\ & + \sum\nolimits_{k=0} \beta_{2k} lnYPC^2{}_{t-k} + \sum\nolimits_{k=0} \beta_{3k} lnFDI_{t-k} \\ & + \sum\nolimits_{k=0} \beta_{4k} lnFERT_{t-k} + \sum\nolimits_{k=0} \beta_{5k} lnUBS_{t-k} \\ & + \sum\nolimits_{k=0} \beta_{6k} lnINFR_{t-k} + \sum\nolimits_{k=0} \beta_{7k} lnFERT \times lnUBS_{t-k} + \varepsilon_{1t} \end{aligned} \quad (4)$$

where δ_0 is the constant term, β_{1k}–β_{7k} represent the coefficients of the long-run component for Eq. (3), and $\mathcal{E}_{1t}$ is the error term. The error term is assumed to be normally distributed and white noise. lnFERT × lnUBS shows the long-run interactive effect of urbanization and fertilizer usage. All other variables are as previously defined. The error correction model (ECM) is then estimated to obtain the short-run coefficients and the rate of adjustment towards the long-run equilibrium given a disturbance in the long-run equilibrium relationship. The ECM model for Eq. (3) is presented as Eq. (5):

$$\begin{aligned} \Delta lnCO_{2t} = {} & \varphi_1 + \sum\nolimits_{k=1} \alpha_{1k} \Delta CO^2{}_{t-k} + \sum\nolimits_{k=0} \alpha_{2k} \Delta lnYPC_{t-k} + \sum\nolimits_{k=0} \alpha_{3k} \Delta lnYPC^2{}_{t-k} \\ & + \sum\nolimits_{k=0} \alpha_{4k} \Delta lnFD1_{t-k} + \sum\nolimits_{k=0} \alpha_{5k} \Delta lnFERT_{t-k} + \sum\nolimits_{k=0} \alpha_{6ik} \Delta lnUBS_{it-k} \\ & + \sum\nolimits_{k=0} \alpha_{7k} \Delta lnINFR_{t-k} + \sum\nolimits_{k=0} \alpha_{8k} \Delta lnFERT \times lnUBS_{t-k} + \lambda_1 ECM_{t-1} + e_{1t} \end{aligned} \quad (5)$$

where φ_1 is the constant term and the difference indicator is denoted by Δ. ΔlnFERT × lnUBS shows the short-run interactive effect of urbanization and fertilizer usage. The coefficient of the error correction term (ECM) is represented by λ_1. The ECM measures the rate of adjustment to long-run equilibrium when there is a shock in the equilibrium relationship. e_{1t} is the white noise error term, α_{1k}–α_{8k} are the short-run coefficients, and all other variables are as previously defined.

Prior to the ARDL short- and long-run estimations for Eq. (3), regression analysis was done which excluded the interaction term (lnFERT × lnUBS) to compare how robust the results are. The final step is the diagnostic test which was done to determine the robustness and stability of the model. The Jarque–Bera, Ramsey RESET, ARCH, and Breusch-Godfrey tests were estimated to respectively test the presence of normality, stability, heteroscedasticity, and autocorrelation in the models.

The study data consisting of annual time series data spanning from 1971 to 2018 was sourced from the World Bank's (2021) World Development Indicators. However, data for the sectoral analysis was from 1971 to 2014 based on data availability. Data series employed in this study include carbon dioxide emissions measured by metric tons per capita was used as a proxy for environmental degradation. For a sectoral analysis, carbon dioxide emissions from manufacturing industries and construction sector, from residential buildings and commercial and public services, and from transport sector were used for further analysis.

The covariates' variables adopted in this study are gross domestic product (GDP) per capita at constant $US and urban population as a percentage of total population which were used as indicators for economic growth and urbanization respectively. Fertilizer consumption was measured as kilograms per hectare of arable land and FDI denoted FDI inflow as a percentage of GDP. Finally, fixed telephone subscription was used as an indicator for ICT development. Table 1 below presents the variables' definition and measurement.

Table 1 Variables' definition and measurement

Variable	Definition	Measurement	Source
CO_2	Total carbon dioxide emissions	1. CO_2 emissions (metric tons per capita)	World Bank (2021)
MANCO	Carbon dioxide emissions from manufacturing industry and construction sector	2. CO_2 emissions from manufacturing industries and construction (% of total fuel combustion	
RESCO	Carbon dioxide emissions from residential building sector	3. CO_2 emissions from residential buildings and commercial and public services (% of total fuel combustion)	
TRANSCO	Carbon dioxide emissions from transportation sector	4. CO_2 emissions from other sectors, excluding residential buildings and commercial and public services (% of total fuel combustion)	
YPC	Gross domestic product (GDP) per capita	Gross domestic product (GDP) per capita at constant $US	World Bank (2021)
UBS	Urban population	Urban population as a percentage of total population	World Bank (2021)
FERT	Fertilizer consumption	Kilograms per hectare of arable land	World Bank (2021)
FDI	FDI inflow	The net inflow of foreign direct investment as a percentage of gross domestic product	World Bank (2021)
ICT	ICT	Fixed telephone subscription	World Bank (2021)

Results and discussion

Unit root and cointegration results

Table 2 shows that the variables at levels did not attain stationarity at any statistically significant level. However, after taking the first difference, they become stationary. This suggests they do not contain unit root and it is appropriate to proceed with estimation. To estimate the long-run and short-run relationship among the variables, a cointegration test was performed. Table 3 presents the cointegration test results indicating the variables included in the aggregate carbon dioxide emission models are cointegrated with total carbon dioxide emission as the dependent variable. This decision is arrived at because the test statistic value exceeds the critical values for the lower and upper bounds. In Table 4, cointegration results for the carbon dioxide emissions from the various sectors also confirm the variables are cointegrated. Therefore, we proceeded to estimate the short-run dynamics and the long-run relationships among the variables using the ARDL method.

Drivers of carbon emission in Ghana (excluding non-interactive variables)

Table 5 shows the long- and short-run results on the effect of the various exogenous variables considered on carbon dioxide emission levels of Ghana. The speed of adjustment coefficient is negative and statistically significant. It suggests that changes in carbon emission from the short and long terms will be corrected by 88.9% each period. Thus, the long-run relationship among the variables return to equilibrium at a shorter period.

GDP per capita has negative significant effects on carbon dioxide emission levels both in the short run and in the long run. Thus, an increase in Ghana's GDP would lead to

Table 2 Unit root test results

Variable	At levels		At first difference	
	T-Statistic	Break point	T-Statistic	Break point
lnCO_2	−3.97	1984	9.35***	1992
LnYPC	−2.70	1983	−5.31**	1986
LnUBS	−5.51	1985	−8.63***	1984
LnICT	−4.12	1997	−9.28***	2008
LnFERT	−4.68	1984	−11.69***	1980
LnFDI	−2.69	1984	−5.55***	2007
lnRESCO	−4.92	1985	−9.30***	2003
lnMANCO	−4.92	1982	−9.66***	1988
lnTRANCO	−4.23	1998	−7.94***	1994

**$p < 0.05$; ***$p < 0.001$

Table 3 Cointegration results for CO_2 emissions (metric tons per capita)

Critical values	Model with no interaction term (F-statistic = 5.02)		Model with interaction term (F-statistic = 8.57)	
	I(0) bound	I(1) bound	I(0) Bound	I(1) bound
10%	2.12	3.23	2.03	3.13
5%	2.45	3.61	2.32	3.53
2.5%	2.75	3.99	2.6	3.84
1%	3.15	4.43	2.96	4.26

Maximum lag length = 3

Table 4 Cointegration results for sectoral CO_2 emissions models with interaction terms

Critical values	Manufacturing sector (F-statistic = 5.06)		Transport sector (F-statistic = 8.72)		Residential sector (F-statistic = 5.52)	
	I(0) bound	I(1) bound	I(0) bound	I(1) bound	I(0) bound	I(1) bound
10%	2.03	3.13	2.03	3.13	2.03	3.13
5%	2.32	3.53	2.32	3.53	2.32	3.53
2.5%	2.6	3.84	2.6	3.84	2.6	3.84
1%	2.96	4.26	2.96	4.26	2.96	4.26

Maximum lag length = 3

Table 5 Short- and long-run regression with no interaction terms results

Variable	Coefficient	Std. error	T-value
Short-run			
D(lnYPC)	−0.520**	0.197	−2.629
D(lnYPC^2)	0.005***	0.002	2.789
D(lnUBS)	−1.639***	0.493	−3.323
D(lnICT)	0.366***	0.095	3.829
D(lnFERT)	0.011	0.033	0.341
D(lnFDI)	0.034***	0.012	2.714
ECM(−1)	−0.889***	0.149	−5.963
Long-run			
lnYPC	−0.584***	0.178	−3.270
lnYPC^2	0.006***	0.001	3.560
lnUBS	−1.843***	0.414	−4.443
LnICT	0.411***	0.074	5.499
lnFERT	0.012	0.037	0.337
LnFDI	0.038***	0.012	3.178
Constant	13.787***	4.842	2.847

**p value < 0.05; ***p value < 0.001. Selected model: ARDL(2, 2, 2, 3, 3, 3, 3)

a reduction in the carbon emission levels of the country and lower environmental deterioration. However, the square of GDP per capita has a positive significant effect on carbon emission levels both in the short run and in the long run. Thus, doubling economic growth leads to an increase in carbon emissions both in the short run and in the long run. These findings suggest that there is a U-shaped relationship between income and carbon dioxide emissions. This means an increase in economic growth leads to a reduction in environmental quality to a point where a further increase in economic growth would result in environmental degradation. With increase in per-capita incomes, the demand for manufactured goods would increase thereby forcing industrialization. Beyene and Kotosz (2019) estimated that there is an inverted U-shaped relationship between economic growth and carbon emissions in the short run while in the long run, the relationship is U-shaped. In a cross-country analyses, Esso and Keho (2016) and Narayan et al. (2016) found that the nature of relationship between economic growth and carbon emissions depends on the country. The implication is that beyond economic growth, other factors are critical in driving carbon emissions including the processes to economic growth itself. The finding suggests Ghana's growth and development agenda may not have helped much in tackling environmental challenges including carbon dioxide emission. In fact, the quest for higher income may lead to environmentally unfriendly way of production. This is not surprising since fossil fuel forms a greater share of energy usage in Ghana.

Urbanization has a negative effect on carbon emission both in the short and in the long run. Thus, an increase in the percentage of people living in the urban areas leads to a decrease in carbon emission both in the short and long runs. Urbanization shifts employment from agricultural to service sector and this could have a negative implication on carbon emission. Evidently, the service sector in the country has grown tremendously over the years. With most of them operating in the urban areas, it could be a reason behind this outcome. Also in Ghana, economic activities are mainly labor-intensive and thus less pollutant to the environment compared to developed countries. As such, the growth in urban activities may not exert pressure on carbon dioxide emissions. The finding could also be that the urban zone has not reached yet the level to trigger much carbon dioxide emissions as seen in other urban centers in other developing and developed countries.

Zhao et al. (2021) has explained that urbanization can result in a reduction in carbon emissions through efficient technological advancement and diffusion including energy-efficient technologies. Chikaraishi et al. (2015) also argued that as urbanization increases, environmental burdens become inelastic with economic growth and that countries become environmentally friendly when their GDP per capita and the percentage share of service industries in GDP are sufficiently high. Contrary to this study, Musah et al. (2021) estimated a positive effect of urbanization on carbon emission using a panel of West Africa countries and argued that this is largely due to poor public transport systems that enhance the use of private transport which aggravates carbon emissions. The results in this study supports other studies including Zhao et al. (2021) and Chikaraishi et al. (2015) assertions. Despite the population pressure in Ghana, the findings lend support to the ecological and compact city theories of urbanization as well as the empirical studies of Balsalobre-Lorente et al. (2022).

The effect of ICT development on carbon emissions both in the short and in the long runs is positive and statistically significant. An increase in ICT development leads to an increase in the demand for energy, thereby translating into higher carbon emissions. Consistently, Altinoz et al. (2021), Raheem et al. (2020), and Majeed (2018) estimated a positive effect of telephone/ICT infrastructure on carbon emissions. Specifically for sub-Saharan Africa, Avom et al. (2020) argued that in addition to its direct effect on carbon emissions, ICT also indirectly increases carbon emissions through its effect on energy consumption.

FDI has positive significant effect on carbon dioxide emissions both in the short and long runs. This means that an increase in FDI in Ghana would lead to an increase in the country's carbon emission levels. The outcome in this study suggests that foreign firms operating in Ghana engage in production activities that result in higher carbon dioxide emissions. This could be related to weak enforcement of the regulations that govern the operations of foreign firms in the country. Thus, the observed positive effect can be explained by the pollution haven effect hypothesis which explains that firms would relocate from stringent environmental regulation and high energy prices to areas or countries with laxer environmental regulations. Thus, because of the generally strongly environmental regulations of richer/developed countries, they tend to have "comparative disadvantage in pollution-intensive industries" and, as a strategy, move such industries to poorer countries (Duan et al. 2021). In their empirical investigation, Duan et al. (2021) observed that richer countries only send the high carbon emitting stages of the production other than the entire production to the poorer countries. Tang (2014) also argued that FDI increases for countries with proximate stricter environmental regulations and that export-oriented FDI are more sensitive to local environmental regulations than local market–oriented FDI. Related to empirical studies on sub-Saharan Africa, the present finding supports that of Ngonadi et al. (2020). Although positive, the effect of fertilizer consumption had no significant effect on carbon emission. This signals fertilizer usage has the tendency to trigger higher carbon dioxide emissions in the country.

The role of urbanization-fertilizer interaction on carbon emission of Ghana

To ascertain how urbanization and fertilizer usage interact to affect carbon dioxide emissions, another estimation which contains the interaction term is done and the results are reported in Table 6. There is a confirmation of the effects of income, ICT development, FDI, and urbanization on carbon emissions as observed in Table 5.

The results in Table 6 show that with an interaction of fertilizer consumption and urbanization, not only is the interaction effect significant in explaining carbon emissions but also, the independent effect of fertilizer consumption on carbon emission becomes significant both in the short and in the long runs. The effect of the interaction between urbanization and fertilizer usage on carbon dioxide emission is seen to be negative. One can interpret this to mean that generally fertilizer consumption in Ghana leads to higher carbon emissions in the country probably through transportation. However, interacting fertilizer usage with urbanization results in lower carbon dioxide emissions. Kwakwa et al. (2022) estimated that urbanization has effect on agricultural development. Urbanization restructures the food system value chain with less people in the production side and more in the transportation, marketing, and processing sides, and also results in shifts in consumer food demand and quantity demanded amidst the need to make agriculture more resilient (Satterthwaite et al. 2010). It stands to reason that urban pressure and congestion, as well as the little space for farming, makes urban farmers utilize fertilizer efficiently. By this, they maximize the little land instead of clearing other forest for farming which can result in further carbon emission reduction. Another explanation could be that greater portion of farming takes place outside urban towns where there is

Table 6 Results for short- and long-run regression with interaction terms

Variable	Coefficient	Std. error	*t*-statistic
Short-run			
D(lnYPC)	−1.401436	0.758455	−1.847750
D(lnYPC^2)	0.018531**	0.007245	2.557720
D(lnUBS)	−3.892760	42.893680	−0.090754
D(lnICT)	0.378818**	0.119946	3.158239
D(lnFDI)	0.112048	0.052769	2.123358
D(lnFERT)	5.557578	2.689288	2.066561
D(lnUBS × lnFERT)	−1.476014*	0.706949	−2.087864
ECT(−1)	−1.867400***	0.316229	−5.905219
Long-run			
lnYPC	−1.812500***	0.407984	−4.442571
lnYPC^2	0.019758***	0.003950	5.001543
lnUBS	−2.950831*	1.390308	−2.122430
lnICT	0.803277***	0.113278	7.091186
lnFDI	0.216131***	0.036983	5.844105
lnFERT	5.915220*	2.731336	2.165687
lnUBS × lnFERT	−1.526644*	0.727408	−2.098743
Constant	40.451848***	10.464639	3.865575

**$p < 0.05$; ***$p < 0.001$. Selected model: ARDL(3, 1, 3, 3, 3, 3, 3, 3) low formal education. Consequently, farmers in urban areas end up applying fertilizers in an efficient manner to reduce the emission effect associated with fertilizer usage. Also, the coefficient of the error correction model is also negative and significant. The coefficient suggests that changes in carbon emission from the short to the long run would be corrected over 100% each period. Obtaining ECT(− 1) figures less than − 1 has been commonly reported in the literature. The common explanation given is that there is convergence but it is oscillatory convergence or over convergence (Narayan and Smith 2008).

A sectoral analysis to ascertain the effects of the variables of interest on carbon emission from transport sector, manufacturing industries and construction sector, and residential building and public sector was performed. For want of space, the long-run results for the models with the interaction terms have been reported in this study for comparison. In Table 7, where the results are reported, it is seen that the EKC hypothesis holds only for the manufacturing industries and construction sector. The fact that the hypothesis does not hold for the other sectors could be the reason why the total carbon dioxide emissions was found not to hold as well. Urbanization was found to increase carbon emission from the transport sector and residential buildings and public services sector. This is an indication that the Ghana's transport sector in the urban areas has not been efficient yet to translate into overall lower carbon emissions. Similar argument can be cited for carbon emissions from residential and public services. The fact that urbanization reduces total carbon emissions as reported in Tables 5 and 6 could be that there are other sectors through which the carbon dioxide emission reduction effect from urbanization outweighs its increasing effect associated with the transport and residential and public sectors. Thus, there are many other sectors that urbanization triggers lower carbon emission leading to an overall reduction in the aggregate carbon emission. Similar argument can be cited for ICT development seen to reduce carbon emissions from the three sectors unlike the total carbon dioxide emissions. Also fertilizer usage interacts with urbanization to reduce carbon dioxide emissions in all the sectors.

Table 8 Diagnostic analysis results

Diagnostic	Test	Model with no interaction term	Model with interaction term
Serial correlation	Breusch–Godfrey (F-stat)	1.87(0.19)	1.22(0.30)
Normality	Jarque–Bera	5.59 (0.10)	19.27 (0.10)
Heteroskedasticity	ARCH (F-stat)	0.48(0.93)	0.57(0.86)
Stability	Ramsey RESET (F-stat)	1.64(0.12)	1.57(0.15)

p-values are in parentheses

Diagnostic analysis

To ascertain the suitability of the results, diagnostic tests are conducted for all models. Table 8 shows the hypotheses test results on the suitability of the aggregate carbon dioxide emission model. This is necessary to determine the robustness of the estimated model or results. The Breusch–Godfrey test result led to the failure to reject a no serial correlation in the error terms of the estimated model. Hence, the estimated model is justified. A Jarque–Bera test result explains whether the data has a skewness and kurtosis that is similar to the normal distribution of the data. From the result, it is concluded that the data is normally distributed. The ARCH is also used to determine the volatility in the time series data estimated, and from the insignificance of the test result, it is concluded

Table 7 Long-run results for sectoral carbon dioxide emissions

Variable	Manufacturing industries and construction sector		Transport sector		Residential buildings and public sector	
	Coefficient	*t*-Statistic	Coefficient	*t*-Statistic	Coefficient	*t*-Statistic
lnYPC	0.577***	6.977	− 0.179**	− 2.435	0.076	0.180
$lnYPC^2$	− 0.005***	− 6.235	0.003***	5.874	− 0.000	− 0.020
lnUBS	0.167	0.372	5.091***	4.925	3.877*	1.997
lnICT	− 0.133***	− 3.029	− 0.315***	− 6.668	− 0.449**	− 3.940
lnFDI	0.0136	1.050	− 0.110***	− 4.108	0.028	0.802
lnFERT	0.774*	2.073	6.606**	3.671	11.984**	3.875
lnUBS × lnFERT	− 0.223**	− 2.123	− 1.787***	− 3.725	− 3.055**	− 3.716
C	− 11.082***	− 4.357	− 9.675	− 1.745	− 12.485	− 0.955

**p value < 0.05; ***p value < 0.001

Selected model for manufacturing industries sector: ARDL(2, 0, 0, 1, 1, 0, 3, 3)

Selected model for transport sector: ARDL(2, 0, 3, 3, 1, 3, 2, 2)

Selected model for residential buildings and public places sector: ARDL(3, 1, 1, 2, 1, 2, 2, 2) that there is no heteroscedasticity from the estimated model. The final test was on the stability using the Ramsey RESET test for functional form analysis. The result shows that the estimated models are stable. In addition, Figs 1, 2, 3, and 4 on the CUSUM and CUSUM of square graphs show the stability of the model as the output lines are generally within the 5% boundaries. Similar outcomes were found for the sectoral regression results although they have not been reported to avoid repetition of tables and figures in the work.

Conclusion and policy implications

This study explored the effects of urbanization, fertilizer usage, FDI, and ICT development on carbon dioxide emissions in Ghana. Based on the identified gap in the literature, this study included an interactive effect of urbanization and fertilizer usage as a distinct determinant of carbon dioxide emissions in Ghana. In previous studies, the Johansen approach to cointegration was used for long- and short-run empirical analysis. However, we employ the ARDL simulations model to estimate the empirical relationships. Our empirical findings show that urbanization has a negative and significant impact on aggregate carbon emissions as suggested by the compact city theory. At the sectoral level, the compact theory did not hold for the transport and residential buildings and public service sectors. This could imply that there are other sectors through which the carbon dioxide emission reduction effect from urbanization outweighs its increasing effect associated with the transport and residential sectors.

FDI has a significant positive impact both in the long run and in the short run confirming the pollution haven hypothesis for aggregate carbon dioxide emissions. At the sectoral level, it was found to reduce emissions from the transport sector. At the aggregate level, ICT increases carbon dioxide emissions but the opposite was observed for emissions from the sectors. This signals that there are other sectors through which the carbon dioxide emission–increasing effect from ICT outweighs its decreasing effect associated with these sectors. Fertilizer interacts with urbanization to further reduce aggregate carbon dioxide emissions. The EKC hypothesis did not hold at the aggregate level. At the sectoral levels, there were mixed outcomes for the EKC hypothesis.

Fig. 1 CUSUM stability results for model without interaction term

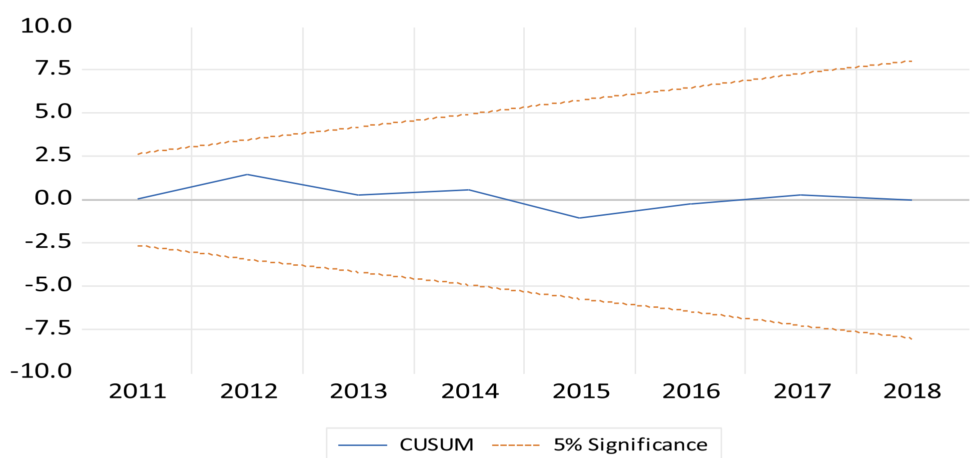
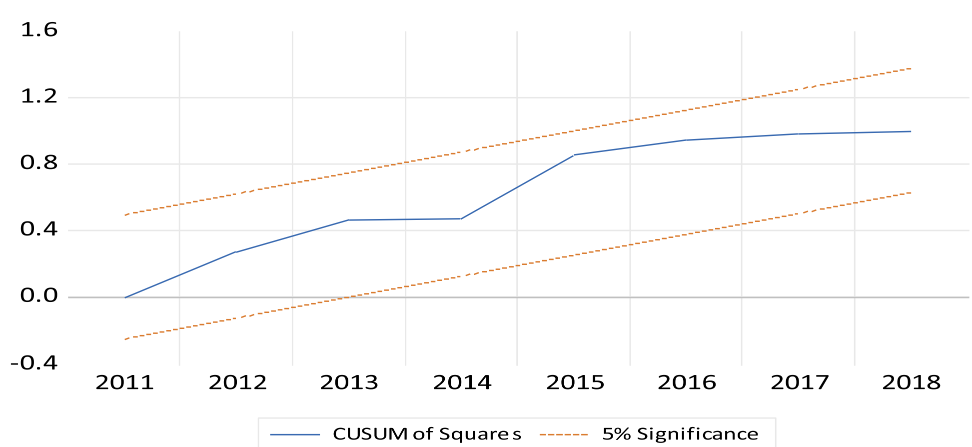


Fig. 2 CUSUM of squares stability results for model without interaction term



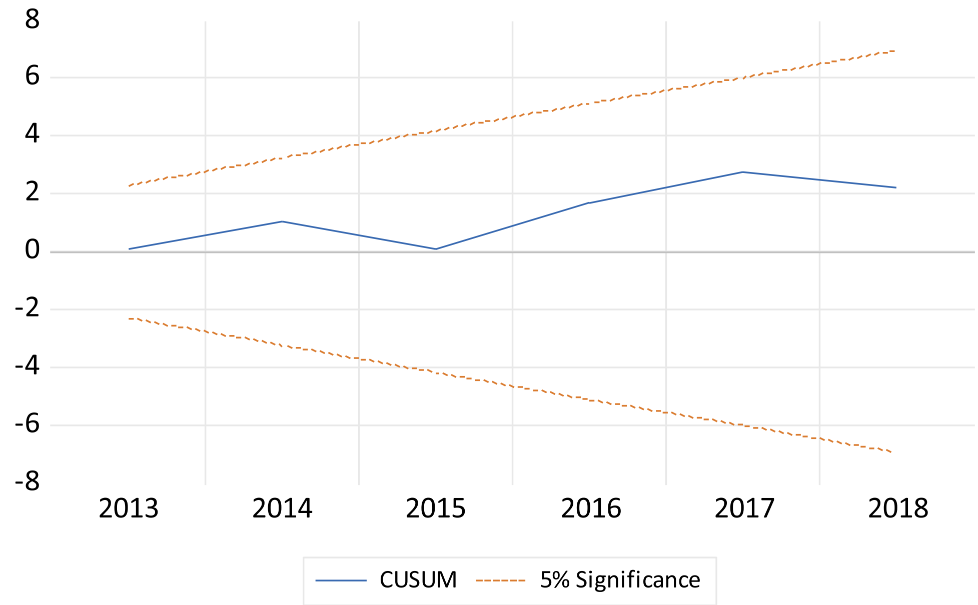


Fig. 3 CUSUM stability results for model with interaction term

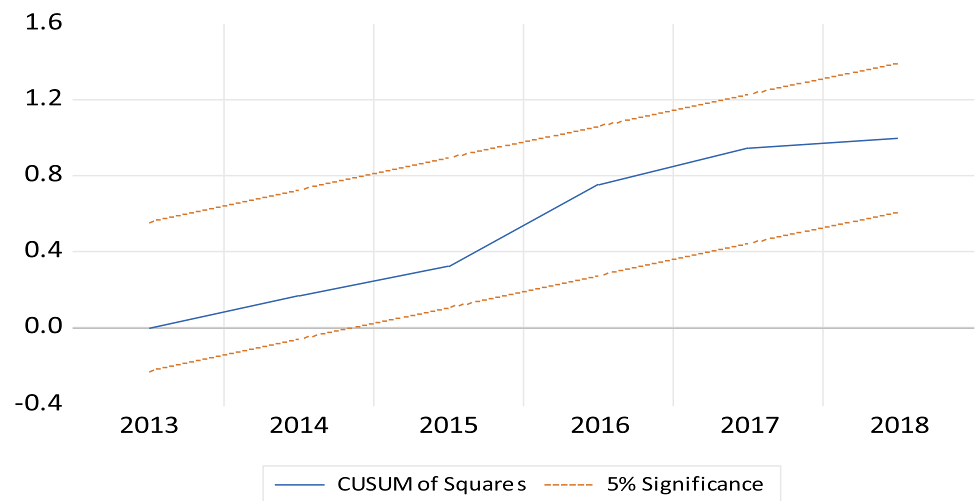


Fig. 4 CUSUM of squares stability results for model with interaction term

The findings obtained from this study hold significant policy implications for Ghana's decision-makers. First, our results indicate that urbanization can shift employment from agricultural to service sector, thereby reducing the levels of carbon emissions. As Zhao et al. (2021) explained, urbanization can result in a reduction in carbon emissions through the efficient technological advancement and diffusion including energy-efficient technologies. It is important therefore that the provision of service-oriented job opportunities in the cities of Ghana should ensure gradual transition into the green cities across the country. Secondly, urbanization can relatively reduce farmland availability and increased fertilizer usage to increase yields instead of clearing more lands. Therefore, urbanization can trigger fertilizer usage to reduce carbon dioxide emissions. It is important to equally emphasize on the need to intensify education given to farmers in the country for efficient application of fertilizers. The reason is that at the moment, inorganic fertilizers dominate the quantity used. Once the country is unable to produce organic ones on a large scale, it becomes crucial to pay attention to efficient application of fertilizer. Although Ghana is not one of the giants in Africa when it comes to ICT infrastructure, the pace of development is commendable. However, for such development to improve environmental outcomes, it is important for policymakers to critically assess ways and means by which ICT development can be deployed to reduce overall carbon dioxide emissions in the country. Sectors other than the transport, residential dwellings and public service and manufacturing industries and construction sectors that have not benefitted from the environmental degradation reduction effect of ICT should be targeted and appropriate actions taken to reverse the trend.

Thirdly, our results indicate that an increase in FDI in Ghana would lead to an increase in the country's aggregate carbon emission levels. This may be that firms responsible for FDI in the country might have relocated from stringent environmental regulation and high energy prices to take advantage of Ghana's relatively laxer environmental regulation. It is therefore important that Ghana takes a critical assessment of its FDI sources and engagements to ensure that it does not become a sink for high toxic-emitting industries. Pursuing green growth will help control carbon dioxide emissions associated with the growing economic activities in the country. Therefore, concerted efforts are needed to ensure that the plan to see renewable energy take a greater share of energy usage in the country become a reality. In all, designing appropriate policies to tackle carbon emissions from specific sectors is very laudable to help reduce the aggregate carbon dioxide emissions.

The paper has some limitations that need to be indicated. First, data constrain did not allow analysis that could have gone beyond the current periods used for the study. Another limitation of the paper is the proxy used for measuring ICT. It is known that ICT encompasses a wide range of items. Using fixed telephone subscription as a result of data challenge over the long period of study for Ghana, it is important for one to be cautious of the interpretation of the effect of ICT on carbon emissions. Future studies may consider, if data is available, disaggregated FDI specific effect on carbon dioxide emissions.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11356-022-23765-4.

Author contribution PAK conceived the research idea, HA built and analyzed the data, WA did the literature review, and EA discussed the results.

Data availability The datasets analyzed during the current study are available in the World Bank's World Development Indicators repository (https://databank.worldbank.org/source/world-development-indicators#).

Declarations

Ethical approval Not applicable.

Ethics approval and consent to participate Not applicable.

Research involving human participants and/or animals Not applicable.

Informed consent The study did not rely on data or participants that consent was needed.

Consent to publish The study did not rely on data/methods/images/figures/participants that consent was needed to publish.

Competing interests The authors declare no competing interests.

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