The effect of energy and urbanisation on carbon dioxide emission: evidence from Ghana

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Abstract

Concerned with the declining trend of renewable energy consumption as well as a change in the energy mix for electricity production amidst growing urban population and carbon dioxide (CO_2) emission in Ghana, this study examines the effect of urbanisation and energy on carbon dioxide emission in Ghana within the framework of the Environmental Kuznets Curve (EKC) Hypothesis over the period 1971–2013. Estimation results from Fully Modified OLS confirm the presence of the EKC hypothesis over the period for Ghana. In addition, combustible renewables and waste consumption, electricity production from hydro and trade openness are found to reduce carbon dioxide emission while fossil fuel consumption, electricity production from fossil fuels, urbanisation and industrialisation increase carbon dioxide emission for Ghana. The study again finds that an interaction between urbanisation and combustible renewables and waste consumption, however, has a positive effect on CO_2 while the interaction between urbanisation and fossil fuel consumption has a negative effect. Further analysis using the Engel–Granger causality test, the variance decomposition and impulse response functions are embarked. The outcome of the study implies the need to pursue the implementation of the low-carbon development strategy.

1. Introduction

The issue of climate change has been on the agenda of most world conferences and discussions. However, there has been a renewed interest among researchers and policymakers in recent times mainly because of its diverse implications, ranging from health to poverty implications. It has been established that carbon dioxide (CO_2) emission is the leading cause of climate change the world is battling with. Belaïd and Zrelli (2016) have described the issue of climate change as a multifarious fact that stems from the complex interactions between economic activities, energy and the environment. Thus, energy is necessary for economic production and, therefore, economic growth and the development of society. But relying on energy to achieve economic growth and development may come at a cost since energy is a major source of greenhouse gas (GHG) emissions, particularly CO_2 that deteriorate the quality of the environment. Consequently, the relationship between CO_2, income and energy has been investigated by researchers (see Ahmed *et al.*, 2016; Kwakwa and Adu, 2016; Shahbaz *et al.*, 2016; Twerefou *et al.*, 2016). However, in recent times, researchers have also paid close attention to the emission effect of population indicators especially urbanisation. Urbanisation has therefore become a force to reckon with in estimating the drivers of CO_2 emissions (see Poumanyvong and Kaneko 2010; Dogan and Turkekul, 2016; Hossain, 2012; Sharma, 2011; Sadorsky, 2014 and Adams *et al.*, 2016).

The present study seeks to examine the effect of energy and urbanisation on Ghana's carbon dioxide emission within the framework of the Environmental Kuznets Curve (EKC) Hypothesis. This study is crucial for Ghana's economy at a time like this on the following compelling grounds. In the first place, it is observed from the World Development Indicator (WDI, 2017) that growth in the country's economic activities and ultimately income has not reflected in the reduction of carbon dioxide emission. At the time Ghana became republic in 1960, the GDP per capita was US$1053.268. Although the country witnessed some abysmal performances that led to fluctuations of per capita income between US$ 700s and US$ 900s in the 1970s and 2001, the country's track record on its per capita income since 2001 has been tremendous. That is, from a per capita income of US$ 989 in the year 2001; the country has consistently increased its per capita income to about US$ 1969 as of 2015. Carbon dioxide emission (metric tons per capita) on the other hand, has increased from 0.2600 in 1971 to 0.2858 in 1993 and then to 0.5887 in 2013. Meanwhile, as suggested by the EKC, the emission effect of economic development will reduce in the long run. As a result, an empirical analysis to scrutinise this theory in the Ghanaian context is important for policy guidelines.

Second, there has been a significant change in Ghana's electricity generation mix and disturbing trends of renewable and non-renewable energy consumption. For many years, the country's electricity generation has come from hydro sources and thermal plants with the former supplying more than half of the total electricity generated in the country. Recent developments including erratic rainfall pattern and insufficient investment in the hydro sector have led to an increasing reliance on thermal plants for electricity generation in Ghana. As of now, close to 40 per cent of total electricity generated in the country come from thermal sources powered by fossil fuel. Data from the WDI (2017) show electricity generation from fossil fuel sources (oil and gas sources) has increased from 0.35 per cent in 1993 to 2.55 per cent in 2004 and then to 35 per cent in 2014. This then implies the share of hydro source in electricity has also reduced from 87.45 per cent to 65 per cent for the same period.

In addition, renewable energy consumption has been on the decline, implying non-renewable energy consumption (fossil fuel) is on the increase. For instance, the share of renewable energy consumption in total energy consumption has consistently reduced from 81.30 per cent in 1993 to 44.01 per cent in 2013 while the share of fossil fuel has increased from 17.45 per cent to 52.50 per cent within the same period (WDI 2017). Although electricity and fossil fuel consumption play an important role in Ghana's economy (Kwakwa, 2012), the changes in the electricity production mix (where fossil fuel source dominates the share of power production) and increasing consumption of non-renewable fossil fuel, have serious environmental concerns. This is because, the combustion of fossil fuel has threatening environmental consequences as the process contributes to the emission of green house gases (GHGs), particularly carbon dioxide (CO_2), which leads to global warming and climate change. This may, consequently, frustrate efforts by policymakers to reduce emissions of GHGs.

Although CO_2 emissions in Ghana is comparatively low, the figure over the years has almost tripled from 4547.08 (kt) in 1993 to 14620.33(kt) in 2013. Similarly, CO_2 emissions from electricity and heat production, (per cent of total fuel combustion) have seen a tremendous increase from 2.94 per cent in 1993 to 17.70 per cent in 2001 and then by 2013 the figure stood at 26.74 per cent with a 5-year average of 25.86 per cent (WDI 2017). As low as the country's share of global CO_2 emission is, the increasing trend of carbon dioxide emission if left unattended to, may among many things bring to futility the goal of achieving a low carbon economy, reduce agricultural yields and hence increase poverty, increase inequality and environmental related diseases in the country and other neighbouring countries. With future electricity generation from thermal plants expected to increase (thereby reducing electricity generation from cleaner hydro sources), as well as future consumption of non-renewable energy, a study that investigates the possible emission effects of the country's energy production and consumption pattern is necessary to offer policy guidelines.

Figures from the 2000 Ghana's population census classified the country as mainly rural with few metropolitan and cities. After 10 years the story changed when the 2010 census showed Ghana is an urbanised country. The country has since witnessed an increase in the number of urban towns as well an increased population growth at the urban centres. For instance, while in the year 2000, nine towns in the country had population between 50,000 and 100,000; by 2010 the number of towns had increased to 36 (Adams *et al.*, 2016). Also, the WDI shows that the population at the largest city has consistently increased from 1,668,240 in 2000 to 2,060,076 in 2010 and then to 2,354,124 in 2013. As some have posited (Sadorsky, 2014; Kwakwa and Adu, 2016), changes in urban population like the case of Ghana can affect the level of economic activities, energy use and CO_2 emissions. The reason is that urban areas are the hub of economic activities that require huge energy consumption and hence increase CO_2 emissions. Moreover, at the urban centres, heavy vehicular traffic movements are associated with the emission of fumes which may increase CO_2 emissions. However, it is also argued that since urbanisation leads to the scarcity of energy resources, dwellers resort to efficient ways of utilising energy which will reduce emission. In addition, urbanisation can reduce carbon dioxide emissions through an improvement in or efficient use of urban infrastructure (Li and Lin, 2015). Therefore, going into the future, once Ghana's urban population is expected to increase (United Nations 2015) it is imperative to estimate its effect on CO_2 emissions for the appropriate actions to be taken.

The foregoing developments make it necessary to examine the effects of energy and urbanisation on Ghana's CO_2 emissions under the EKC hypothesis. Our study is somewhat related to studies that have among other things examined the effect of energy (see Kwakwa *et al.*, 2014; Twerefou *et al.*, 2016), urbanisation (Adams *et al.*, 2016; Aboagye, 2017) or both urbanisation and energy (Opoku, 2013) on carbon dioxide emission for Ghana and other countries or regions (Jebli *et al.*, 2013; Sadorsky, 2014; York and McGee, 2017). However, this paper differs from these existing studies in four ways. First, the analysis of the energy variable by studies like Kwakwa *et al.* (2014), Twerefou *et al.* (2016) and Opoku (2013) among others was limited to the consumption effect while studies like York and McGee, 2017 focused on the production side. In this study, we appreciate the changing trend of energy mix for the production of electricity and thus examine the emission effect of electricity production sources (renewable and non-renewable) as well as that of consumption. Secondly, although there is much talk about the effect of fossil fuel on carbon dioxide emission, no study in Ghana has examined the effects of its rising levels on carbon dioxide emission. This study will bridge this gap.

Third, we analyze the effect of both renewable and non-renewable energy consumption on CO_2 emission which is an uncommon approach among studies that have focused on African countries. Fourth, unlike the other studies, apart from including both energy and urbanisation in the estimation process, we also analysed the interactive effect of energy consumption and urbanisation on CO_2 emission. The interactive term is necessary on the grounds that urban activities have direct effect on energy consumption which also affects the level of carbon dioxide emission. Thus, it can be established that the emission effect of urbanisation may be dependent on how efficient urban dwellers use energy. Furthermore, the argument that the development of renewable energy may reduce the emission effect of economic activities prevalent at urban centres may not hold since technological developments do not always yield the expected outcome owing to the dynamic behaviour of individuals in the society (Merton, 1936). In the light of this, we interacted urbanisation with both renewable and non-renewable energy consumption to appreciate how that affects carbon dioxide emission in the country. By doing so, our paper becomes different from Adusah-Poku (2016) who recently in his study on CO_2 emission for sub-Sahara Africa interacted total energy consumption and urbanisation.

2. Literature review

2.1. Review of theoretical argument

The theoretical underpinning for studies on the relationship between income and carbon dioxide emission has largely been the Environmental Kuznets Curve (EKC) hypothesis. The hypothesis argues that initial growth and development of economies is associated with high level of environmental degradation. However, beyond a certain threshold of growth and development, the rate of carbon dioxide emission declines. This thus forms, in the long run, an inverted U-shaped relationship between income and environmental degradation of which carbon dioxide emission is key. The common reasons for such a situation as given by Grossman and Krueger (1995), Panayotou (1997) and Stern (2003) are the scale effect (an expansion in economic activities that relies on energy will increase carbon dioxide emission and deteriorates the environment); composition effect (a change in output composition from agrarian to manufacturing will initially increase carbon dioxide emission; and then later to service activities which will reduce pollution); and abatement effect of economic growth and development (once economic development has been attained individuals and policymakers become more environmentally conscious and thus put policies in place to reduce carbon dioxide emission). Copeland and Taylor (2004) also attribute the existence of the EKC hypothesis to the source of economic growth. An economy whose initial growth is powered by capital accumulation but has human capital acquisition as the source of its advanced growth will witness this inverted U relationship between income and environment.

The effect of energy on the environment is through its combustion activities that release GHGs like nitrogen oxides, sulphur dioxide and carbon dioxide to pollute the environment. In this light, any inefficiency in the usage of energy will lead to more environmental degradation. On the other hand, efficiency in energy usage will help reduce environmental degradation via carbon dioxide emission (Sharma, 2011; Kwakwa and Adu, 2016). The discussion on the effect of urbanisation is based on three main theories namely the urban transition, ecological modernisation, and the compact city theories. The theory of ecological modernisation posits that economic transformation of the sectoral structure from agricultural through industry to the service sector is necessary to tackle environmental problems including carbon dioxide emissions and as such, urbanisation is necessary for such changes to be witnessed (Huber, 1982; Gouldson and Murphy, 1996; Gibbs, 1998; Sadorsky, 2014; Adams *et al.*, 2016).

The argument of the urban transition theory portrays a relationship between environmental problems and the level of affluence at the urban areas (Marcotullio and Lee, 2003). Thus, low-income countries are characterised by localised, immediate and health-threatening environmental problems while high-income countries are characterised by environmental problems that are global, delayed (intergenerational) and ecosystem threatening (Marcotullio and Lee, 2003). Ultimately, as urban cities transit from low income to high income, there is an increased environmental pollution but when high income is attained, environmental regulations and technological innovations may reduce pollution (McGranahan *et al.*, 2001; Sadorsky, 2014; Adams *et al.*, 2016). The compact city theory hypothesises that as urban cities get compacted through the development of existing urban areas rather than in suburbs or exurbs, activities and floor space become concentrated rather than dispersed. Consequently, transportation means to access services and workplace becomes easy thereby reducing carbon dioxide emissions from transportation and buildings (see Breheny, 1995; Holden and Norland, 2005; Sadorsky, 2014; Adams *et al.*, 2016; Yi *et al.*, 2017).

2.2. Review of empirical studies

The above review brings to bear that theoretically, income may have a non-monotonic relationship with carbon dioxide emission, while energy may have a positive or negative relationship depending on the efficiency involved in its usage and/or whether it is renewable or non-renewable. The effect of urbanisation is also indeterminate based on the ecological modernisation, urban transition and compact city theories. There has been a growing interest among scholars to investigate the underlying causes of carbon dioxide emission under the environmental Kuznets curve (EKC) hypothesis. A careful survey of the increasing number of empirical works on the subject shows there are conflicting results on the effect of income, energy and urbanisation on carbon dioxide emissions. There are those studies (Grossman and Krueger, 1995; Kwakwa *et al.*, 2014; Aboagye, 2017) that confirmed the EKC hypothesis for the countries of studies while others (Akpan and Akpan, 2012; Dogan and Ozturk 2017) did not. However, on the whole, majority of these studies have confirmed the EKC hypothesis. Studies that did not confirm the EKC hypothesis are mainly studies on developing countries with few from developed countries. Again, while some studies reported a positive effect of energy and urbanisation on carbon dioxide emission (Kwakwa and Adu, 2016; Ali *et al.*, 2017a), others had the opposite with some recording insignificant effects (Zhang *et al.*, 2015; Aboagye, 2017). The differences in these results could be attributed to the estimation methods used, data used and the differences in some features characterising the countries used for the study.

For instance, some researchers have focused on country-specific studies to examine effect of income, energy or/and urbanisation under the environmental Kuznets curve (EKC) hypothesis (Dogan and Ozturk 2017; Kwakwa *et al.*, 2014; Aboagye, 2017; Rafindadi, 2016b; Zhang *et al.*, 2015; Akpan and Akpan, 2012; Alam *et al.*, 2016; Ozturk and Al-Mulali, 2015; Arouri *et al.*, 2014; Ali *et al.*, 2017b, 2017a; Grossman and Krueger, 1995; Jayanthakumaran *et al.*, 2012). In the case of Ali *et al.* (2017a), they investigated the dynamic relationship between structural changes, real GDP per capita, energy consumption, trade openness, population density and carbon dioxide (CO_2)

emissions within the EKC framework over a period of 1971–2013 for Malaysia and reported a negative relationship between structural change and CO_2 emissions; a positive relationship between energy consumption, trade openness and CO_2 emissions; and no support for the EKC hypothesis.

Kwakwa *et al.* (2014) analysed the effect of agricultural growth, industrial growth and energy consumption on carbon dioxide emission in Ghana under the EKC hypothesis. Using time series data for the 1971–2008 period, the Johansen cointegration technique employed confirmed a long-run EKC hypothesis. The effect of energy consumption on carbon dioxide emission was also found to be positive in the long run. Rafindadi (2016a) was motivated by the deteriorating income of the Japanese economy after a natural disaster (Fukushima energy crisis) to examine the EKC hypothesis for the 1961–2012 period. The author employed the ARDL bounds test and the results indicated the presence of EKC. In addition, export, import and energy were found to increase carbon dioxide emission in the short run while in the long run, with the exception of export that reduced carbon dioxide emission, the rest increased carbon dioxide emission. Shahbaz *et al.* (2014) confirmed an inverted U-shaped relationship exists for the UAE. Also, they found that while electricity consumption reduced carbon dioxide emission, urbanisation was found to increase it. For their study, Ahmed and Long (2013) did not confirm the EKC hypothesis in the short run but confirmed it in the long run. In addition, energy consumption, trade and population density were observed to have a long-run positive effect on carbon dioxide emission in Pakistan. Zhang *et al.* (2017) found the EKC exist for Pakistan in the long run but not in the short run. Again, in both the short run and long run periods, non-renewable energy was noted to increase carbon dioxide emission while renewable energy reduced carbon dioxide emission.

Dogan and Aslan (2017) assessed the influence of renewable and non-renewable energy consumption and real income on CO_2 emissions in the United States of America (USA). They reported that the EKC does not hold for the United States; renewable energy reduces carbon dioxide emission and non-renewable emission increases carbon dioxide emission. Aboagye (2017) also examined the effect of economic growth on environmental degradation for Ghana over the period of 1975–2015 and established the EKC hypothesis. In addition, the effect of urbanisation on carbon dioxide emission was not significant while population and industrialisation exerted a positive effect on carbon dioxide emission. Trade was also reported to have a negative effect on carbon dioxide emission.

For the Nigerian economy, Akpan and Akpan (2012) had no support for the EKC hypothesis; a positive impact of income on carbon dioxide emission and a negative effect of electricity consumption on carbon dioxide emission. Also established by the authors were a unidirectional causality from income to emission, and no causality between energy and carbon dioxide emission. Also, using a time series data for the Sub-Saharan Africa, Aka (2008) employed the ARDL model to analyse both the short- and long-run impacts of trade and growth on carbon dioxide emissions on the region over the 1961–

2003 period. The findings were that income increases carbon dioxide emission in the short run but reduces carbon dioxide emission in the long run confirming the EKC hypothesis. Also, trade intensity was found to reduce carbon dioxide emission in both the short- and long-run period.

Also, there are those studies that have analysed the effect of income, energy or/and urbanisation on carbon dioxide emission under the EKC hypothesis for a panel of countries (Kwakwa and Adu, 2016; Aboagye and Kwakwa, 2014; Chakravarty and Mandal, 2016; Al-Mulali and Ozturk, 2016; Apergis and Payne, 2010; Shahbaz *et al.*, 2014, 2016; Jebli *et al.*, 2016; Al-Mulali and Ozturk, 2016; Dogan and Seker, 2016; Amuakwa-Mensah and Adom, 2017; Al-Mulali *et al.*, 2015; Apergis and Ozturk, 2015; Arouri *et al.*, 2014 and Iwata *et al.*, 2011 among others) but with different results.

For instance, Kwakwa and Adu (2016) modelled sub-Saharan Africa (SSA)'s CO_2 emission as a function of income, energy, trade, urbanisation and industrialisation. Their estimated results from the FMOLS and DOLS confirmed an inverted U-shaped relationship between income and CO_2 emission; an inverted U-shaped relationship between trade and CO_2 emissions and a positive effect from energy consumption and urbanisation. In a long-run analysis for six Central American countries, Apergis and Payne (2009) also had a confirmation of the EKC hypothesis and a positive impact of energy on carbon dioxide emission for the countries. Results from granger causality test showed a short-run one-way causality from energy consumption and real output to carbon dioxide emission but a long-run bidirectional causality between energy consumption and emissions.

A study by Jebli *et al.* (2013) confirmed the EKC hypothesis for 25 OECD countries. In addition, renewable energy, export and import were found to reduce carbon dioxide emission while non-renewable energy increased carbon dioxide emission. Jebli *et al.* (2013) obtained similar outcome regarding effect of income, renewable energy and non-renewable energy for a panel of 25 OECD countries over the period 1980–2010. Pandey and Mishra (2015) reported a U-shaped relationship between carbon dioxide emissions and economic growth in the context of South Asian Association for Regional Cooperation together with a unidirectional causality from economic growth to carbon dioxide emission was reported in both the short and long run.

In their study, Dogan and Seker (2016) confirmed the EKC hypothesis for the United States of America. Furthermore, the effects of renewable and non-renewable energy consumption were negative and positive on carbon dioxide emission, respectively. Trade was reported to reduce carbon dioxide emission for the country. Amuakwa-Mensah and Adom (2017) looked into the effects of quality of institution, forest, energy intensity and globalisation on carbon dioxide emission for sub-Saharan Africa within the EKC framework. Among other things, the authors found a confirmation of the EKC hypothesis; and a positive effect of urbanisation, energy intensity, petroleum intensity, electricity intensity and industrialisation.

There are those who have also explored the effects of these variables under the impact, population, affluence and technology (IPAT)/Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) models (Adams *et al.*, 2016; Li and Lin, 2015; Hassan, 2016; Shahbaz *et al.*, 2015; Sheng and Guo, 2016; Sadorsky, 2014; Martínez-Zarzoso 2008; Adusah-Poku, 2016). For instance, under the STIRPAT model, Li and Lin (2015) assessed the effect of urbanisation and industrialisation on carbon dioxide emission for 73 countries. Various estimations showed a positive effect from population, income, urbanisation, industrialisation and energy intensity on carbon dioxide emission for the sampled countries. However, when distinctions were made based on income groupings, urbanisation was observed to have reduced carbon dioxide emissions for middle-high-income countries while energy intensity reduced carbon dioxide emission for low-income countries. For the economy of Bangladesh, Hassan (2016) examined the effect of urbanisation on CO_2 emission for the period of 1972–2013. They found that income, urbanisation and technology exerted positive effects on carbon dioxide emission for the country. Shahbaz *et al.* (2015) in a study for Malaysia observed that the effect of income, energy and trade openness on carbon dioxide emission was positive in the long run. The relationship between urbanisation and emission was U-shaped in the long run. For the short run, only energy consumption was observed to have a positive effect on carbon dioxide emission.

There are other studies that did not rely on either the EKC hypothesis or the IPAT/STIRPAT models but still analysed the drivers of carbon dioxide emission for some countries or region that had income, energy or urbanisation as part of the explanatory variables (Al-Mulali *et al.*, 2015; Rafindadi, 2016b; Ahmed and Ozturk, 2016; Baek and Kim, 2013; Adusah-Poku, 2016; Dogan and Aslan, 2017; and Belaïd and Zrelli, 2016; Behera and Dash, 2017 among others). Halicioglu (2008) for the Turkish economy found that for the period of 1960–2005, carbon dioxide emission was positively affected by energy consumption, economic growth and trade. Also, Adusah-Poku (2016) found that population, trade and energy have positive effects on CO_2 emission in sub-Sahara Africa. He also reported that the interactive term between urbanisation and energy have a positive effect on emission in the subregion. York and McGee (2017) assessed how renewable electricity production interacts with GDP per capita to influence CO_2 emissions per capita for 128 nations from 1960 to 2012 and found that renewable electricity reduced carbon dioxide emission; interaction between income and renewable energy sources increase carbon dioxide emission; insignificant effect from urbanisation; a positive carbon dioxide emission effect from production per capita and manufacturing; and a negative effect from age dependency.

As clearly seen, there is no consensus from the above empirical studies on the effects of income, energy and urbanisation on carbon dioxide emission. This makes it necessary to avoid generalisation from empirical results for some countries in the policymaking process for another countries. Thus, empirical studies for specific countries are needed to design the appropriate policies to deal with climate change via carbon dioxide emission. However, the aforementioned analysis reveals that comparatively, fewer studies have explored the drivers of carbondioxide in the Ghanaian context. The few ones like Kwakwa *et al.* (2014), Adams *et al.* (2016) and Aboagye (2017) have at least analysed the emission effects of economic growth, energy consumption and urbanisation population. Nevertheless, the analysis of the source of electricity production has been overlooked in these studies. Moreover, and even beyond the Ghanaian literature, studies on the subject matter have paid little attention to the effect of the interaction term between energy and urbanisation on carbon dioxide emission. These important issues lacking in the extant literature are addressed by this present study.

3. Model specification, data and empirical strategy

3.1. Empirical model and data

Drawing inspiration from effect of income within the Environmental Kuznets curve hypothesis and theoretical arguments regarding the effects of energy and urbanisation on carbon dioxide emission, the main model used in this study is presented in equation (1).

$$CO_{2t} = \alpha + \beta Y_t + \chi Y_t^2 + \delta URB_t + \phi ENER_t + \mu_t \quad (1)$$

Where CO_{2t} is carbon dioxide emission which represents environmental degradation, α is the intercept, t represents time and μ is the stochastic error term. Y is income, Y^2 is income squared, URB is urbanisation and ENER is energy.

Previous studies (Kwakwa and Adu, 2016; Arouri *et al.*, 2014; Kwakwa *et al.*, 2014; Aboagye, 2017 and Al-Mulali and Ozturk, 2016) have indicated significant effect of trade (TO) and industrialisation (IND) on carbon dioxide emission. We account for these two by including them in our equation above. Furthermore, since our focus is to assess the effect of the energy mix for electricity production as well as the changing trends in renewable and fossil energy consumption, four separate variables are used to measure energy in the above equation. These are (i) renewable energy consumption, (ii) non-renewable energy consumption, (iii) electricity production from hydro source, and (iv) electricity production from fossil energy. Because the study also aims to examine the interaction effect of urbanisation and energy consumption on carbon dioxide emission, we also interact urbanisation with renewable energy consumption and urbanisation with fossil energy consumption. Consequently, equation (1) will be modified into equations (2–7) as follows:

$$CO_{2t} = \alpha + \beta Y_t + \chi Y_t^2 + \delta URB_t + \phi HYELE_t + \theta TO_t + \lambda IND_t + \mu_t \quad (2)$$

$$CO_{2t} = \alpha + \beta Y_t + \chi Y_t^2 + \delta URB_t + \phi FOSELE_t + \theta TO_t + \lambda IND_t + \mu_t \quad (3)$$

$$CO_{2t} = \alpha + \beta Y_t + \chi Y_t^2 + \delta URB_t + \phi COM_t + \theta TO_t + \lambda IND_t + \mu_t \quad (4)$$

$$CO_{2t} = \alpha + \beta Y_t + \chi Y_t^2 + \delta URB_t + \phi FOS_t + \theta TO_t + \lambda IND_t + \mu_t \quad (5)$$

$$CO_{2t} = \alpha + \beta Y_t + \chi Y_t^2 + \delta URB_t + \phi COM_t + \varpi URB * COM_t + \theta TO_t + \lambda IND_t + \mu_t \quad (6)$$

$$CO_{2t} = \alpha + \beta Y_t + \chi Y_t^2 + \delta URB_t + \phi FOS_t + \varpi URB * FOS_t + \theta TO_t + \lambda IND_t + \mu_t \quad (7)$$

Where *HYELE* is electricity production from hydro, *FOSELE* is electricity production from fossil energy, *COM* is renewable energy consumption and *FOS* is fossil energy consumption. The interaction between urbanisation and renewable energy consumption is represented by *URB*COM* while the interaction between urbanisation and fossil energy consumption is represented by *URB*FOS*.

3.2. Empirical strategy

The econometric analysis begins with unit root test to examine the stationarity situation of the variables. The unit root test is critical since most time series data are reported to contain unit roots, and thus to avoid spurious regression (Gujarati and Sangeetha, 2007); their stationarity properties need to be examined. Based on this premise, all the variables are subjected to a unit root test using the Augmented Dickey Fuller (ADF) test developed by Dickey and Fuller (1979) and Phillips–Perron (PP) test by Phillips-Perron (1998) that has been extensively used in most studies. The two unit root tests work under the null hypothesis of a unit root or non-stationary variables and the alternative hypothesis of, no unit root or stationary variables. Accepting the null hypothesis require that the series are differenced until stationary is attained.

After examining the unit root and the integration of the variables, the next step was to examine whether a long-run relationship between the variables exist. Hence, the cointegration test was conducted. This study employed the Engel–Granger residual-based test due Engle-Granger (1987) and the Phillips–Ouliaris residual-based test by Phillips-Ouliaris (1990). Both cointegration tests examine whether the residual obtained from the OLS regression is stationary. A stationary residual implies that the variables are cointegrated. The null hypothesis for both tests is no cointegration as against an alternative hypothesis of cointegration.

After attaining cointegration among the variables, the fully modified ordinary least square (FMOLS) developed by Phillips and Hansen (1990) is used to analyse the long-run relationship between the dependent and independent variables. The FMOLS estimator is used over other estimators because it is appropriate for estimating models with I (1) variables and endogenous regressors and does not require pretesting of cointegration rank. It is also reported to be robust for both non-stationary and endogenous variables. Following Adom and Kwakwa (2014), the FMOLS model is presented as:

$$\Phi_{FME} = \left(\sum_{t=1}^{T} Z_t Z_t'\right)^{-1} \left(\sum_{t=1}^{T} Z_t y_t^{+} - T\hat{J}^{+}\right) \tag{6}$$

where $Y_{t^+} = y_t - \hat{\lambda}_{ox}\hat{\lambda}_{xx}^{-1}\Delta x_t$ is the correction term for endogeneity, and $\hat{\lambda}_{qx}$ and $\hat{\lambda}_{xx}$ are the kernel estimates of the long-run covariances, $\hat{J} = \hat{\Delta}_{ox} - \ddot{\lambda}_{ox}\hat{\lambda}^{-1} xx\Delta_{xx}$ is the correction term for serial correlation, and $\hat{\Delta}_{ox}$ and $\hat{\Delta}_{xx}$ are the kernel estimates of the one-sided long-run covariances.

For further analysis, the study undertakes the Toda and Yamamoto (1995) causality analysis as well as the impulse response and variance decomposition analysis.

3.3. Data source and description

This study relies on time series data for period 1971–2013 accessed from WDI (2017) published by the World Bank. The dependent variable, CO_2 is measured by the log of carbon dioxide emissions in metric tons per capita. Income is measured by the log of per capita GDP. The EKC hypothesis is said to exist, if, income has a positive coefficient and a negative coefficient for income squared. Urbanisation whose effect can be positive or negative is measured as the urban population (per cent of the total population). Renewable energy consumption is measured as combustible renewables and waste (per cent of total energy) and it is expected to reduce carbon dioxide emission. Fossil fuel consumption measured as fossil fuel energy consumption (per cent of total energy) on the other is expected to increase carbon dioxide emission. Also, electricity production from fossil energy source is measured as electricity production from oil, gas and coal sources (per cent of total) while electricity production from hydro source is measured as electricity production from hydroelectric sources (per cent of total). The former is expected to increase carbon dioxide emission while the later is expected to reduce it. Trade openness is represented by the sum of import and export as a share of GDP and its influence can be positive or negative based on the argument in the literature (Kwakwa and Adu, 2016). The level of industrialisation measured by the industrial value added as a share of GDP is expected to increase carbon dioxide emissions (Aboagye, 2017). The effects of the interaction between urbanisation and fossil fuel consumption and urbanisation and combustible renewables and waste consumption are indeterminate.

Table 1 reports the descriptive statistics of the annual time series data covering the period 1971 to 2013. The mean of CO_2 is 0.32 with a standard deviation of 0.07. The mean for income is US $32,991.74 with a standard deviation of US $78750.07. Urban

Table 1 Descriptive statistics

Statistics	COM	CO_2	HYELE	FOSELE	FOS	IND	TO	URB	Y
Mean	64.59131	0.316190	89.62318	10.37627	27.45978	21.24710	56.66007	39.11502	32991.74
Median	69.07673	0.298966	98.87750	1.122496	22.09113	20.85505	51.33136	38.27450	265.9898
Maximum	80.99769	0.558786	100.0000	46.58928	52.61600	28.93804	116.0484	52.73500	332212.9
Minimum	39.68207	0.209693	53.41072	0.000000	15.14111	6.467179	6.320343	29.17400	5.676208
Std. Dev.	11.45639	0.073940	13.99063	13.98959	11.60276	6.147063	29.55348	7.706272	78750.07
Skewness	−0.885916	1.073159	−1.020675	1.020609	0.971954	−0.392674	0.209598	0.260717	2.593362
Kurtosis	2.506628	4.120935	2.567882	2.567786	2.503842	2.240421	1.970428	1.664323	8.694473

population as a share of total population has a mean value of 39.11 per cent and a standard deviation of 7.70 per cent. Combustible renewables and waste consumption, fossil fuel consumption and electricity production from hydro, respectively, has a mean of 64.59 per cent, 27.45 per cent and 89.62 per cent with a standard deviation of 11.45 per cent, 11.60 per cent and 13.99 per cent, respectively. The mean rate of urbanisation is 39.12 per cent with a standard deviation of 7.71 per cent.

4. Findings and discussion of results

4.1. Results for unit root and cointegration tests

This section presents and discusses the results from the econometric analysis. **Tables 2** and **3** presents the result of the unit root tests at level and first difference, respectively. The results as shown in Table 2 indicate that at level the PP test rejects the presence of unit root for Y and FOSELE, whiles the ADF test rejects the presence of unit root for Y and URB. This suggests that the variables Y, FOSELE and URB are stationary at levels or integraded of the order zero I(0). At first difference of the other variables (as shown in **Table 3**), both tests reject the presence of unit root for all the variables. Thus, all the other variables are stationary at first difference making them I(1) variables.

The Engel–Granger test and the Phillips–Ouliaris test were then used to check for cointegration among the variables. The result from the Engel–Granger test reveals that the null hypothesis of no cointegration is rejected by the tau-tests and the *z*-tests for each group of series. On the other hand, the results from Phillips–Ouliaris's tau-test reject the null

Table 2 Unit root test at levels

	PP		ADF	
	At levels			
Variables	Intercept	Intercept and trend	Intercept	Intercept and trend
CO_2	−0.3982	−2.8488	−0.0296	−3.0434
Y	−3.3234**	−0.2705	−3.8925***	−0.0710
HYELE	−1.3045	−3.2040	−1.3346	0.9272
FOSELE	−1.3063	−3.2044*	0.9253	−1.3355
COM	0.6682	−1.1422	0.3954	−1.3372
FOS	1.1358	−1.4109	0.5088	−0.9232
URB	2.6328	−3.008	0.0814	−3.6237**
TO	−0.7040	−2.1062	−0.7075	−2.0575
IND	−0.7317	−1.5323	−0.7319	−1.5323

***, ** and * denotes 1%, 5% and 10% level of significance, respectively.

Table 3 Unit root test at first difference

	PP		ADF	
	Intercept	Intercept and trend	Intercept	Intercept and trend
Variables	At first difference			
CO_2	−10.8348***	−24.8674***	−9.2197***	−9.3769***
Y	NA	−5.6309***	NA	−5.6509***
HYELE	−8.3442***	−9.4751***	−7.8889***	−8.4101***
FOSELE	−8.3442***	NA	−7.8910***	−8.4103***
COM	−6.6188***	−7.9918***	−6.6185***	−7.1099***
FOS	−7.9154***	−9.5148***	−7.8916***	−7.1731***
URB	−1.5045	−1.0987	−1.7066	NA
TO	−5.7037***	−5.6689***	−5.5108***	−5.4937***
IND	−5.5968***	−5.7016***	−5.5914**	−5.7015***

***, ** and * denotes 1%, 5% and 10% level of significance, respectively.

hypothesis of no cointegration for each group of series, but that of the *z*-test was mixed. The *z*-test accepts the null hypothesis of no cointegration for some of the group of series while it rejects others (**Table 4**). However, the overall results points to the conclusion that there is a long-run relationship between CO_2 emission, and the other explanatory variables.

4.2. Long-run determinants of carbon dioxide emission in Ghana

After confirming the existence of a long-run relationship among the variables, the FMOLS was used to examine the long-run relationship between the dependent and independent variables. The estimation results are reported in **Table 5**.

Table 4 Cointegration results

	Engel–Granger test (Ho: series are not cointegrated)		Phillips–Ouliaris test (Ho: series are not cointegrated)	
Series	tau-statisitc	*z*-statistic	tau-statisitc	*z*-statistic
CO_2|*HYELE, Y,* Y^2*, URB, IND and TO*	−6.2204**	−41.2654**	−6.3201***	−36.3646**
CO_2|*FOSELE, Y,* Y^2*, URB, IND and TO*	−6.2198**	−41.2637***	6.3194***	−36.3317**
CO_2|*COM, Y,* Y^2*, URB, IND and TO*	−5.3793*	−35.4094**	−5.3553*	−30.4322
CO_2|*FOS, Y,* Y^2*, URB, IND and TO*	−5.5016**	−35.9497**	−5.5027**	−30.8808

***, ** and * denotes 1%, 5% and 10% level of significance, respectively.

Table 5 Long-run estimates

Variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Y	0.2641***	0.2642***	0.2419**	0.2609**	0.2191*	0.2857**
	(2.8797)	(2.8763)	(2.0799)	(2.4223)	(1.8650)	(2.5723)
Y^2	−0.0100**	−0.0100**	−0.0100*	−0.0106**	−0.0097*	−0.0119**
	(−2.4354)	(−2.4354)	(−1.9625)	(−2.1403)	(−1.8763)	(−2.3617)
HYELE	−0.0050***					
	(−3.5824)					
FOSELE		0.0050***				
		(3.5794)				
COM			−0.0079		−0.0406**	
			(−1.6745)		(−2.4407)	
FOS				0.0070*		0.0378**
				(1.8168)		(2.5036)
URB	0.0764***	0.0764***	0.0629**	0.0689***	0.0139	0.0910***
	(4.3864)	(4.3865)	(2.3309)	(3.0360)	(0.3824)	(3.5283)
*URB*COM*					0.0010**	
					(2.040)	
*URB*FOS*						−0.0010*
						(−2.0010)
IND	0.0115***	0.0115***	0.0169***	0.0154***	0.0195***	0.0167***
	(3.8208)	(3.8196)	(3.3968)	(3.7568)	(3.7230)	(3.9187)
TO	−0.0025***	−0.0025***	−0.0029**	−0.0027**	−0.0050***	−0.0043***
	(−2.9562)	(−2.9564)	(−2.6738)	(−2.700)	(−3.5367)	(−3.5446)
Constant	−4.9453***	−5.4471***	−4.3113**	−5.3163***	−1.7395	−6.3334***
	(−4.7899)	(−5.3263)	(−2.6647)	(−4.3017)	(−0.8483)	(−4.6718)

***, ** and * denotes 1%, 5% and 10% level of significance, respectively.

Based on the results, log of income (Y), log of income squared (Y^2), urbanisation (URB), and industrialisation (IND) and trade openness (TO) have a significant effect on carbon dioxide emissions in all the six models. In all income, urbanisation and industrialisation increase carbon dioxide emissions, while income square and trade openness decrease carbon dioxide emissions. Specifically, a 1 per cent increase in real per capita GDP increases carbon dioxide emission between 0.24–0.29 per cent, while a 1 per cent increase in the square of income will decrease carbon dioxide emission by 0.01 per cent. The finding confirms the EKC hypothesis, indicating that continuous economic growth results in the reduction of carbon dioxide emission in the long run. In this case, one can conclude that Ghana's economic growth and developmental process over the period of study has not been detrimental to the country's environment. This finding is consistent with a number of past studies conducted by Kwakwa *et al.* (2014), Rafindadi (2016b) and Zhang *et al.* (2017), but is contrary to what Dogan and Aslan (2017) observed.

Trade openness is found to decrease CO_2 emissions from all the six models. According to the estimates, a unit increase in trade openness is expected to cause CO_2 emission to decrease between 0.25 and 0.50 per cent. The result suggests that trade openness has a technical and composition effects which could reduce environmental degradation (Adams *et al.*, 2016). Thus, trade openness among other things has helped make available energy efficient technology in the country. Furthermore, this finding could be attributed to the strict environmental regulation instituted by the government. The ban on the importation of energy inefficient electrical appliances especially refrigerators and penalty for the clearance of over age vehicles (above 10 years) are examples of such policies instituted by the government to promote the usage of efficient technology and automobiles (Adams *et al.*, 2016). The emission reduction impact of trade openness is consistent with the results of Arouri *et al.* (2014), and Al-Mulali and Ozturk (2016). However, it contradicts the arguments made by Twerefou *et al.* (2016) that in Ghana, the increased importation of e-waste and exportation of gold which uses petroleum product for power generation result in increased CO_2 emissions that are detrimental to the environment.

The long-run effect of industrialisation on CO_2 emissions is positive, suggesting that a unit increase in industrialisation share of the GDP is expected to cause CO_2 emission to increase by 1.15–1.95 per cent. The reason why industrialisation increases carbon dioxide emission could be explained by the argument made by Grossman and Krueger (1995) and Jalil and Feridan, (2011) that developing countries, including Ghana, tend to have dirty industries which use unclean energy that emits more carbon dioxide. This supports the studies of Kwakwa *et al.* (2014) and Aboagye (2017) who found industrial growth to be associated with a rise in CO_2 emissions in Ghana.

Regarding urbanisation, the study observed that an increase in urban population as a share of total population will cause carbon dioxide emissions to increase for all other models, except model 5 in which urbanisation has no significant effect on carbon dioxide emission. The general result that urbanisation increases carbon dioxide emission can be explained by the high concentration of manufacturing firms and heavy vehicular traffic that lead to continuous increased consumption of fossil energy as well as the loss of vegetable cover associated with urban development. The outcome then implies that the emission reduction effect associated with urbanisation as suggested by urban transition and ecological modernisation theories may not hold for Ghana. The finding is similar to what was found by Kwakwa and Adu (2016) and Amuakwa-Mensah and Adom (2017).

For model 1, the results show that electricity production from hydro sources has a statistically significant negative long-run effect on carbon dioxide emissions in Ghana. A unit increase in hydro source of electricity will decrease carbon dioxide emission by 0.005. Similarly, in model 3, combustible renewables and waste consumption has a significant negative effect on carbon dioxide emission as a unit increase in combustible renewables and waste consumption decreases carbon dioxide emission by 0.008. Thus, the generation of hydro electricity and consumption of combustible renewables and waste in the country are environmentally friendly. This is reasonable because these are renewable and clean sources of energy, which emit less carbon dioxide, thereby reducing carbon dioxide emissions in the country. The findings are in line with Jebli *et al.* (2013), Dogan and Seker (2016) and Al-Mulali and Ozturk (2016). On the other hand, the production of electricity from fossil fuel sources has a significant positive effect on carbon dioxide emissions as shown in model 2. Similarly, the effect of fossil energy consumption on carbon dioxide emissions is positive and statistically significant at 10 percent level (as shown in model 4). A unit increase in fossil consumption will lead to about 0.007 increases in carbon dioxide emissions. The reason why both fossil energy consumption and production of electricity from fossil fuel increase carbon dioxide emissions can be explained by the fact that fossil is an unclean energy source, which emits more carbon dioxide, thereby increasing carbon dioxide emissions in the country. This confirms the findings of Jebli *et al.* (2013), Dogan and Seker (2016) and Al-Mulali and Ozturk (2016).

The interaction between urbanisation and combustible renewables and waste consumption on carbon dioxide emission is positive and statistically significant at 5 per cent in model 5. This implies that urbanisation is likely to deteriorate environmental quality in the long run (even) when more combustible renewables and waste is consumed in such centres. However, earlier finding reveals that consumption of combustible renewables and waste reduces carbon dioxide, in the long run. This goes to suggest that there is a rebound effect in urban centres regarding the use of combustible renewables and waste which may lead to an increased carbon dioxide emission. Another possible explanation for this observation is that the negative effect of urbanisation may outweigh the positive effect of combustible renewables and waste on CO_2 emissions. Thus, the high urban population density increases the demand for land for development thereby reducing the vegetation cover which deteriorates the environment more than combustible renewables and waste consumption improves the quality of the environment. This finding is consistent with Adusah-Poku (2016), who found that the interaction of urbanisation and energy increases CO_2 emission.

The interaction between urbanisation and fossil fuel consumption on carbon dioxide emissions is negative and statistically significant at 10 per cent. Thus, urbanisation is likely to improve environmental quality in the long run, when fossil fuel is used to generate energy. The theory of compact city which argues that because of urbanisation, cities get compacted and make maximum use of little space available and therefore can reduce carbon dioxide emissions from transportation and buildings, may explain this outcome. Thus, urban dwellers in Ghana make efficient use of non-renewable energy than they do for renewable energy hence the emission reduction effect of the interaction term between urbanisation and fossil fuel consumption. Generally, this could be true because the use of fossil fuel which is unclean energy and the emphasis on environmental sustainability as a result of urbanisation may motivate government and policymakers to make environmental policy that promotes the use of efficient technology in the usage of fossil fuels.

4.3. Results for Granger causality, variance decomposition and impulse response analysis

Many studies (Salahuddin *et al.*, 2015; Sbia *et al.*, 2014; Al-mulali *et al.*, 2015; Adom *et al.*, 2012) on carbon dioxide emission have examined causality among the variables using mainly the Granger vector error correction model (VECM) and error correction model (ECM). To provide better and reliable results, some empirical causality studies have also taken into consideration structural breaks in the usual granger causality test (Huang *et al.*, 2017; Hassan *et al.*, 2016; Dramani *et al.*, 2012; Altinay and Karagol, 2004; Narayan and Smyth, 2008). Furthermore, Toda and Yamamoto (1995) have also built upon the ECM and VECM to eliminate a major shortfall (the situation where the results are sensitive to the values of the nuisance parameters in finite samples). The results of the approach by Toda and Yamamoto (1995) to the Granger causality employed in this study for further analysis are reported in **Table 6**.

The causality results generally show that the type of causality that exists among the variables is somehow sensitive to the measurement of energy. For instance in Panel A where energy is measured as combustible renewables and waste, one sees a unidirectional causality from urbanisation and trade to carbon dioxide emission; from combustible renewables and wastes to income; and from urbanisation to combustible renewables and waste. The unidirectional causality from urbanisation and trade to carbon dioxide emission suggests that efforts to influence the level of urbanisation and trade may affect the level of

Table 6 Toda and Yomamoto causality

Dependent variables

Panel A	CO_2	*Y*	*URB*	*COMB*	*TO*	*IND*
CO_2		1.0346	2.3233	5.8485	4.6811	0.8491
Y	2.7444		1.0643	2.3241	3.6113	4.5224
URB	11.8650**	5.1783		8.0065**	2.8300	2.7346
COMB	4.0153	8.4696*	1.5069		4.1963	3.6971
TO	9.8602**	6.6533	9.387*	3.3858		1.5881
IND	5.3263	4.3127	2.7752	2.7761	2.7106	

Dependent variables

Panel B	CO_2	*Y*	*URB*	*HYELE*	*TO*	*IND*
CO_2		62.0178***	5.0632	22.6935***	44.2661***	8.4384*
Y	59.6966***		3.7321	10.5116***	27.8783***	6.7352
URB	416.1857***	25.3566***		20.3577***	11.2597**	2.0230
HYELE	289.8945***	72.9124***	3.4710		124.4865***	16.0467***
TO	188.1439***	129.2649***	1.5105	33.8969***		7.5703
IND	224.8585***	59.2827***	1.3280	28.1704***	14.7698***	

Dependent variables

Panel C	CO_2	*Y*	*URB*	*ELEFOS*	*TO*	*IND*
CO_2		62.0178***	5.0632	22.6647***	44.26813***	8.4384*
Y	59.6996***		3.7329	10.4986**	27.8783***	6.7352
URB	416.1857***	25.3566***		20.3555***	11.25971***	2.0234
ELEFOS	289.8945***	72.9124***	3.4710		124.4861***	16.0467***
TO	188.1439***	129.2649***	1.5105	33.8722***		7.5703
IND	224.8585***	59.28276***	1.3280	28.1535***	14.7689***	

Dependent variables

Panel D	CO_2	*Y*	*URB*	*FOS*	*TO*	*IND*
CO_2		3852.914***	0.2667	2.3629	1.4646	8.5914*
Y	3.9339		0.5694	3.5452	0.6231	9.3357*
URB	6.2317	2308.470***		3.0074	0.7452	7.4942
FOS	1.4859	4142.079***	1.0235		0.6878	7.5869
TO	6.2733	4697.974***	0.2957	2.4996		8.1646*
IND	4.4829	4659.826***	0.5656	1.9528	0.6446	

***, ** and * denotes 1%, 5% and 10% level of significance, respectively.

carbon dioxide emission without any feedback effect. In Panel D, where fossil fuel is the energy variable, a unidirectional causality is seen from carbon dioxide emission, urbanisation, fossil fuel, trade openness and industrialisation to income.

However, in Panel B, where energy is measured as electricity from hydro, a bidirectional causality is found between carbon dioxide emission on the one hand and income, hydro power, trade openness and industrialisation on the other hand while a unidirectional causality is found from urbanisation to carbon dioxide emission, income, hydro power and trade. Similarly in Panel C, a bidirectional causality is found between carbon dioxide emission on the one hand, and income, power from fossil fuel source, trade openness and industrialisation on the other hand while a unidirectional causality is found from urbanisation to carbon dioxide emission, income, power from fossil fuel source and trade. The existence of bidirectional causality between carbon dioxide emission on one hand and income, power from fossil fuel source/hydro source, trade openness and industrialisation on the other hand supports the feedback hypothesis. The implication is that there is an interdependency between carbon dioxide emission and these variables. Thus, policies aimed at influencing the level of income, power from fossil fuel/hydro source, trade openness and industrialisation may affect the level of carbon dioxide emission and efforts to reduce emissions may also affect income, power from fossil fuel source, trade openness and industrialisation

The study takes a further look at the variance decomposition analysis to examine the actual contribution of each of the variables to a shock in carbon dioxide emission and the result is presented in **Table 7**. Both electricity from fossil fuel source and hydro source could not be included in estimating the variance decomposition and impulse response analysis at the same time since their presence created near singular matrix. The reason is that the two are exactly collinear. When separate analysis was done with each of them, the opposite results were obtained for each, while the results for the other regressors remained same. For want of space one of them is reported. From the results, the contribution of each variable namely, income, production of electricity from hydro sources, fossil energy, combustible renewables and waste consumption, trade openness and urbanisation, to a shock in the emission of carbon dioxide appears to increase over the period while that of industrialisation reduces. For instance, a shock in carbon dioxide emission increases the share of income from 5.61 per cent in the second period to 12.43 per cent in the tenth period. Also, trade openness increases its contribution from 1.00 per cent in the second period to 14.31 per cent in the sixth period and finally to 15.64 per cent in the tenth period. Also fossil fuel consumption increases its share from 0.01 per cent in period two, then to 2.46 per cent in period five and finally to 4.56 per cent in the tenth period. The impact from trade, hydroelectricity production and income seem to be moderate while that of urbanisation and fossil fuel consumption is weak.

Table 7 Variance decomposition analysis

Period	S.E.	CO_2	Y	HYELE	FOS	COM	TO	URB	IND
1	0.059757	100.0000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	0.070286	73.81379	5.613124	0.301590	0.015587	8.451869	1.002296	0.053358	10.74839
3	0.084926	52.61155	4.662878	15.37673	2.285277	5.872707	1.044874	0.094987	18.05100
4	0.096054	41.86663	10.83191	12.05385	1.823106	13.20029	5.537482	0.075089	14.61164
5	0.100887	38.13888	11.24023	14.49113	2.458606	12.89396	6.754301	0.431398	13.59149
6	0.108975	33.15645	10.10689	12.48854	4.808433	12.38050	14.30650	1.100732	11.65195
7	0.112640	31.79939	10.90884	13.23133	4.505942	12.26297	14.69383	1.691122	10.90657
8	0.114723	30.71184	12.11124	13.53988	4.778999	11.85290	14.22667	2.257798	10.52067
9	0.116951	30.35325	12.38255	13.54453	4.695568	11.94197	13.87328	3.030384	10.17846
10	0.120475	28.60329	12.42555	13.93302	4.565476	11.29984	15.63685	3.944305	9.591672

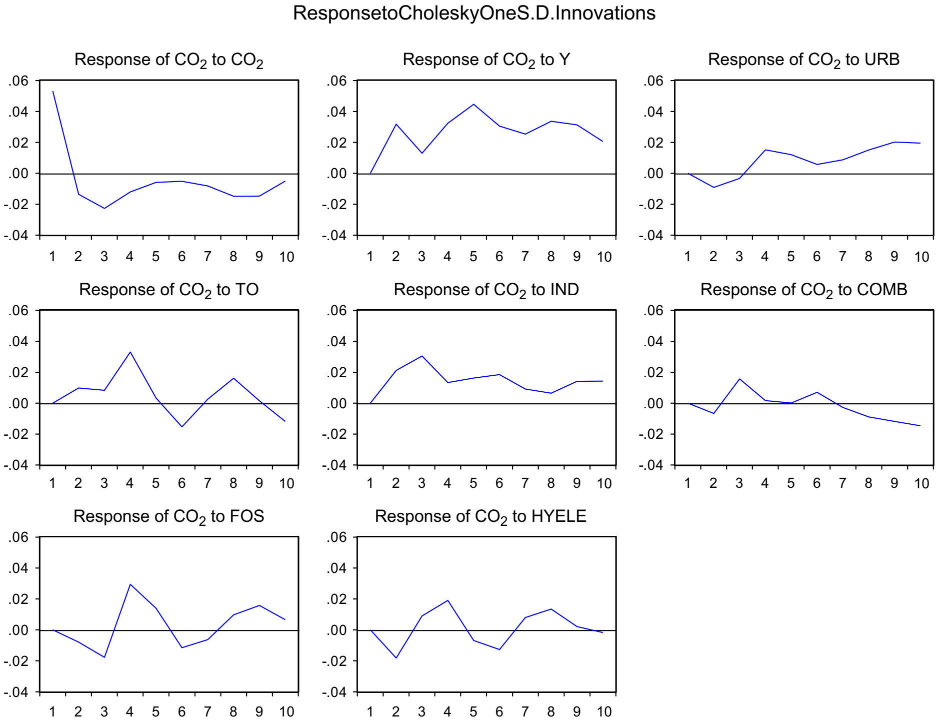

Figure 1 Impulse response function.

The study also runs an impulse response test to determine how carbon dioxide emission responds to a shock in the other variables initially and whether the effect of the shock persists or dies out quickly. The outcome presented in **Fig. 1** shows that carbon dioxide emission fluctuates in its response to the variables of interest at different periods.

For instance, carbon dioxide emission responds positively to a shock in income in the first two periods, picks a negative response to the fifth period after which it stabilises. For a shock in electricity production from hydro, carbon dioxide emission responds positively in the first three periods, falls to the fifth period and picks up positively to the eight period. After this, it negatively reacts to a shock in electricity production. Also, for a shock in urbanisation, carbon dioxide emission seems to not respond to it in the first three periods. However, from period four it moderately responds positively to a shock in urbanisation. Furthermore, carbon dioxide emission responds positively to a shock in combustible renewable energy consumption from the second to the fourth period and takes a negative response to the sixth period and then reacts positively.

5. Concluding remarks and policy implications

This study examines the influence energy and urbanisation have on carbon dioxide emissions in Ghana, using time series data from the period of 1971–2013. The outcome from the Engel–Granger and the Phillips–Ouliaris tests indicate that there is a long-run cointegration among the series. Afterwards, the FMOLS model was employed to examine the long-run relationship between the dependent and independent variables. The results from the six models estimated indicate that income and income square have statistically significant positive and negative effects on carbon dioxide emissions, respectively; which confirms the existence of the EKC hypothesis in Ghana. In addition, urbanisation, industrialisation and trade openness were observed to have a significant effect on carbon dioxide emissions. While trade openness reduces carbon dioxide emission, urbanisation and industrialisation increase it. The study also observed that renewable energy, particularly hydroelectricity and combustible renewables and waste reduce carbon dioxide emissions while non-renewable energy—fossil fuel consumption and generation of electricity from fossil fuel increase carbon dioxide emissions. Furthermore, the interaction between urbanisation and energy reveals that urbanisation consumption of combustible renewables and waste deteriorates the environmental quality while the opposite holds for urbanisation and fossil fuel consumption. A causality test suggests that some form of feedback effect exists between carbon dioxide emission, and income, power from fossil fuel source/hydro source, trade openness and industrialisation

Based on the findings of this study, a number of policy implications emerge. The confirmation of the EKC hypothesis implies that continuous income growth and development will reduce carbon dioxide emission. Consequently, policies that stimulate economic growth and development should be promoted vigorously. Since urbanisation, industrialisation, consumption of non-renewable energy increase carbon dioxide emissions and trade openness and consumption of renewable energy reduce carbon dioxide emissions, it is important to promote the usage of renewable energy by providing incentives to industries and consumers that use renewable energy as well as promoting research in renewable energy technologies. In addition, the private sector should be encouraged to invest in environmentally friendly technology and the environmental regulations instituted to promote environmental sustainability should be implemented effectively to control the activities of the industrial sector. Also, government should promote rural development to reduce rural–urban migration, which will help check urbanisation and consequently reduce environmental degradation. Overall, the results imply the need to implement Low Carbon Development Strategy which integrates development and climate change mitigation actions.

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