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Original article

An empirical examination of the Environmental Kuznets Curve hypothesis for carbon dioxide emissions in Ghana: an ARDL approach

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ABSTRACT

The Environmental Kuznets Curve (EKC) hypothesis postulates an inverted U-shaped relationship between different pollutants and economic growth. In Ghana, as in many other developing countries, there exist scanty studies that confirm or otherwise the EKC hypothesis with regards to CO_2 emissions as well as the factors that drive CO_2 emissions. This work aims to bridge this knowledge gap by addressing these two major questions using data from 1970 to 2010 and the Auto Regressive Distributed Lag (ARDL) Bounds Testing approach. The results rather suggest a U-shaped relationship between per capita GDP and CO_2 emissions per capita indicating the non-existence of the EKC hypothesis for CO_2 in Ghana. This implies that further increase in per capita Gross Domestic Product (GDP) will only be associated with increase in CO_2 emissions as the income per capita turning point of about $624 at constant 2000 prices occurred between 1996 and 1997. Furthermore, our results reveal energy consumption and trade openness are positive long run drivers of CO_2 emissions. It is therefore recommended that the enhancement of trade liberalization policies should ensure the use of cleaner technologies and products while investment in cleaner energy alternatives could help reduce CO_2 emissions. We also recommend the implementation of the Low Carbon Development Strategy which integrates development and climate change mitigation actions.

KEY WORDS: economic growth, CO_2 emissions, Environmental Kuznets Curve, ARDL, Ghana

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1. Introduction

Economists first reported a systematic relationship between changes in income and environmental quality in the early 1990s. GROSSMAN & KRUEGER (1991) introduced the term Environmental Kuznets Curve (EKC) which has now become a debatable issue in the literature with some findings being used for environmental policies. The EKC hypothesizes an inverted U-shaped relationship between environmental indicators of degradation such as carbon dioxide (CO_2) and sulphur dioxide (SO_2) on the one hand and income per capita on the other. Early estimates of EKC studies such as BECKERMAN (1992) demonstrate that some important indicators of environmental quality such as concentrations of SO_2 and air particulates matter improved as incomes increased over time. This study uses CO_2 emissions as a proxy for environmental degradation since it is a major determinant of greenhouse gas (GHG) emissions contributing about 74% of GHG emissions (INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, 2007).

In recent years, the interrelationship between economic growth and CO_2 emissions has received more attention globally because of climate change. This contentious issue appears to be comprehensively researched more in developed countries than developing ones. Studies on EKC with CO_2 emissions as the pollutant over the past years has been inconclusive suggesting that further studies need to be undertaken. As FRIEDL & GETZNER (2003, pp. 133) put it, "*While the EKC hypothesis has been confirmed-albeit far from unanimously for a set of air pollutants, water and land use, the* *empirical evidence is very inconclusive in the case of GHG emissions, in particular CO_2 emissions*''. STERN ET AL. (1996, pp. 1156) also argue that "*a more fruitful approach to the analysis of the relationship between economic growth and environmental impact would be the examination of the historical experience of individual countries, using econometric and a qualitative historical analysis*''.

The Ghanaian economy has experienced some appreciable growth over the past decades with growth increasing from an average of about 4% in the 1980s to about 9% in the 2010s. The discovery of oil and gas in 2007 suggests that potential for growth is quite enormous. However, caution must be applied since this growth could lead to increasing emission of CO_2 which may thwart international and national efforts being made to reduce emissions of GHGs which are responsible for climate change. Unfortunately, very little has been done empirically on the relationship between income growth and CO_2 emissions and consequently the satisfaction of the EKC hypothesis or otherwise. Research questions that arise are: Does the EKC hypothesis hold in Ghana? What factors determine CO_2 emissions in Ghana? What has been the trend in greenhouse gas (GHG) emissions? This study investigates the satisfaction or otherwise of the EKC hypothesis in Ghana as well as identifying the determinants of CO_2 emissions in Ghana.

The motivation for undertaking this study emanates from the fact that the argument to develop and implement a Low Carbon Development Strategy (LCDS) by Ghana which integrates development and climate change mitigation is being met with some reservations by some organizations, arguing that policies that have already been put in place are enough and could have some impact on emission reduction. Establishment of the relationship between CO_2 emissions and growth will put to rest this argument and enable policy makers to make concrete decisions on the implementation or otherwise of the LCDS. Additionally, clear information on the macroeconomic drivers of CO_2 emissions will be obtained for Ghana which will provide pointers on how to best reduce CO_2 emissions based on scientific evidence, an issue that has not been properly taken care of in developing climate change mitigation policies. Analysis of the sectors and the gases that drive GHG emissions in Ghana will also enable the government to provide the right interventions in the right sectors.

The rest of the study is organized as follows: section 2 discusses relevant literature on EKC while section 3 provides an overview of CO_2 emissions in Ghana. Section 4 discusses the empirical model followed by section 5 which presents the empirical results. The last section concludes and makes policy recommendations.

2. Literature review

2.1. Theoretical literature

PANAYOTOU (1993) reports that, the theoretical explanation for the EKC hypothesis depends not only on the characteristics of production and abatement technology but also on their relationship with income growth. A comprehensive review of the theoretical framework for the EKC hypothesis has been provided by DEBRUYN & HEINTZ (2002). In this work, the EKC hypothesis is explained using the following five factors: behavioral changes and preferences, income elasticity of demand, technological and organizational changes, structural changes and demand for environmental quality even though many EKC theoretical models are based on the first three factors.

Different studies have explained the EKC hypothesis using one or two of these five factors. GROSSMAN & KRUEGER (1991) and PANAYOTOU (1993) explained the EKC hypothesis using structural changes resulting from economic growth that cause shifts in production technology. On the other hand, SELDEN & SONG (1995) and ANDREONI & LEVINSON (2001) explained the EKC hypothesis using the features of abatement technology. MCCONNELL (1997) and KRISTRÖM & RIVERA (1995) used the income elasticity of demand for environmental quality to explain the EKC hypothesis. Other studies such as LOPEZ (1994) and SELDEN & SONG (1995) departed slightly from these by developing their own growth models but with plausible assumptions on preferences and technology.

Technological progress has been identified as an important factor for the pollution path. Even though it is not clear, a priori, whether technological progress increases or reduces emissions, it is argued that technological progress will move in an environmentally friendly direction with appropriate policies (LIEB, 2002). SMULDERS & BRETCHGER (2000) incorporated technological progress into their model that enabled them to provide an analytical foundation and explanation to the claim that the rise and decline of pollution can be explained by policy-induced technology shifts. Specifically, the transition from dirty production processes to clean production processes made possible by improved technology and regulations explains the EKC.

Another explanation of the EKC hypothesis is the structural change model. In his model, DE GROOT (1999) concluded that, under plausible conditions and assumptions, structural change can help reduce emissions. However, he emphasizes that structural change is not sufficient to cause the downturn of the EKC but rather emissions-saving technological progress.

In the context of behavioral changes and preferences, LOPEZ (1994), using a growth model underpinned by certain assumptions, argues that growth leads to higher pollution levels when producers do not pay for environmental/ industrial pollution or pay fixed pollution prices. However, when producers decide to pay the full marginal social cost of pollution, then the pollution-income relationship will depend on the properties of technology and preferences. He argues that pollution increases with income when preferences are homothetic but with non-homothetic preferences, the relationship between pollution and income will depend on the speed of change of marginal utility with respect to changes in consumption and the elasticity of substitution between pollution and other inputs. He concluded that, an inverted U-shaped pollution-income relationship is achieved if empirically plausible values of parameters of technology and preferences are found.

Other theoretical EKC models have explained the inverted U-shaped pollution-income relationship using the income elasticity of demand for environmental quality. Mention can be made of EKC models proposed by ANTLE & HEIDEBRINK (1999) and MCCONNELL (1997). For instance, MCCONNELL (1997) in examining the role played by income elasticity of demand for environmental quality in explaining the inverted U-shaped pollution-income relationship, adapted a static model of an infinitely lived household in which pollution is consumption induced and that the consumption induced pollution is reduced by abatement. The study concluded that even though preferences, consistent with positive income elasticity of demand for environmental quality are important, they are neither necessary nor sufficient conditions for the inverted U-shaped pollution-income relationship.

Another possible cause of the down turn of the EKC is the assumption that environmental quality is a normal good and that, demand for environmental quality increases with income. LIEB (2002) in his model with pollution generated by consumption shows that, the necessary condition for the downturn of the EKC is the assumption of environmental quality as a normal good.

2.2. Empirical literature

GROSSMAN & KRUEGER (1995) used the Global Environmental Model System (GEMS) dataset to estimate EKCs for SO_2, dark matter (fine smoke), and Suspended Particulate Matter (SPM) for 52 cities in 32 countries during the period 1977-1988. Income per capita turning point for both SO_2 and dark matter was found to be \$4,000-\$5,000 whereas the concentration of suspended particulate matter appeared to decline even at low-income levels. The study also found a positive relationship between all the pollutants used in the study at per capita income levels of between \$10,000 and \$15,000.

SHAFIK & BANDYOPADHYAY (1992) estimated EKCs for ten different environmental indicators using three different functional forms: log-linear, log quadratic and logarithmic cubic polynomial functional forms. Using a sample of observations of 149 countries from 1960-1990, the study found a negative uniform relationship between income and three of the ten environmental indicators used in the study namely: lack of clean water, river quality and sanitation. The study also found no relationship between deforestation and levels of income. Air pollutants on the other hand conform to the EKC hypothesis with per capita income turning points between \$3,000 and \$4,000. Municipal waste and carbon emissions however rise with increasing incomes. These results were used in the 1992 World Development Report. PANAYOTOU (1993) also found similar results like that of GROSSMAN & KRUEGER (1991) and SHAFIK & BANDYOPADHYAY'S (1992) for these pollutants: NOx, SO_2 and SPM using cross section data and a translog specification. The study found turning point at per capita income levels of about \$3,000 for SO_2 emissions, \$5,500 for NO_x emissions and about \$4,500 for SPM. Deforestation was found to be conforming to the EKC hypothesis, with a turning point around \$800 per capita concluding that turning point per capita is significantly greater in tropical and densely populated countries if income distribution is controlled.

Studies after the late 1990s have made use of more complex estimation techniques and have obtained turning points for CO_2 emissions. SCHMALENSEE ET AL. (1998) found an inverted U-shaped income-environment relationship using a spline regression with ten piece-wise segments and the data set employed by HOLTZ-EAKIN & SELDEN (1995). Negative relationships were found between CO_2 emissions and income per capita at the lowest and highest income spline. The income turning point per capita was between \$10,000 and $17,000. The results of Panayotou et al. (1999) mimic that of Schmalensee et al. (1998), where low income elasticity of emissions was obtained at the lowest income spline which rises to a maximum turning point of about $11,500 per capita. At per capita incomes around $17,500, the income elasticity of emissions was found to be negative.

Another study by Galeotri & Lanza (1999), using functional specifications such as Gamma, Weibrill, quadratic and cubic functions found turning points to be between $15,000 and $22,000. Using a ten segment piece-wise spline function and panel data for 150 countries for the period 1960-1992, Nguyen (1999) tested EKC for CO_2 emissions with data from three Organization for Economic Cooperation and Development (OECD) countries and three rapidly developing Asian countries, and confirmed the EKC for CO_2 emissions reaching a turning point at $18,000. In general, a comprehensive review of empirical literature up to the year 2000 has been provided by Panayatou (2000).

More recently, Halicioglu (2009) examined the dynamic relationship between CO_2 emissions, energy consumption, income and foreign trade in Turkey using time series data for the period 1960-2005, the Bounds test to cointegration procedure, and found energy consumption, income and foreign trade to be the long run determinants of CO_2 emissions. Saboori & Soleymani (2011), using the Auto Regressive Distributed Lag (ARDL) estimation method and data for the period 1971-2007 tested the existence, or otherwise, of the EKC for Iran. The results did not support the EKC hypothesis.

In Sub Saharan Africa, a number of studies has been conducted to test the existence, or otherwise, of the EKC hypothesis of some pollutants. Omojolaibi (2010) tested the EKC hypothesis for CO_2 using panel data from Ghana, Nigeria and Sierra Leone over the period of 1970-2006. The pooled Ordinary Least Squares (OLS) results satisfied the EKC hypothesis whereas the Fixed Effects (FE) results contradicted the EKC hypothesis in these countries. Omisakin (2009) investigated the EKC hypothesis for CO_2 emissions in Nigeria with annual data from 1970-2005 and found no long run relationship between CO_2 emissions per capita and income per capita. A U-shaped income-environment relationship was also established contradicting the EKC hypothesis. Similarly, Abimbola & Bello (2010) concluded the non-existence of the EKC hypothesis in Nigeria confirming earlier studies. Similarly, using time series data from 1980-2008, Omisakin (2009) concluded that CO_2 emission in Nigeria is not driven by economic growth but rather by financial developments such as foreign direct investment (FDI). Also, using ARDL bounds testing to cointegration, Onafowora & Owoye (2014) examined the long run relationship between economic growth, energy consumption, population density, trade openness and CO_2 emissions in Brazil, China, Egypt, Japan, Mexico, Nigeria, South Korea and South Africa and found the EKC hypothesis to hold for only two countries, namely Japan and South Korea, whereas an N-shaped trajectory was found for the other 6 countries.

A summary of the review indicates that the EKC has been confirmed for some countries but refuted for other countries. Also, there is no work purporting to investigate the hypothesis in Ghana. It is in this regard that this study becomes imperative.

3. Overview of GHG emissions in Ghana

Ghana aims to achieve an upper middle income status by 2020. However, climate change is a serious issue that threatens the achievement of this aim. This is because many of the important sectors that contribute significantly to economic growth, such as the service and agriculture sectors, are highly sensitive to climate change. It is for this reason that paying more attention to mitigating climate change becomes imperative.

Information from EPA (2015) indicates that over the past two decades, Ghana's GHG emissions has risen from about 50 $TgCO_2e$ in 1990 to about 57 $TgCO_2e$ in the year 2012 at an average annual rate of 0.7% (Fig. 1). Increase in total GHG emissions is driven mainly by rising CO_2 emissions which increased from about - 1.1 $TgCO_2e$ in 1990 to about 14.81 $TgCO_2e$ in 2012 at an average annual rate of 86.9% over the period and has contributed about 60% of all GHG emissions.

CO_2 emissions are emitted mainly from the following sectors of the economy - energy, agriculture, forestry and other land uses (AFOLU), industrial processes and product use (IPPU) and waste. Since 1990 the energy sector has been the highest contributor to CO_2 emissions followed by the IPPU, waste and the AFOLU sectors in order of decreasing contribution to CO_2 emissions. (Fig. 2).

Net CO_2 emissions from all sectors were negative for the country until 1998 when it turned positive largely driven by CO_2 emissions in the energy and AFOLU sectors. The AFOLU sector used to be a net remover of CO_2 emissions until 2007 when it became a net emitter largely as a result of deforestation and forest degradation. One major observation is that CO_2 emissions in the IPPU and waste sectors have stabilized around 0.2 TgCO2e and 0.005 TgCO2e respectively. This again suggests that CO_2 emissions mitigation efforts should focus more on the energy and AFOLU sectors.

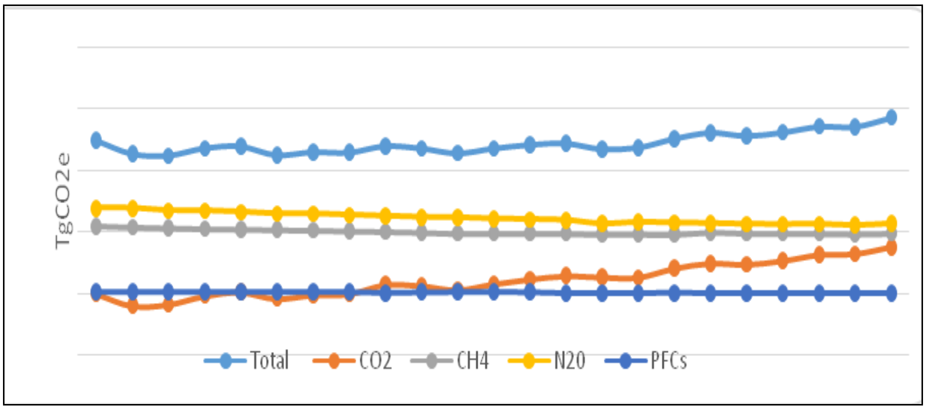

Fig. 1. GHG emissions by type of gas ($TgCO_2e$) (1990-2012)
(source: Climate Change Unit, Environmental Protection Agency, Ghana, 2014)

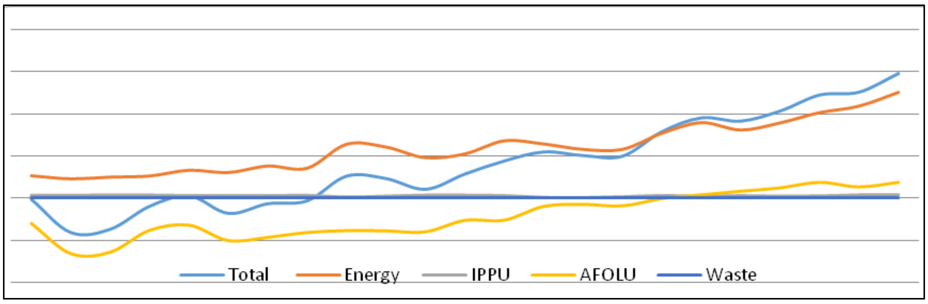

Fig. 2. Trends in CO_2 emissions by sector
(source: Climate Change Unit, Environmental Protection Agency, Ghana, 2014)

4. Methodology

The study employs the reduced-form model in which the environment-income indicator is a quadratic function of income as employed by SABOORI & SOLEYMANI (2011). Specifically, to examine the curvilinear nature of the EKC hypothesis, the square of per capita GDP is added to the model as used by HOSSAIN (2012) and presented as equation 1.

$$\text{InCO}_{2t} = \beta_0 + \beta_1 InY_t + \beta_2 InY^2{}_t + \beta_3 InFDI_t + \beta_4 InENERGY_t + \beta_5 InTRADE + ct + \varepsilon_t \text{...........(1)}$$

where:
CO_{2t} is per capita CO_2 emissions, Y_t is per capita GDP, ENERGY is energy consumption per capita, TRADE is trade openness equal to the sum of exports and imports divided by GDP, ct is the time trend and FDI is foreign direct investment proxied by percentage of FDI net inflows to GDP.

The choice of these variables is justified by a plethora of empirical studies such as: MUHAMMAD ET AL. (2011), HOSSAIN (2012), TAMAZIAN ET. AL (2009), MENSAH (2014), SABOORI & SOLEYMANI (2011) and HALICIOGLU (2009). Equation (1) allows us to test the various forms of pollution-income relationships. Specifically:

If $\beta_1 > 0$ and $\beta_2 = 0$, then there is a monotonically increasing linear relationship, indicating that rising incomes are associated with rising levels of emission. If $\beta_1 < 0$ and $\beta_2 > 0$, then there is a U-shaped relationship. If $\beta_1 > 0$ and, $\beta_2 < 0$,then there is an inverted U-shaped relationship and confirms the EKC hypothesis.

4.1. Estimation technique

The study adopts the Augmented Dickey-Fuller (ADF) test as the main technique for testing for unit roots and the Phillips-Perron unit root test to confirm the results of the ADF test. To investigate the long run equilibrium relationship between economic growth and CO_2 emissions in Ghana, the Auto Regressive Distributed Lag (ARDL) Bounds Testing approach developed by PESARAN ET AL. (1999) was used. This technique is used to test the existence of long run relationships between variables in multivariate time series models irrespective of whether the underlying explanatory variables are either integrated of order zero I(0), one I(1) or mutually cointegrated. The ARDL approach was used because of its advantages such as the involvement of just a single equation set-up making it easier and simpler to interpret compared to other conventional techniques which involves several equations set-up.

The ARDL approach is first carried out by estimating an Unrestricted Error Correction Model (UECM) in equation (2) using ordinary least squares.

$$\Delta InCO_{2t} = \beta + \sum_{j=1}^{a}\lambda_{1j}\Delta InCO_{2t-j} + \sum_{j=0}^{b}\lambda_{2j}\Delta InY_{t-j} + \sum_{j=0}^{c}\lambda_{3j}\Delta InY^2{}_{t-j} + \sum_{j=0}^{d}\lambda_{4j}\Delta InENERGY_{t-j} + \sum_{j=0}^{e}\lambda_{5j}\Delta InFDI_{t-j}$$
$$+\sum_{j=0}^{f}\lambda_{6j}\Delta InTRADE_{t-j} + \delta_1 InCO_{2t-1} + \delta_2 InY_{t-1} + \delta_3 InY^2{}_{t-1} + \delta_4 InENERGY_{t-1}$$
$$+\delta_5 InFDI_{t-1} + \delta_6 InTRADE_{t-1} + ct + \varepsilon_t \text{.......................................(2)}$$

where:
Δ is a difference operator, *a, b, c, d, e* and *f* represent the lag length on the regression variables and ε_t is the error term assumed to be white noise. The parameters, λ_{nj} for n=1, 2, ..., 6, represent the short run dynamics of the EKC model whereas the parameters for the long run relationships are given by the δ s. The study employs the Akaike Information Criterion (AIC) to determine the optimal lag length.

The UECM examines the long run relationships between the variables and in doing so, the F test is used to test for the joint significance of the coefficients of the lagged level variables. The Bound test developed by PESARAN ET AL. (1999) is the Wald test for the lagged level variables. Hence, we test the null hypothesis of non-cointegrating equation by performing a joint significance test on the lagged level variables. The null and alternative hypotheses for testing for the cointegration are given as:

$$H_0:\ \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = 0$$
$$H_1:\ \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq \delta_6 \neq 0$$

Under the conventionally used level of significance such as 10%, 5% and 1%, we reject the null hypothesis of no cointegrating equation if the F-statistic exceeds the upper critical value. We also fail to reject the null hypothesis of no cointegrating equation if the F-statistic falls below the lower critical value. In the final step of the ARDL approach, the short-run dynamics associated with the long run estimates are ascertained by constructing an Error Correction Model (ECM) as shown in equation (3):

$$\Delta InCO_{2t} = b_0 + \sum_{j=1}^{p} b_{1j} InCO_{2t-j} + \sum_{j=o}^{q} b_{2j}\Delta InY_{t-j} + \sum_{j=o}^{r} b_{3j}\Delta InY^2{}_{t-j} + \sum_{j=o}^{s} b_{4j}\Delta InENERGY_{t-j}$$
$$+\sum_{j=o}^{t} b_{5j}\Delta InFDI_{t-j} + \sum_{j=o}^{u} b_{6j}\Delta InTRADE_{t-j} + \Omega ecm_{t-1} + ct + \varepsilon_t \text{................(3)}$$

where:
Δ is a difference operator, *p, q, r, s, t* and *u,* represent the lag length on the regression variables, b_{mj} for j=1, 2, 3,...6, are the short run equation coefficients, Ω is the speed of adjustment to the long run equilibrium.

In terms of a priori expectations, the literature predicts a positive relationship between energy consumption per capita and CO_2 emissions per capita but the relationship between CO_2 emissions per capita and variables such as FDI, economic growth and international trade could either be positive or negative. Annual time series data on the variables spanning from the time period 1970 to 2010 was used. All Data for this study was obtained from the World Development Indicators (WDI) of the World Bank.

5. Results and discussions

5.1. Unit root and cointegration tests

Summary statistics of the natural log of the variables are shown in Table 1. The stationarity or non-stationarity of a time series can strongly influence its behavior, hence, the need to undertake stationarity tests to ascertain the unit root properties of the series. As a result, two tests were conducted: Philips-Perron (PP) and Augmented Dicky-Fuller (ADF). The confirmation of stationarity will pave the way for cointegration testing.

Table 2 shows the results of the ADF and Phillips-Perron unit root tests at levels and at first difference. At levels, all the variables were not stationary with the exception of CO_2 emissions per capita and energy consumption per capita which were significant at 1% significant levels. As a result, the ADF and Phillips-Perron unit root tests were carried out at first difference making all the variables stationary at 1% level of significance.

Table 1. Summary statistics of variables from 1970-2010 (source: author's estimations)

Variable	Observations	Mean	Standard deviation	Minimum	Maximum
CO_2 per capita	40	-8.133171	0.172411	-8.482065	-7.771176
GDP per capita	41	6.548248	0.158031	6.252247	6.902019
GDP per capita squared	41	13.09650	0.316062	12.50449	13.80404
Energy cons. per capita	40	5.913059	0.069540	5.720160	6.031714
FDI	34	-0.183846	1.521072	-3.093829	2.253044
Trade	41	-4.265742	3.994019	-10.30348	1.308382

Note: The number of observations are not the same for all variables because of missing data for some of the variables

Table 2. Results of ADF and PP unit root tests (source: author's estimations)

Variables	ADF unit root test	Phillips-Perron unit root test
	At levels	
CO_2 per capita	-2.269435ƚ***	-2.072466ƚ***
GDP per capita	-0.399846!	-0.239536!
GDP per capita squared	-0.399846!	-0.239536!
Energy cons. per capita	-2.292091ƚ***	-2.256252ƚ***
FDI	-0.774737!	-0.701080!
Trade	-0.483998ƚ	-0.482375ƚ
	At first difference	
CO_2 per capita	-9.021749ƚ***	-17.81089ƚ***
GDP per capita	-4.249725!***	-4.265279!***
GDP per capita squared	-4.249725!***	-4.265279!***
FDI	-5.001361!***	-5.071469!***
Trade	-5.144540ƚ***	-5.144540ƚ***

Note: *, **, ***, represent 10%, 5% and 1% significant levels. ƚ and ! denote constant with trend and constant only model specifications respectively

We proceed to investigate the cointegration relationship between CO_2 emissions and its long run forcing variables. Results of the test (Table A1) confirm the presence of cointegration as the bounds test F-statistic for models 1 and 2 (8.33146) exceed the upper bound critical value (3.34) and are significant at 5%. The validity of this result is also tested.

Forecasting requires that the model is free from problems such as serial correlation, heteroscedasticity and so on. As a result, some diagnostic tests were conducted to ascertain the suitability of the model for forecasting. The diagnostic tests were conducted based on equations 1 and 2 using the Akaike Information Criteria (AIC). Due to the nature of the data (i.e. annual data), the maximum number of lags included in the model was 2. Given the p-values of serial correlation, functional form, normality and heteroscedasticity tests of 0.204, 0.1019, 0.224 and 0.243 respectively (Table A2), we fail to reject the null hypothesis of no serial correlation, correct functional form, normally distributed residuals and homoscedasticity at 5% level of significance. This implies that our model is correctly specified. Also, the model does not suffer from severe multicollinearity as the estimated VIFs are all below 10 (as a rule of thumb, if the VIF of a variable exceeds 10, then the variable is said to be highly collinear; GUJARATI, 2004) (Table A3).

Table A1. Test Results of the long run relationships between the variables (source: author's estimations)

Computed ARDL F-Statistic	8.33146**
Bounds Test critical values at 5% level of significance: (with no intercept and no trend) Lower Bound: 2.14 Upper Bound: 3.34	
K=5, where K is the number of explanatory variables in the model	

** represent significant at 5% level of significance

Table A2. Results of ARDL Diagnostic tests (source: author's estimations)

Test Statistic	LM Version	F Version
A: Serial Correlation	CHSQ (1) = 2.4843 (0.129)	F (1, 34) = 2.5635 (0.204)
B: Functional form	CHSQ (1) = 1.9390 (0.115)	F (1, 34) = 1.1077 (0.1019)
C: Normality	CHSQ (2) = 2.8954 (0.224)	Not applicable
D: Heteroscedasticity	CHSQ (1) = 1.2927 (0.243)	F (1, 37) = 1.3644 (0.151)

Figures in parenthesis are the P-values
Note: A: Lagrange multiplier test of residual serial correlation; B: Ramsey's RESET using the square of the fitted values; C: Based on a test of skewness and kurtosis of residuals; D: Based on the regression of squared residuals

Table A3. Results of Variance Inflation Factor (VIF) (source: author's estimations using EViews 9)

Variable	Uncentered VIF
Energy cons. per capita	4.013387
GDP per capita	3.866430
GDP per capita squared	4.430076
FDI	1.408218
Trade	3.101292

The Cumulative Sum (CUSUM) and the Cumulative Sum of Squares (CUSUMSQ) techniques are employed to assess the stability of the short run and long run coefficients. We test the null hypothesis of stable parameters against the alternative hypothesis that both the long and short run parameters are not stable. The plots of CUSUM (Fig. A1) and CUSUMSQ (Fig. A2) are well within the critical bounds implying that the estimated model and its coefficients are stable at 5% level of significance. This stability result, according to HOSSAIN (2012), implies that the model can be used for the purpose of policy decision making in such a way that the impact of policy changes with regards to the explanatory variables of the CO_2 emissions equation will not cause a major distortion in the level of CO_2 emissions. On the basis of the above evidence, we proceed to estimate the long run and short run elasticities.

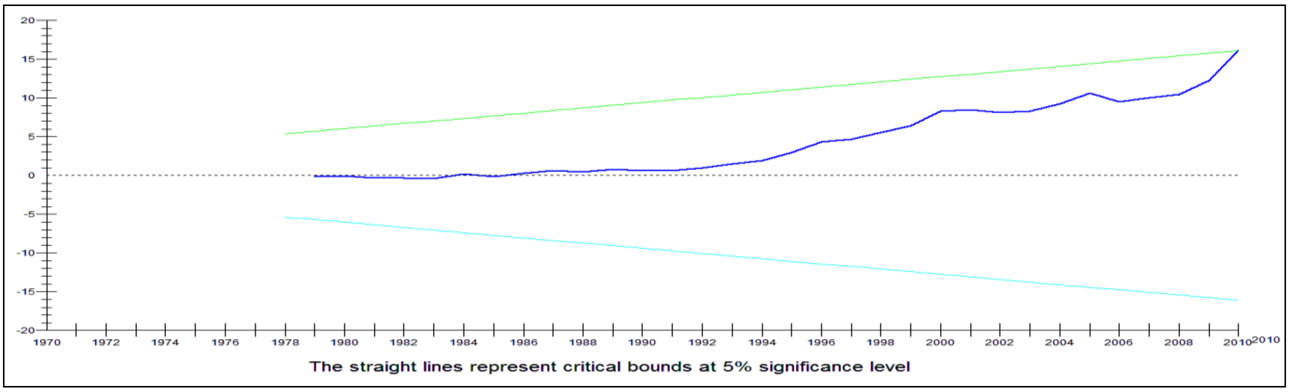

Fig. A1. Plot of Cumulative Sum of Recursive Residuals (CUSUM)

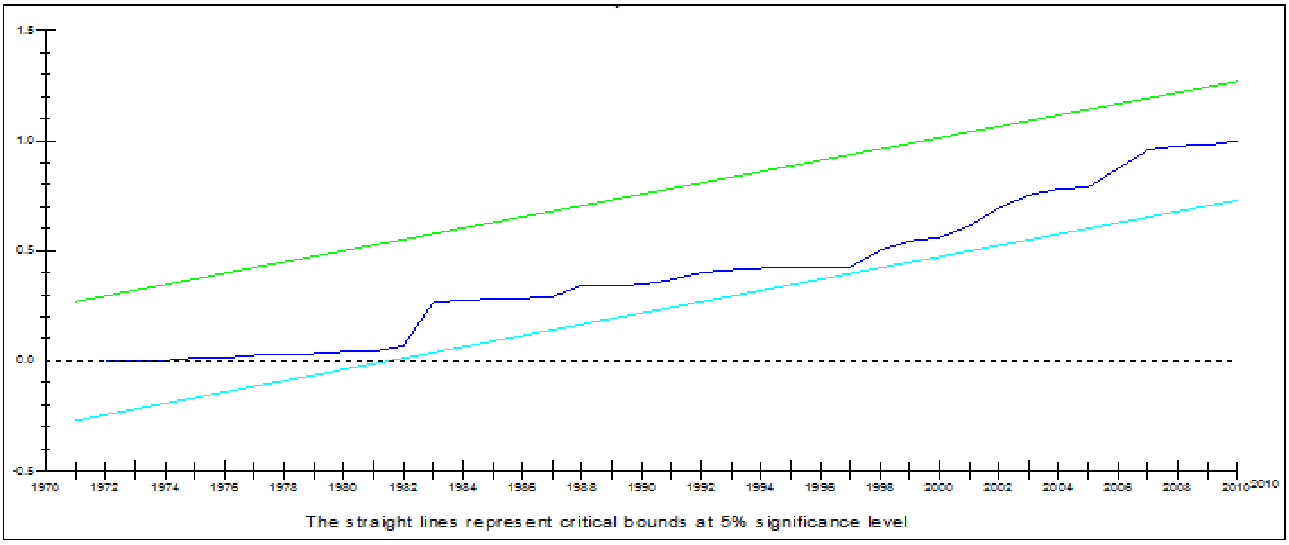

Fig. A2. Plot of Cumulative Sum of Squares of Recursive Residuals (CUSUMSQ)

5.2. Long run elasticities

Estimation of the long run results presented as Table 3 indicates that international trade, energy consumption per capita, per capita GDP, the trend term of the ARDL model and per capita GDP squared were all significant, while FDI was not significant. It can also be observed that, most of the long run coefficients (elasticities) of the regression variables have their expected theoretical signs.

Table 3. Estimated long run coefficients (source: author's estimations)

Regressor	Coefficient	Standard Error	T-Ratio
GDP per capita	-0.8522	0.1301	-6.5503***
GDP per capita squared	0.0662	0.0141	4.6917** 4.24382***
Trade	1.1101	0.3611	3.0743*
FDI	-0.0158	0.2031	-0.0778
Energy Cons. per capita	0.2411	0.0324	7.4414**
Trend	1.2103	0.1983	6.1020***

*, **and *** above represent significant at 10%, 5% and 1% level of significance respectively

The long run coefficients of GDP per capita and GDP per capita squared of -0.8522 and 0.0662 respectively imply the non-existence of the EKC hypothesis for CO_2 emissions in Ghana as elaborated in the methodology[1]. These results indicate that per capita CO_2 emissions in Ghana initially falls with per capita GDP up to a threshold level and increases with further increases in GDP per capita, yielding a U-shaped relationship. We therefore predict that CO_2 emissions would be on the increase as per capita income increases. This could be attributed to the fact that, as the economy expands beyond the threshold level, the income effect would not be strong enough to cause a decline in CO_2 emissions. This finding is in consonance with that of ABIMBOLA ET AL. (2010) and OMISAKIN (2009) who obtained a U-shaped relationship between per capita GDP and CO_2 emissions per capita in Nigeria and that of OMOJOLAIBI (2010) for Ghana, Nigeria and Sierra Leone using panel data.

Furthermore, the confirmation of a U-shape nexus implies the need to investigate the turning point defining the relationship. According to DEBRUYN ET AL., (1998), the income turning point of this representation of the inverted-U curve is obtained by setting the derivative of equation (1) with respect to InY to zero, which yields: $Y_t = e^{-\beta_1/2\beta_2}$. Using the coefficients of GDP per capita and GDP per capita squared from Table 3 gives an income per capita turning point of about $624 at 2000 constant prices. This is the level of income per capita at which CO_2 per capita emissions begin to increase. This value occurs between 1996 and 1997. This figure, to some extent, appears to be in line with national data as information from the EPA (2015) of Ghana indicates that Ghana was a net remover of CO_2 up to the years 1997 and only became a net emitter after that year.

The long run results also show that CO_2 emissions per capita and energy consumption per capita have a positive and significant relationship. Specifically, a percentage increase in energy consumption per capita leads to an expected increase in CO_2 emissions per capita by 0.2411% all other variables held constant. This finding is consistent with that of ABIMBOLA ET AL. (2010), MUHAMMAD ET AL. (2011), SABOORI & SOLEYMANI (2011) and HOSSAIN (2012). Evidently, the excessive use of fossil fuels is bound to increase with increase in incomes. The main sources of energy in Ghana are biomass, petroleum and hydro. The largest share of CO_2 emissions comes from the energy sector accounting for about 41% of the country's total emissions from 1990-2006 (EPA, 2011). Biomass accounts for about 60% of the country's total energy consumption and its combustion leads to increases in emissions.

The results establish a positive long run relationship between trade openness and CO_2 emissions per capita at 10% level of significance. Specifically, a 1% increase in international trade leads to a 1.1101% increase in per capita CO_2 emissions holding all other variables constant. Evidently, the excessive use of fossil fuels, such as oil which is a major component of imports, increased importation of e-waste which are disposed of through burning and the increased production and export of gold which uses a lot of petroleum products for power generation tends to increase CO_2 emissions and are some of the possible factors accounting for the detrimental effect of trade on CO_2 emissions in Ghana. This result is in line with the findings of TWEREFOU ET AL. (2015) which showed that trade liberalization has adverse effects on emissions of CO_2 as a result of negative scale and composition effects of trade overriding the positive technique effect of trade as well as that of FERIDUN ET AL. (2006), MANAGI ET AL. (2008) and the WORLD BANK (2012) which indicate that Ghana has experienced an increase in CO_2 emissions in the post liberalization period (1983) as a result of deforestation, persistent increase in imports and usage of fossil fuels as well as other pollution intensive goods such as e-waste (outdated electrical gadgets, such as, used televisions, microwaves, computers, etc.) and inefficient second-hand automobiles, among others.

5.3. Short run elasticities

Table 4 presents the results of the ECM and the estimated short run coefficients of the variables. Evidence from the short run dynamics of the EKC model shows the non-existence of the EKC hypothesis for CO_2 emissions with the signs of GDP per capita and GDP per capita squared being negative and positive respectively and statistically significant. The impact of energy consumption per capita on per capita CO_2 emissions is positive and statistically significant. A 1% increase in energy consumption per capita causes an increase in per capita CO_2 emissions by 1.2201% in the short run, all other variables held constant.

[1] A robust linear model of the form $InCO_{2t} = \beta_0 + \beta_1 InY_t + \beta_2 InFDI_t + \beta_3 InENERGY_t + \beta_4 InTRADE_t + \varepsilon_t$ (excluding the squared of per capita GDP) was estimated and the results showed a positive long run relationship between economic growth and CO_2 emissions

Table 4. Results of the Error Correction Model (source: author's estimations)

Regressor	Coefficient	Standard error	T-Ratio
dIn(CO_2)1	0.8210	2.9800	0.2755
dInY	-0.5322	1.1462	-4.6433***
dInY1	-0.2054	1.2862	-0.1597
dInY^2	1.0251	0.1447	7.0843**
dIn$Y^2$1	1.2066	1.3799	0.8744
dInenergy	1.2201	0.30401	4.0133**
dInenergy1	0.6577	1.1418	0.5760
dIntrade	0.5330	1.8341	0.2906
dIntrade1	1.0055	2.4693	0.4072
dInFDI	-0.2007	0.3297	-0.6088
dInFDI1	-0.1906	0.2362	-0.8069
Trend	1.0605	0.1790	5.9241***
ecm (-1)	-0.4412	0.0818	-5.3936***

Note: *, **and *** above represent significant at 10%, 5% and 1% level of significance respectively

The sign of the coefficient of the lagged ECM term in Table 4 is negative and statistically significant at 1% and supports the conclusion of cointegration between the variables in the long run (MUHAMMAD ET AL., 2011). The error correction term of -0.4412 suggests that when per capita CO_2 emissions are above, or below, equilibrium level, it adjusts by almost 44.12% within the first year.

6. Conclusions

In Ghana, as in many other developing countries, there exist few studies that confirm or reject the EKC hypothesis with regards to CO_2 emissions as well as the factors that drive CO_2 emissions which is quite important for policy making. This study aims to bridge this knowledge gap by addressing these two major questions using data from 1970 to 2010 and the ARDL Bounds Testing approach.

The results suggest a U-shaped relationship between per capita GDP and CO_2 emissions per capita indicating the non-existence of the EKC hypothesis for CO_2 in Ghana. This implies that further increase in per capita GDP will only be associated with increase in CO_2 emissions since the income turning point occurred between 1996 and 1997. The study therefore recommends the development and implementation of the Low Carbon Development Strategy (LCDS) which integrates development and climate change mitigation actions as elaborated in the Conference of Parties 15 of the United Nations Framework Convention on Climate Change if its international commitments to climate change mitigation are to be met. Such solutions should revolve around technology improvement and policies that will lead to the right pricing of resources.

With regards to the determinants of CO_2 emissions, the results indicate that international trade has positive effects on CO_2 emissions in Ghana. We therefore recommend trade openness and enhancement of trade liberalization policies that ensure the use of cleaner technologies and products. Furthermore, energy consumption was found to have a significantly positive impact on per capita CO_2 emissions in the long run indicating that investment in cleaner energy alternatives such as biofuels, biogas, solar and the implementation of energy efficiency programmes could help reduce CO_2 emissions. In general, the study recommends the country to pursue LCDS which integrate development and climate change mitigation actions as elaborated in COP 15 if its international commitments to climate change mitigation are to be achieved.

References

Abimbola O.M., Bello A.K. 2010. Does the level of economic growth influence environmental quality in Nigeria: A test of Environmental Kuznets Curve hypothesis. *Pakistan J. Soc. Sci.*, 7, 4: 325-329.

Andreoni J., Levinson A. 2001. The simple analytics of the Environmental Kuznets curve. *J. Public Economics,* 80: 269-286.

Antle, J. M., Heidebrink, G. 1999. Environment and Development: Theory and International evidence. *Environ. Econ. Dev.,* 43: 603-625.

Beckerman W. 1992. Economic growth and the environment: Whose growth? Whose environment? *World Dev.*, 20, 4: 481-496.

DeBruyn S.M., Heintz R.J. 2002. The Environmental Kuznets curve hypothesis. [In:] Bergh J.C.J.M.V.D. (ed.). *Handbook* *of Environmental and Resource Economics.* Edward Elgar Publ., Oxford: 656-677.

DeBruyn S.M., Opschoor S. 1998. Developments in the throughput-income relationship: theoretical and empirical observations. *Ecol. Econ.*, 20, 3: 255-268.

De Groot H.L.F. 1999. Structural Change, Economic Growth and the Environmental Kuznets Curve. *OCFEB Research Memorandum 9911, Environmental Policy, Economic Reform and Endogenous Technology,* Working Paper Series 1: 7-39.

Environmental Protection Agency. 2011. Ghana's Second National Communication to the United Nations Framework Convention on Climate Change, EPA, Accra, Ghana. http://unfccc.int/resource/docs/natc/ghanc2.pdf [Accessed 10th May, 2015].

Environmental Protection Agency. 2015. Ghana's Third National Communication to the United Nations Framework Convention on Climate Change, EPA, Accra, Ghana.

Friedl B., Getzner M. 2003. Determinants of CO_2 emissions in a small open economy. *Ecol. Econ.*, 45, 1: 133-148.

Galeotri M., Lanza A. 1999. Richer and cleaner? A study on carbon dioxide emissions in developing countries. *Energy Policy*, 27, 10: 565-573.

Grossman G.M., Krueger A.B. 1991. Environmental impacts of a North American Free Trade Agreement. *Natl. Bureau Econ. Res.* Working Paper No. 3914. http://www.nber.org/papers/w3914.pdf

Grossman G.M., Krueger A.B. 1995. Economic growth and the Environment. *Quarterly J. Econ.*, 110, 2: 353-377.

Gujarati, N. D. 2004. *Basic Econometrics*. Fourth Edition. The McGraw-Hill Companies.

Halicioglu, F. 2009. An econometric study of CO_2 emissions, energy consumption, income and foreign trade in Turkey. *Energy Policy*, 37, 3: 1156-1164.

Holtz-Eakin D., Selden T. 1995. Stoking the fires? CO_2 emissions and economic growth. *J. Publ. Econ.*, 57: 85-101.

Hossain S. 2012. An econometric analysis for CO_2 emissions, energy consumption, economic growth, foreign trade and urbanization of Japan. *Low Carbon Econ.*, 3: 92-105.

Intergovernmental Panel on Climate Change. 2007. The physical science basis. Contribution of Working group 1 to the fourth assessment report of the IPCC, Cambridge Univ. Press. http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4_wg1_full_report.pdf [accessed 25th June, 2015].

Kriström B., Rivera P. 1995. Is the income elasticity of environmental improvement less than one*?, Environ. Res. Econ,.* 7: 45-55.

Lieb Ch.M. 2002. The Environmental Kuznets Curve - A survey of the Empirical Evidence and of Possible Causes. *Discussion Paper Ser., No. 391,* Interdisci. Inst. of Environ. Econ., Univ. of Heidelberg. http://www.uni-heidelberg.de/md/awi/forschung/dp391.pdf.

Lopez R. 1994. The environment as a factor of production: The effects of economic growth and trade liberalization. *J. Environ. Econ. Manage.*, 27: 163-184.

Managi S., Hibiki A., Tetsuya T. 2008. Does trade liberalization reduce pollution emissions? *Discussion Papers*, 08013. Res. Inst. Econ. Trade Industry (REITI). http://www.rieti.go.jp/jp/publications/dp/08e013.pdf

Mensah J.T. 2014. Carbon emissions, Energy consumption and Output: A Threshold Analysis of the Causal dynamics in Emerging African Economies. *Energy Policy*, 70: 172-182.

McConnell, K.E. 1997. Income and the demand for environmental quality. *Environ. Dev. Econ.,* 2, 4: 383-400.

Muhammad S., Faridul I., Muhammad S. 2011. Financial Development, Energy Consumption and CO_2 emissions: evidence from ARDL approach for Pakistan. *MPRA paper* No. 30138. https://mpra.ub.uni-muenchen.de/30138/1/MPRA_paper_30138.pdf

Nguyen T.A. 1999. Evidences of Environmental Kuznets Curve from CO_2 emissions in six-country analysis. *Working Paper.* Inst. d'Econ. de Polique de l'Energie (IEPE) BP 47, 38040 Grenoble Cedex 09.

Omisakin A.O. 2009. Economic growth and environmental quality in Nigeria: Does environmental Kuznets curve hypothesis hold? *Environ. Res. J.,* 3, 1: 14-18.

Omojolaibi A.Y. 2010. Environmental Quality and Economic Growth in some selected West African countries: A panel data assessment of the EKC. *J. Sustain. Dev. Africa*, 12, 8: 35-48.

Onafowora O.A. and Owoye, O. 2014. Bounds Testing Approach to analysis of the environment Kuznets curve hypothesis. *Energy Econ.*, 44: 47-62.

Panayotou T. 1993. Empirical tests and policy analysis of environmental degradation at different stages of economic development. *Working paper WP238,* Tech. Employment Programme, Geneva: Int. Labour Office. http://www.ilo.org/public/libdoc/ilo/1993/93B09_31_engl.pdf

Panayotou T. 2000. Economic Growth and the Environment. *Working Paper*, 56, *Environ. Dev. Paper*, 4. Center Int. Dev., Harvard Univ.

Panayotou T., Sachs J., Peterson A. 1999. Developing countries and the control of climate change: A theoretical perspective and policy implications. *CAER II Discussion paper*, 45.

Pesaran M.H., Shin Y. 1999. An Autoregressive Distributed-Lag Modelling Approach to Cointegration Analysis. Econometrics and Economic Theory in the 20th century. [In:] Strom S. (ed.) *The Ragnar Frisch Centennial Symp.* Cambridge Univ. Press, Cambridge: 371-413.

Saboori B., Soleymani A. 2011. CO_2 emissions, economic growth and energy consumption in Iran: A cointegration approach. *Int. J. Environ. Sci.,* 2, 1: 44-53.

Schmalensee R., Stoker T.M., Judson R.A. 1998. *World carbon dioxide emissions: 1950-2050*. http://globalchange.mit.edu/files/document/MITJPSPGC_Rpt5.pdf

Selden T.M., Song D. 1995. Neoclassical growth, the J curve for abatement and the inverted U curve for pollution. *J. Environ. Econ. Manage.*, 29, 2: 162-168.

Shafik N., Bandyopadhyay S. 1992. *Economic Growth and Environmental Quality: Time Series and Cross Country Evidence*. World Bank Policy Res. Working Paper, WPS 904.

Smulders S., Bretschger L. 2000. Explaining Environmental Kuznets Curves: How Pollution induces policy and new technologies. *Center Econ. Res., Tilburg, Discussion Paper, 2000-95.*

Stern D.I., Common M.S., Barbier E.B. 1996. Economic Growth and environmental degradation: The Environmental Kuznets Curve and sustainable development. *World Dev.*, 24, 7: 1151-1160.

Tamazian A., Chousaa J.P., Vadlamannatia K.C. 2009. Does higher economic and financial development lead to environmental degradation? Evidence from BRIC countries. *Energy Policy*, 37, 1: 246-253.

Twerefou D.K., Appiah-Konadu P. 2015. The Impact of Trade Liberalization on the Environment: Evidence from Ghana. *Ghana Soc. Sci. J.***,** 12, 1.

Word Bank. 2012. World Development Indicators Online Database. The World Bank Group. Available On-Line: http://devdata.worldbank.org/dataonline.