Multivariate co-integration analysis of the Kaya factors in Ghana

Samuel Asumadu-Sarkodie¹ · Phebe Asantewaa Owusu¹

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Abstract The fundamental goal of the Government of Ghana's development agenda as enshrined in the Growth and Poverty Reduction Strategy to grow the economy to a middle income status of US\$1000 per capita by the end of 2015 could be met by increasing the labour force, increasing energy supplies and expanding the energy infrastructure in order to achieve the sustainable development targets. In this study, a multivariate co-integration analysis of the Kaya factors namely carbon dioxide, total primary energy consumption, population and GDP was investigated in Ghana using vector error correction model with data spanning from 1980 to 2012. Our research results show an existence of long-run causality running from population, GDP and total primary energy consumption to carbon dioxide emissions. However, there is evidence of short-run causality running from population to carbon dioxide emissions. There was a bi-directional causality running from carbon dioxide emissions to energy consumption and vice versa. In other words, decreasing the primary energy consumption in Ghana will directly reduce carbon dioxide emissions. In addition, a bi-directional causality running from GDP to energy consumption and vice versa exists in the multivariate model. It is plausible that access to energy has a relationship with increasing economic growth and productivity in Ghana.

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✉ Samuel Asumadu-Sarkodie
asumadusarkodiesamuel@yahoo.com

¹ Orta Dogu Teknik Universitesi Kuzey Kibris Kampusu, Guzelyurt, Turkey

Keywords Multivariate co-integration · Kaya factors · Carbon dioxide emission · Causality · Ghana

JEL classifications Q43

Abbreviations

TCE	Total carbon dioxide emissions	34
GDP	Gross domestic product	35
TPEC	Total primary energy consumption	36
VEC	Vector error correction	37
VECM	Vector error correction model	38
VAR	Vector autoregression	39
OLS	Ordinary least squares	40
IMF	International monetary fund	41
LR	Sequential likelihood ratio	42
AIC	Akaike information criterion	43
SC	Schwarz information criterion	44
HQ	Hannan-Quinn information criteria	45
FPE	Final prediction error	46
MMT	Million metric tons	47
QBtu	Quadrillion British thermal units	48
P	Population	49
GNI	Gross national income	50
HDI	Human development index	51
SDG	Sustainable development goal	52
MDGs	Millennium development goals	53
χ^2	Chi square	54
<i>df</i>	Difference	55
Prob	Probability	56
_ce	Co-integrated equation	57
Coef.	Coefficient	58
Std. Err.	Standard error	59

Greek letter
 π Rank

96 Introduction

97 The dominance of fossil-fuel based energy generation within
98 the past decades has led to global challenges associated with
99 greenhouse gas emissions (Asumadu-Sarkodie and Owusu
100 2016). A consistent exponential growth in population within
101 the last decades has led to a growing demand for energy
102 resulting in carbon dioxide emissions leading to climate
103 change. As a result, mitigating carbon dioxide emissions have
104 become a priority in both developed and developing countries
105 due to its consequences. The Sustainable Development Goal
106 (SDG) 13 emphasises on the integration of climate change
107 measures into national policies, planning and strategies of
108 both developed and developing countries. Access to energy
109 is one of the many ways of achieving higher levels of eco-
110 nomic productivity in every technological and advancing
111 country. The fundamental goal of the Government of
112 Ghana's development agenda as enshrined in the Growth
113 and Poverty Reduction Strategy (GPRS II) is to grow the
114 economy to a middle income status of US\$1000 per capita
115 by the end of 2015. The goal will be met by increasing energy
116 supplies and expanding the energy infrastructure in order to
117 achieve the development targets (Energy Commission 2015).
118 The current human development report by the United Nations
119 Development Programme indicates that Ghana has a human
120 development index of 0.573/1 ranking higher than Nigeria.
121 The report further indicates that Ghana has a gross national
122 income (GNI) per capita of US\$3,532.33, 30.46 % population
123 in multidimensional poverty, 37.37 % of primary energy sup-
124 ply, 0.37 t of carbon dioxide emission per capita and a popu-
125 lation of 25.9 million (United Nations Development
126 Programme 2015). Ghana has suffered from many setbacks
127 ranging from health, energy-crisis (Asumadu-Sarkodie and
128 Owusu 2016a, b), floods (Asumadu-Sarkodie et al. 2015a,
129 b) and economic crisis within the last decades. Ghana like
130 any developing country emits carbon dioxide through the
131 burning of firewood and charcoal in rural areas for heating
132 purposes, deforestation, bush fires and pollution from emerg-
133 ing industries in the country. Nevertheless, research is limited
134 in the scope of assessing the causes of climate change and its
135 related impacts.

136 To the best of our knowledge, this is the first time the
137 Kaya factors are investigated in Ghana. Against this back-
138 ground, the study presents a multivariate analysis of the
139 relationship between carbon dioxide emissions and the
140 Kaya factors in Ghana by employing dataset from 1980
141 to 2012. The outcome of the study will be a contribution
142 to the literature under-studied. The study is envisioned to
143 create awareness on the causal nexus between carbon di-
144 oxide, GDP, population and energy consumption. Finally,
145 the study will outline some policy recommendations that
146 can be integrated into national policies, strategies and
147 planning towards climate change mitigation in Ghana.

The remainder of the study comprises of "Literature re- 148
view", "Methodology", "Results and Discussion", 149
"Comparison with previous studies and policy recommenda- 150
tions" and "Conclusion". 151

Literature review 152

Many studies have investigated the causal relationship be- 153
tween carbon dioxide emissions, gross domestic product 154
(GDP), energy intensity/consumption, population, etc. 155
Nevertheless, not all outcomes between carbon dioxide emis- 156
sions and economic growth or energy intensity/consumption 157
and economic growth are in agreement with each other in 158
previous studies. It may be argued that the outcome of these 159
studies maybe country-specific and/or econometric-method- 160
adopted-specific. Huang et al. (2008) investigated the causal 161
relationship between energy consumption and GDP for 82 162
countries using the generalized method of moments which 163
they found no evidence between energy consumption and 164
GDP. Lozano and Gutiérrez (2008) investigated the relation- 165
ship among GDP, carbon dioxide, energy consumption and 166
population using a non-parametric approach. Their proposed 167
model was applicable to USA. Soytaş and Sari (2009) inves- 168
tigated the relationship between carbon dioxide emission, en- 169
ergy consumption and economic growth using the long run 170
Granger causality test. They concluded that carbon dioxide 171
emissions Granger cause energy consumption but however 172
not valid for the reverse. Zhang and Cheng (2009) investigat- 173
ed the Granger causality between carbon dioxide, economic 174
growth, population and energy consumption. From their 175
study, neither carbon dioxide emissions nor energy 176
consumption leads to economic growth. Gul et al. (2015a) 177
studied on the relationship energy consumption and carbon 178
dioxide emissions in Malaysia spanning from 1975 to 2013 179
by employing the maximum entropy bootstrap method. Their 180
study identified a unidirectional causality running from energy 181
consumption to carbon dioxide emissions. Jammazi and Aloui 182
(2015) also studied on the relationship between carbon diox- 183
ide emissions, energy consumption and economic growth for 184
six countries spanning from 1980 to 2013 by employing 185
wavelet window cross-correlation approach. Their study iden- 186
tified a bilateral causality between energy consumption and 187
economic growth, while a unidirectional causality exists 188
running from energy consumption to carbon dioxide 189
emissions. Qureshi et al. (2016) on the other hand investigated 190
the energy crisis, greenhouse gas emissions and economic 191
growth for Asia, Africa, Europe, Latin America and the 192
Caribbean spanning from 1975 to 2012 by employing 193
Johansen co-integration technique and variance 194
decomposition. Their study identified a negative and 195
significant linkage between access to electricity and power 196
shortage in some regions of Asia and Europe. Remuzgo and 197

198 Sarabia (2015) investigated on the global distribution inequality of carbon dioxide emissions in regions considered by IEA
199 from 1990 to 2010 using the factorial decomposition. Their
200 study associated economic growth as the cause of global distribution inequality of carbon dioxide emissions. Zou et al.
201 (2015) investigated the impact of air pollution and environmental indicators on health and wealth within low-income
202 countries by employing the vector error correction model. Their study confirmed the association of environment and
203 air pollution to health and wealth in low-income countries.
204
205 Nevertheless, our study is in line with Chang (2010) who
206 investigated the relationship between carbon dioxide emissions, energy consumption and economic growth in China
207 using a multivariate co-integrated Granger causality tests. Their results showed a bidirectional causality from GDP to
208 carbon dioxide emission and electricity consumption to GDP. Unlike Chang (2010) who employed carbon dioxide
209 emissions, energy consumption and economic growth, we employ the Kaya factors which comprises of carbon dioxide,
210 total primary energy consumption, population and GDP. Furthermore, we employ the Kaya identity to model all the
211 kaya factors aside co-integration analysis and vector error correction model (VECM).
212
213 Developing countries like Ghana have being ignored in the
214 debate on climate change mitigation since the United Nations framework convention on climate change (UNFCCC) instituted
215 the Kyoto protocol. Nonetheless, Ghana consented to the Kyoto Protocol in November 2002 and was indexed in non-
216 annex 1 countries that “can only participate in the clean development mechanism as her contribution to reducing emission
217 levels of her greenhouse gases” (UNTC). Ghana’s contribution to reducing carbon dioxide emissions as established
218 in the MDGs and SDG (13) is yet to be assessed. This study will increase the debate on sustainable development and serve
219 as a reference tool for integrating climate change measures into national policies, strategies and planning by the
220 Government of Ghana, since the study is the first of its kind done in Ghana.

236 **Methodology**

237 This section outlines the methodology employed in the study. This employs the ordinary least squares estimation, the Kaya
238 identity, Phillips-Perron unit root test, lag selection criteria, vector autoregression (VAR), Johansen co-integrated test,
239 vector error correction model (VECM) and Granger causality test by using a dataset spanning from 1980 to 2012. Total
240 primary energy consumption and carbon dioxide emission data were derived from the U.S. Energy Information
241 Administration (EIA 2015) database, while population and GDP were derived from the World Bank.

For brevity, all the equations are not indicated in the study due to the availability in existing literature (Chang 2010; Fei et al. 2011; Gul et al. 2015a; Soytaş and Sari 2009; Zhang and Cheng 2009). Nevertheless, Vector autogression can be calculated as

$$y_t = E_1y_{t-1} + \cdots + E_p y_{t-p} + Fx_t + \epsilon_t \tag{1}$$

where y_t is a k vector of the endogenous variables, x_t is the d vector of exogenous variables, $E_1, \dots, E_p$ and F are the matrices of the coefficients estimated, and ϵ_t is the white noise residuals.

Descriptive analysis

This section provides a descriptive statistical analysis of the study variables. Variables employed in the study are total carbon dioxide emission (TCE) measured in million metric tons, total primary energy consumption (TPEC) measured in quadrillion Btu and gross domestic product (GDP) measured in billions of US\$ and population measured in million per persons respectively. Table 1 shows the descriptive statistical analysis of the research variables. From 33 observations, it is evident from Table 1 that almost all the variables excluding GDP have close relationship with their mean and median. In this scenario, the median of GDP (6.4161) presents a robust measure of the centre of dispersion among the overall data, while the mean (11.2062) is more sensitive to outliers which may lead to over or under representation of the population. Positive skewness of the variables shows a long-right-tail of the distribution; however, GDP has the longest-right-tail distribution and a non-significant Jarque-Bera test statistics at 5 % probability. Jarque-Bera tests the normal distribution of series by the difference of skewness and kurtosis (Descriptive Statistics & Tests). GDP shows a platkurtic distribution to the normal, while TEC, TPEC and population show leptokurtic distribution to the normal.

Table 1 Descriptive statistical analysis

Descriptive statistic	Number	GDP	TPEC	TCE	Population
Mean	33	11.2062	0.1193	4.6088	17.4783
Median	33	6.4161	0.1160	3.8660	17.1692
Maximum	33	41.9397	0.2053	9.2475	25.5446
Minimum	33	4.0360	0.0514	1.9074	10.8020
Std. dev.	33	10.8080	0.0394	2.2171	4.3744
Skewness	33	1.7153	0.4510	0.6701	0.2159
Kurtosis	33	4.5779	2.8465	2.3677	1.9084
Jarque-Bera	33	19.6067	1.15127	3.01918	1.89481
Probability	33	0.0001	0.56235	0.221	0.38775

Model estimation

Ordinary least squares estimation (OLS) is employed to estimate the true population relationship between the study variables (total carbon dioxide emissions, total primary energy consumption, GDP and population). OLS requires that the mean of variables and all its autocovariances are infinite and unchangeable over time (i.e. covariance stationary $I(0)$). Salahuddin et al. (2015) claim that OLS leads to spurious coefficient and bias reporting at first sight due to multicollinearity. However, Gujarati (2003) in Agung (2011) stated that multicollinearity is the will of God, not the problem with ordinary least squares estimation. Agung (2011) argued that multicollinearity should not be a concern since the bivariate and multiple correlations between independent variables always exist even if it is theoretically wrong. Based on this statement, results from OLS will be compared with Granger causality test and co-integration analysis in order to limit or eliminate spurious regressions. Table 2 shows the summary statistics of ordinary least squares estimation. Presumably, the relationships between TPEC and TCE, TCE and TPEC, TCE and population, TCE and GDP, population and TCE, population and GDP, GDP and TCE, and GDP and population are significant at 1 and 5 %, respectively. From first sight, the relationships seem plausible but inconclusive and would therefore be tested with co-integration analysis.

Table 2 Summary statistics of ordinary least squares estimation

	Estimate	Std. error	t value	Pr(> t)
TPEC				
(Intercept)	0.0823	0.0315	2.6160	0.0140*
TCE	0.0216	0.0050	4.3020	0.0002*
Population	-0.0032	0.0029	-1.1230	0.2705
GDP	-0.0005	0.0003	-1.5990	0.1207
TCE				
(Intercept)	-4.8791	0.4469	-10.9180	0.0000*
TPEC	18.0181	4.1882	4.3020	0.0002*
Population	0.3998	0.0419	9.5350	0.0000*
GDP	0.0313	0.0080	3.8980	0.0005*
Population				
(Intercept)	11.1704	0.7343	15.2110	0.0000*
TPEC	-12.8398	11.4299	-1.1230	0.2710
TCE	1.8965	0.1989	9.5350	0.0000*
GDP	-0.0804	0.0156	-5.1480	0.0000*
GDP				
(Intercept)	82.8040	11.0230	7.5120	0.0000*
TPEC	-153.8500	96.2370	-1.5990	0.1207
TCE	10.9800	2.8170	3.8980	0.0005*
Population	-5.9410	1.1540	-5.1480	0.0000*

*p value <0.05

Figure 1 shows the diagnostics for ordinary least squares estimation. Model diagnostics for regression analysis is very crucial in making statistical inferences. The residuals of the variables show a uniform distribution and a close relation with the predicted variables in the regression. Three data points corresponding to TEC variables in 1981, 1989 and 2010 as depicted in Cook's distance look like outliers due to the absence of leverages but were however ignored because the data points are useful and will be corrected by co-integration analysis if they are influential.

Kaya factors

The Kaya identity framework expresses the amount of carbon dioxide emissions as the product of carbon content of the energy, energy intensity of the economy, economic production per person and the population. The elaborated equations of Kaya identity can be found in the work of Remuzgo and Sarabia (2015). For brevity, Kaya Identity outlines the four driving forces of decomposition of carbon dioxide emissions, which is expressed as Kaya (1990):

$$CO_2 = \frac{CO_2}{TPEC} \times \frac{TPEC}{GDP} \times \frac{GDP}{P} \times P \tag{2}$$

where CO_2 is the carbon dioxide emissions, $TPEC$ is the total primary energy consumption, GDP is the gross domestic product and P is the population. Figure 2 shows the trend of the Kaya factors in Ghana. All the Kaya factors excluding GDP are directly proportional to the given period (1980–2012); however, Ghana's GDP decreases with time, which confirms HDI report that Ghana has a gross national income (GNI) per capita of US\$ 3,532.33 with 30.46 % population in multidimensional poverty (United Nations Development Programme 2015).

Data and unit root test

Performing unit root test is a pre-specification of Johansen's method of co-integration and vital in minimizing spurious regression since it ensures that variables used in a regression are stationary by differencing them and estimating the equation of interest through the stationary processes (Mahadeva and Robinson 2004). The study uses augmented Dickey-Fuller and Phillips-Perron (Phillips and Perron 1988) tests to examine the existence of unit roots for the variables. Table 3 presents a summary of augmented Dickey-Fuller and Phillips-Perron unit root test results. The null hypothesis that a variable has a unit root is accepted at the level but rejected by the first and second difference based on 5 % significance. As a requirement for testing Johansen's method of co-integration, variables for the co-integration must have a unit root at level and

Fig. 1 Ordinary least squares estimation diagnostics, **a** residuals vs fitted, **b** normal Q-Q plot, **c** scale-location and **d** cook's distance

be integrated at $I(1)$. Hence, TCE, TPEC, GDP and population fulfil the requirement for Johansen's method of co-integration.

Co-integration test and vector error correction model

After unit root test, the next step is to test for co-integration using Johansen's method due to the prior knowledge of $I(1)$ in the model. Before executing Johansen's method of co-integration, we employ Vector autoregression (VAR) lag order selection criteria to select the optimal lag for co-integration

analysis. VAR lag order selection criteria selected lag 4 as the optimum lag to test of co-integration in the research analysis. Table 4 shows VAR Lag order selection criteria. Four lags are employed for this multivariate model because the sequential likelihood ratio (LR), final prediction error (FPE), Akaike information criterion (AIC), Schwarz information criterion (SC) and Hannan-Quinn information criteria (HQ) all chose 4 as indicated by “*” in Table 4.

Unlike OLS, co-integration provides a framework for estimation, inference and interpretation when the variables are not

Fig. 2 Trend of the Kaya factors in Ghana, **a** TCE (MMT), **b** TPEC (QBtu), **c** Population (1,000,000/persons) and **d** GDP (Billion US\$)

t3.1 **Table 3** Summary of augmented Dickey-Fuller and Phillips-Perron unit root test

t3.2		Variable	Levels adj. <i>t</i> -stat	Prob.	First difference adj. <i>t</i> -stat	Prob.	Second difference adj. <i>t</i> -stat	Prob.
t3.3	ADF unit root test							
t3.4	Intercept	TCE	−0.1195	0.9388	−4.2439	0.0026	−3.9039	0.0071
t3.5		TPEC	−0.4798	0.8826	−5.6440	0.0001	−4.7701	0.0007
t3.6		GDP	−2.5734	0.1088	−4.2962	0.0020	−8.2273	0.0000
t3.7		Population	−1.9985	0.2855	−1.2337	0.6453	−2.3632	0.1628
t3.8	Trend and intercept	TCE	−3.4003	0.0697	−4.1529	0.0147	−4.0075	0.0233
t3.9		TPEC	−4.0676	0.0166	−5.3460	0.0008	−4.6927	0.0045
t3.10		GDP	−2.0312	0.5620	−4.7651	0.0031	−8.0764	0.0000
t3.11		Population	−3.3979	0.0713	−4.3585	0.0113	−1.5242	0.7894
t3.12	PP unit root test							
t3.13	Intercept	TCE	3.9379	1.0000	−6.0526	0.0000	−23.0300	0.0001
t3.14		TPEC	1.8145	0.9996	−5.4622	0.0001	−25.3101	0.0000
t3.15		GDP	−6.3214	0.0000	−3.5658	0.0126	−13.3032	0.0000
t3.16		Population	7.6785	1.0000	2.8080	1.0000	−3.3866	0.0196
t3.17	Trend and intercept	TCE	−1.8193	0.6717	−14.6245	0.0000	−25.3101	0.0000
t3.18		TPEC	−2.2855	0.4294	−7.8354	0.0000	−12.3190	0.0000
t3.19		GDP	−3.4932	0.0572	−4.6884	0.0038	−16.4481	0.0000
t3.20		Population	2.8080	1.0000	−1.7158	0.7199	−3.4503	0.0636

368 covariance-stationary (StataCorp 2015). Table 5 presents the
369 summary of Johansen co-integration test by max-eigenvalue
370 and trace statistic methods. Based on 5 % significance in the
371 results shown in Table 5, we strongly reject the null hypothesis
372 of no co-integration and fail to reject the null hypothesis of at
373 most three co-integrating equations. Thus, we accept the null
374 hypothesis that there are three co-integrating equations in the
375 multivariate model.

376 **Results and discussion**

377 **Vector error correction model**

378 Using three co-integration equations, the study estimates the
379 long-run and short-run causality using the vector error correc-
380 tion model. Table 6 presents a long-run and a short-run cau-
381 sality on the error correction model. The error correction co-
382 efficient (−3.4869) is significant at 1 % significance level and

therefore rejects the null hypothesis of no long-run causality
and accepts the alternative hypothesis that there is a long-run
causality running from independent variables (population,
GDP and TPEC) to the dependent variable (TCE). Significantly,
the speed of adjustment in the VECM is almost 349 % which is
substantial. However, on checking for individual short-run cau-
sality using Wald test coefficient restrictions, there is evidence of
only short-run causality running from population to TCE.

Pairwise Granger Causality Wald Tests

Vector error correction model is capable of estimating long-
run and short-run causal relationship between time series var-
iables. Nevertheless, it fails in its capacity to show the direc-
tion of causality. Granger causality test is used to estimate the

Table 5 Summary of Johansen co-integrated test by max-eigenvalue and trace methods

Rank (π)	Eigenvalue	Max-eigenvalue		Trace	
		statistics	<i>p</i> values**	Statistics	<i>p</i> values**
0*	0.877813	58.8616	0.0000	129.65	0.0000
1*	0.787426	43.357	0.0000	70.7884	0.0000
2*	0.616352	26.8248	0.0003	27.4314	0.0005
3	0.021432	0.60661	0.4361	0.60661	0.4361

*Rejection of the hypothesis at the 0.05 level

**MacKinnon-Haug-Michelis (1999) *p* values

t4.1 **Table 4** VAR lag order selection criteria

t4.2	Lag	LogL	LR	FPE	AIC	SC	HQ
t4.3	0	−86.2175		0.0059	6.2219	6.4105	6.2810
t4.4	1	102.5241	312.3998	0.0000	−5.6913	−4.7484	−5.3960
t4.5	2	138.7414	49.9549	0.0000	−7.0856	−5.3883	−6.5540
t4.6	3	203.7063	71.6854	0.0000	−10.4625	−8.0108	−9.6947
t4.7	4	238.2729	28.6068 ^a	0.0000 ^a	−11.7430 ^a	−8.5369 ^a	−10.7389 ^a

^a Lag order selected by the criterion

t6.1

Table 6 Long-run multivariate causality on the error correction model						
	Eqn.	Coef.	Std. Err.	<i>z</i>	<i>p</i> > <i>z</i>	
t6.3	D_TCE	_ce1 L1.	−3.4869	0.7778	−4.4800	0.0000*
t6.4		_ce2 L1.	6.0382	1.1990	5.0400	0.0000*
t6.5		_ce3 L1.	0.0349	0.0973	0.3600	0.7200
t6.6	D_Population	_ce1 L1.	0.0015	0.0015	1.0500	0.2920
t6.7		_ce2 L1.	−0.0007	0.0022	−0.3200	0.7490
t6.8		_ce3 L1.	0.0000	0.0002	0.1600	0.8720
t6.9	D_GDP	_ce1 L1.	−0.1046	1.2074	−0.0900	0.9310
t6.10		_ce2 L1.	−0.3499	1.8613	−0.1900	0.8510
t6.11		_ce3 L1.	−0.4598	0.1511	−3.0400	0.0020*
t6.12	D_TPEC	_ce1 L1.	−1.4017	1.0187	−1.3800	0.1690
t6.13		_ce2 L1.	3.2330	1.5704	2.0600	0.0400*
t6.14		_ce3 L1.	−0.3098	0.1274	−2.4300	0.0150*

*Rejection of the hypothesis at 0.05 level

t7.1

Table 7 Summary of a pairwise Granger causality Wald tests				t7.2
Null hypothesis	Chi square	<i>p</i> values		
TPEC does not Granger-cause TCE	15.2550	0.0040*	t7.3	
TCE does not Granger-cause TPEC	15.1820	0.0040*	t7.4	
Population does not Granger-cause TCE	30.2850	0.0000*	t7.5	
TCE does not Granger-cause Population	1.6e + 06	0.0000*	t7.6	
GDP does not Granger-cause TCE	34.7750	0.0000*	t7.7	
TCE does not Granger-cause GDP	14.9450	0.0050*	t7.8	
Population does not Granger-cause TPEC	34.8480	0.0000*	t7.9	
TPEC does not Granger-cause Population	4.1e + 06	0.0000*	t7.10	
GDP does not Granger-cause TPEC	2.0170	0.7330	t7.11	
TPEC does not Granger-cause GDP	17.4490	0.0020*	t7.12	
GDP does not Granger-cause Population	3.57335	0.0420*	t7.13	
Population does not Granger-cause GDP	0.52194	0.5995	t7.14	

*Rejection of the hypothesis at 5 %

direction of causality between the study variables. If *M* is said to Granger-cause *N*, Granger model based on bivariate VAR models is given as (Granger 1969)

402

$$N_t = \alpha_0 + \sum_{i=1}^c \alpha_i N_{t-i} + \sum_{i=1}^c \beta_i M_{t-i} + \epsilon_t \quad (3)$$

400

$$N_t = \alpha_0 + \sum_{j=1}^d \alpha_j M_{t-j} + \sum_{j=1}^d \beta_j N_{t-j} + \epsilon_t \quad (4)$$

In testing the null hypothesis, $H_0: \beta_i (1, 2, \dots, c) = 0$, means that *M* does not Granger-cause *N*. A rejection of the null hypothesis, $H_0: \beta_i (1, 2, \dots, c) = 0$ at 5 % significance level means that *M* Granger-causes *N* and vice versa.

Table 7 presents the summary of a pairwise Granger causality Wald tests. The null hypothesis that TPEC does not Granger-cause TCE, TCE does not Granger-cause TPEC, population does not Granger-cause TCE, TCE does not Granger-cause population, GDP does not Granger-cause TCE, TCE does not Granger-cause GDP, population does not Granger-cause TPEC, TPEC does not Granger-cause population, TPEC does not Granger-cause GDP and GDP does not Granger-cause population is rejected at 5 % significance.

Generalised impulse response

Figure 3 shows the log estimation of the Kaya factors using the Kaya identity framework equation. The primary driving forces of CO₂ emissions, increasing GDP, population and total primary energy consumption, drive CO₂ emissions upwards in Ghana which is also true globally. Figure 4 shows the generalised impulse response of CO₂ emissions, TPEC, GDP and population to other Kaya factors. The generalised impulse response helps to ascertain the long-run causality existing between variables without testing for co-integration and estimating co-integration equations (Soytas and Sari 2009). All the Kaya factors tend to have shocks as a response mechanism

towards each other; however, population receives more shocks from the other Kaya factors, but in return, CO₂ emissions, TPEC and GDP seem unperturbed to impulses from the population. One reason may be the power of population as the only variable in the study to cause short-run causality to CO₂ emissions which is impossible for the other Kaya factors based on the study results. There is a bi-directional causality running from carbon dioxide emissions to energy consumption and vice versa. In other words, decreasing the primary energy consumption in Ghana will directly reduce carbon dioxide emissions. Amazingly, there is a bi-directional causality running from GDP to energy consumption and vice versa. This is not a co-incidence, but it is plausible that access to energy has a relationship with increasing economic growth and productivity. The inception of power outages and low shedding in Ghana have affected industries both public and

Fig. 3 Estimation of Kaya factors

Fig. 4 Generalised impulse response of CO₂ emissions, TPEC, GDP and population to other Kaya factors

private resulting in either the collapse of private sector industries or reducing its labour force. According to 2014 IMF report, Ghana’s economy is slowing from previously higher levels. Ghana’s GDP in 2013 was 5.5 % but depreciated to 4.75 % resulting in price increase and increasing inflation. To overcome this problem, the International Monetary Fund (IMF) suggests that Ghana changes its policies on private sector by reducing its borrowing needs (IMF). There exists a unidirectional causality running from GDP to population, but the reverse does not hold. However, as population is directly proportion to the given period, GDP is inversely proportional to the same given period. Ghana has a great future if the labour

force is expanded to get more youth employed and focus on transforming its economy into an industrialized one.

Diagnostics and stability test

Model verification and validation of a selected model is a requirement prior to making statistically inferences in order to prevent misleading results. In this study, diagnostic checking and stability is employed which examines the residuals from the fitted model to ascertain residual independence in the selected model. Table 8 shows the summary of

Table 8	Summary of diagnostics tests results			
Lag range-multiplier test				
Lag	χ^2	df	Prob> χ^2	
1	15.3694	16	0.4978	
2	16.2175	16	0.4379	
3	25.3381	16	0.0641	
4	11.1356	16	0.8010	
Jarque-Bera test				
Equation	χ^2	df	Prob> χ^2	
D_TCE	4.0650	2	0.1310	
D_Population	0.8520	2	0.65318	
D_GDP	1.4610	2	0.48178	
D_TPEC	0.9130	2	0.63353	
ALL	7.2900	8	0.50566	

Fig. 5 Roots of characteristics polynomial

diagnostics test results conducted on the multivariate model. Lagrange-multiplier test is used to test for autocorrelation. The null hypothesis is that no autocorrelation at lag order is accepted which is desirable for the multivariate model. Jarque-Bera test is used for residual checking. The null hypothesis that residuals are normally distributed is accepted which is desirable for the multivariate model. Results from the diagnostics test show that the model is robust to make unbiased statistical inferences and policy recommendations.

Figure 5 shows the inverse roots characteristic polynomial. VEC specification imposes one unit root, and VAR stability condition check does not present a root outside the unit circle besides the first unit root of 1. Therefore, the VEC model is acceptable and stable in statistical sense.

Comparison with previous studies and policy recommendations

Similar work has been reported in literature under different countries and continents assessing the relationship between carbon dioxide emissions, energy consumption, population and GDP. Gul et al. (2015b) established a unidirectional causality from energy consumption to carbon dioxide emissions. Furthermore, Jammazi and Aloui (2015) established a causality from energy consumption to economic growth, while Chang (2010) established a bidirectional causality from GDP to carbon dioxide emissions and electricity consumption to GDP.

In contrast, our results show a bi-directional causality running from carbon dioxide emissions to energy consumption and a bi-directional causality running from GDP to energy consumption. The following policy recommendations are made based on the results from the study:

- As a contribution towards climate change mitigation, the Government of Ghana should incorporate climate change measures into national policy planning and strategies.
- The Government of Ghana should establish and empower institutions that will improve education and raise awareness on climate change impact reductions, adaptations and early warnings.
- With regard to the relationship between GDP and energy consumption in the study, Government should adopt policies that ensure stability of the economy, provide employment to youth and ensure access to affordable, reliable and clean sources of energy by incorporating renewables into Ghana's energy-mix.

Conclusion

In this study, a multivariate co-integrated analysis of the Kaya factors namely carbon dioxide, total primary energy

consumption, population and GDP was investigated in Ghana. Using a dataset from 1980 to 2012, Ghana's GDP has the longest right-tail distribution and a significant Jarque-Bera test statistics at 1 % probability. GDP shows a platkurtic distribution, while TEC, TPEC and population show leptokurtic distribution to the normal. VAR stability condition check suggests that the VEC model is acceptable statistically due to normal residual distribution and the absence of autocorrelation. Our study suggests that ordinary least square estimate really results in spurious regression which is a confirmatory to Mahadeva and Robinson (2004) who stated that the effects of GDP when subjected to shocks do not die away with time. However, co-integration analysis using vector error correction model minimized the spurious regression in OLS.

Our research suggests that a long-run causality exist running from independent variables (population, GDP and TPEC) to the dependent variable (TCE). However, there is evidence of short-run causality running from population to carbon dioxide emissions. Moreover, there is a bi-directional causality running from carbon dioxide emissions to energy consumption. In other words, decreasing the primary energy consumption in Ghana will directly reduce carbon dioxide emissions. The Government of Ghana should establish and empower institutions that will improve education and raise awareness on climate change impact reductions, adaptations and early warnings.

In addition, there is a bi-directional causality running from GDP to energy consumption. This is not a co-incidence, but it is plausible that access to energy has a relationship with increasing economic growth and productivity, since the inception of power outages and low shedding in Ghana have affected industries both public and private resulting in either the collapse of private sector industries or reducing its labour force. According to 2014 IMF report, Ghana's economy is slowing from previously higher levels. The International Monetary Fund (IMF) suggests that Ghana changes its policies on private sector by reducing its borrowing needs (IMF) in order to have a more resilient economy. Government should adopt policies that ensure stability of the economy, provide employment to youth and ensure access to affordable, reliable and clean sources of energy by incorporating renewables into Ghana's energy-mix.

The fundamental goal of the Government of Ghana's development agenda as enshrined in the Growth and Poverty Reduction Strategy (GPRS II) to grow the economy to a middle income status of US\$1000 per capita by the end of 2015 could be met by increasing the labour force, increasing energy supplies and expanding the energy infrastructure in order to achieve the sustainable development targets. Further studies should employ other econometric methods like ARDL and variance decomposition in order to know how each random innovation affects the variables in the VAR.

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