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# A time series analysis of fossil fuel consumption in Sub-Saharan Africa: evidence from Ghana, Kenya and South Africa

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ABSTRACT

This study investigated the determinants of fossil fuel consumption for three Sub-Saharan African countries – Ghana, Kenya and South Africa – to help manage the rising consumption fossil fuel consumption. The study employed the Fully Modified Ordinary Least Square and Canonical co-integration regression techniques using data from 1975–2013. Among other results, the study revealed that income and urbanization increased fossil fuel consumption for all the countries. Also, while trade reduced fossil fuel consumption for Kenya and South Africa, the opposite was found for Ghana. In addition, the efficiency of the service sector reduced fossil fuel consumption for all the countries. The results of the study suggest efforts should be geared towards strengthening the energy efficiency system in each of these countries to help reduce fossil fuel consumption. Also, it is necessary that tariff and non-tariff barriers on products that do not promote energy efficiency is raised and vice versa, *inter alia*.

***Keywords:***

Energy;
Fossil fuel;
Ghana;
Kenya;
South Africa;

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## 1. Introduction

Energy has become an engine that turns the wheels of economic activities in every country, because of its crucial role in the production process just like capital and labour. It also has a direct effect on the wellbeing of humans since it plays important role in a country's transportation, industry, agriculture, communications, commercial and public services and other sustainability issues like education, health and alleviation of poverty [1]. A plethora of empirical studies have also underscored the important contribution of energy to economic growth [2–6].

Owing to its importance, inadequate supply of energy does negatively affect the economic and social developments of countries. To avoid such situation, empirical investigations are carried out among other efforts to predict and regulate energy consumption. The evidence from such investigations indicates varied factors influence energy consumption for specific countries. Moreover, high level of energy consumption is known to emit green house gases especially carbon dioxide that leads to climate change. As a result, empirical studies are also embarked upon to ascertain the drivers of energy consumption in order to curtail the emission of carbon dioxide ($CO_2$). Among all forms of energy, fossil fuels are those whose consumption emits more carbon dioxide. This paper thus investigates into the drivers of fossil energy consumption for three Sub-Saharan African countries – Ghana, Kenya and

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South Africa. This is to unravel the possible factors behind the rising fossil fuel consumption in these countries in order to help reduce carbon dioxide emission while also bridging the gap between the rising fossil energy consumption and the inadequate supply in these selected countries.

The share of fossil fuel in the total energy consumption for Ghana, Kenya and South Africa has been increasing over the years. For instance, available data shows the share of fossil fuel in the total energy consumption in South Africa has exceeded 84% for more than four decades. In the case of Ghana, it has more than doubled from 16.5% in 1991 to 37.4% in 2011 and for Kenya it has increased from 16.9% in 1991 to 19.7% in 2011 [20]. However, the above mentioned countries are unable to meet their fossil energy demand requirement which has dire consequences on households, firms and the entire economy. It has been suggested that failure to predict future energy demand has been a major factor for the inadequate energy supply in Sub-Saharan African countries [7]. Predicting future energy demand requires the need to identify the forces of energy demand and thus to avoid a worsening energy security situation in the future, this paper seeks to identify the factors behind the increasing trend of fossil fuel consumption in Ghana, Kenya and South Africa.

Countries that do not meet their domestic fossil energy supply import from other counties. The challenge however is that importation of fossil energy entails considerable fiscal planning since it is dependent on the price at which the energy is sold on the world market. The implication is, fluctuations of fossil energy price on the international market do have serious macroeconomic impact on the importing countries. It is imperative therefore, for countries that import fossil energy to reduce their consumption of fossil energy in order to lessen their exposure to international price shock [9]. Global energy price shocks have had significant effects on macroeconomic variables such as inflation, gross domestic product, balance of payments and budget stances for the economies of Ghana [see 10–12], Kenya (see 13–15] and South Africa [see 16–17]. Moreover as stated earlier, the increasing level of fossil fuel consumption raises environmental concerns. This is due to the fact that the combustion of fossil fuel for energy releases greenhouse gases (GHG) that contribute to global warming and climate change whose effects Sub-Saharan African countries are vulnerable to [8;18–19]. This development has led many organizations, environmentalists and policy makers to campaign aggressively for countries to reduce the pollution effects of fossil fuel production and consumption. According to the World Development Indicators (WDI) [20], solid fossil fuel consumption has accounted for about 79%–91% of carbon dioxide emission in South Africa while liquid fossil fuel constitutes between 70%–90% and 77%–91% of carbon dioxide emission in Ghana and Kenya respectively. Figures 1, 2 and 3 show the trends of fossil fuel consumption and the share of $CO_2$ emission attributed to fossil fuels in Ghana, South and Kenya respectively as sourced from the WDI (20).

It is seen from Figure 1 that the share of fossil fuel consumption in Ghana's total energy consumption increased from a little above 20% in 1971 to above 50% in 2013. Compared with the emission of $CO_2$ from liquid fuel, its share in Ghana's total $CO_2$ has remained above 80% over the years except 2013 where the figure dropped to 69.4%. From Figure 2 it is seen that although the share of fossil fuel consumption reduced between 1984 and 2001 after which it began to rise again, it has been dominantly above 85% over the years. Regarding the emission of $CO_2$ from solid fuels, the share has been fluctuating largely between 80% and 90% over the same period. The Kenyan experience as shown in Figure 3 is that $CO_2$ emission from liquid fuel has taken about 71%–90% of the total $CO_2$ emission while fossil fuel consumption increased its share of the total energy consumption from about 17% in 1991 to close to 20% in 2013.

Because the solution to the problem of GHG requires concerted efforts from all countries, Ghana, Kenya and South Africa equally have a role to play (at least by reducing their fossil energy consumption). To this end, knowledge of the determinants of fossil energy consumption is crucial for Ghana, Kenya and South Africa.

Although some studies exist on the consumption of (the various forms of)fossil fuel for the countries under study, [for example 18, 21–22] there is still room for further investigations since these previous studies have relied on cross sectional or short span time series data. Such studies only offer estimates for the short-run which renders policy consequences inappropriate for long-term measures. Cross sectional studies again are susceptible to subject bias, observer error, observer bias, low response and inability to measure long term change and development [24]. The study addresses these weaknesses associated with previous studies by using a relatively

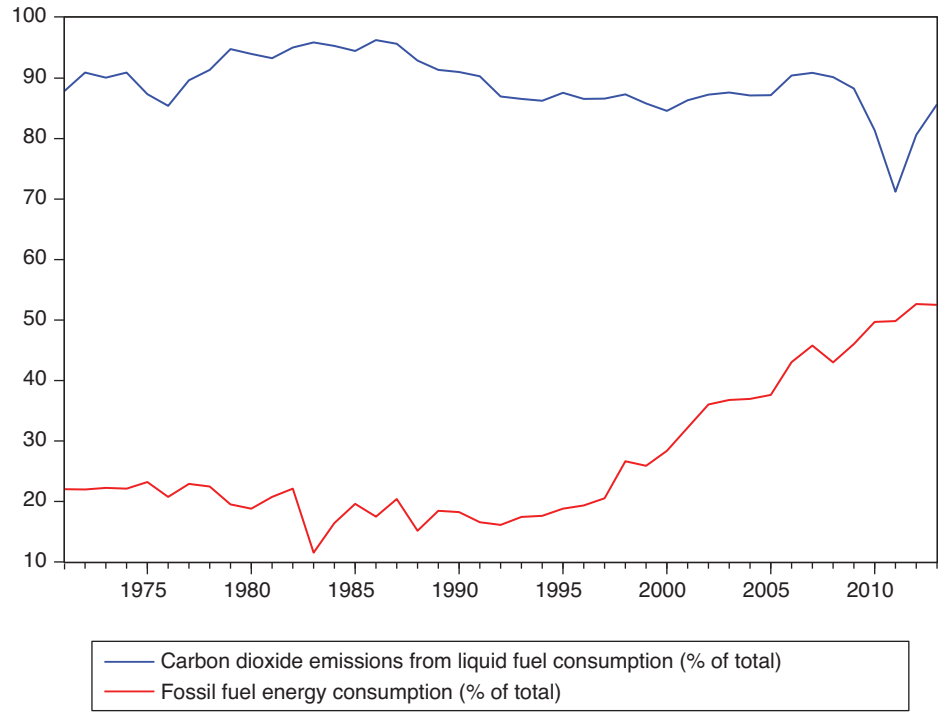


Figure 1: Trends of fossil fuel consumption and $CO_2$ emission from liquid fuel consumption in Ghana. Data source: WDI [20]

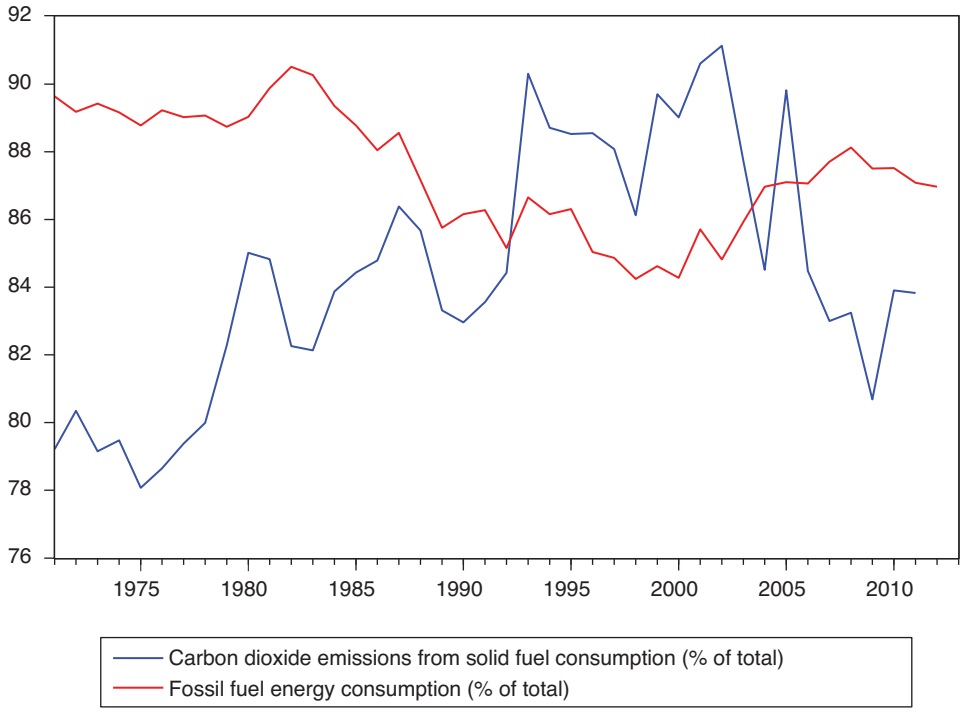


Figure 2: Trends of fossil fuel consumption and $CO_2$ emission from Solid fuel consumption in South Africa. Data source: WDI [20]

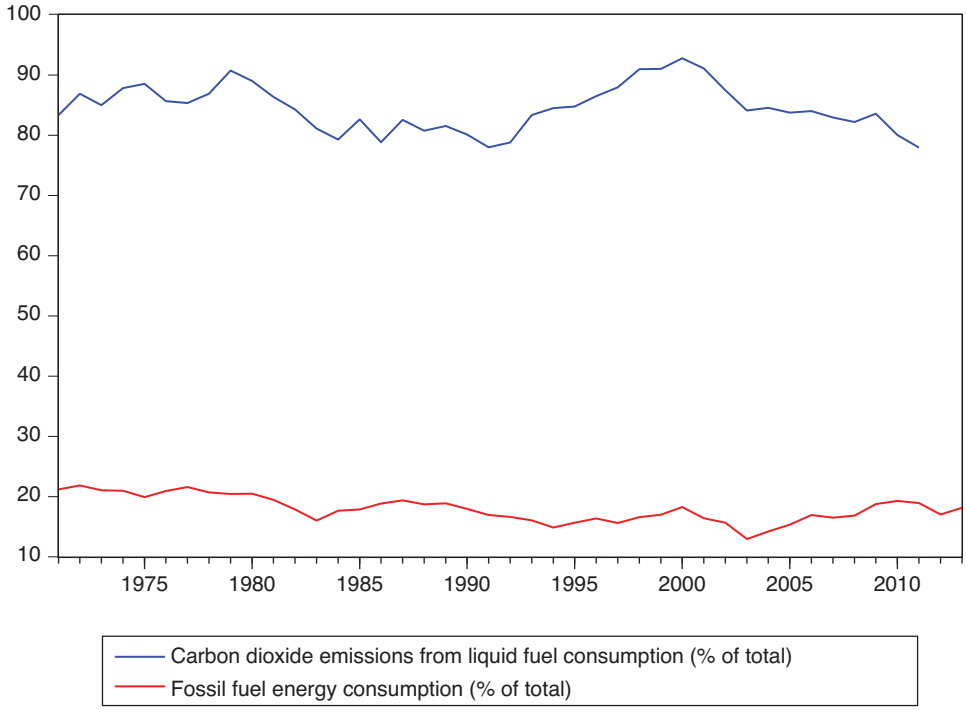


Figure 3: Trends of fossil fuel consumption and $CO_2$ emission from liquid fuel consumption in Kenya. Data source: WDI [20]

longer annual time series data spanning from 1975–2013 which is free from the biases associated with cross sectional data and also has the capacity to offer estimates that have long-term implications. We employ long-run cointegrating estimation techniques – the Fully Modified Ordinary Least Square (FMOLS) by Phillips and Hansen [25] and Canonical cointegration regression (CCR) by Park [26] – to estimate the determinants of fossil energy consumption for each of the three countries.

This current study also differs from other studies that have examined the long-run determinants of fossil energy consumption [27–34] in one unique way. This stems from the fact that such studies have focused on mainly the price and income effects on fossil fuel consumption. However, since energy is consumed by both residential and non residential sectors of the economy, it is important to consider other variables in addition to price and income when it comes to identifying the determinants of fossil fuel consumption. Accordingly, the present study examines the effects of price, income, trade, urbanization, industrial efficiency and efficiency of the service sector on fossil fuel consumption for Ghana, Kenya and South Africa. The inclusion of the service sector to the explanatory variables contributes to the energy consumption literature, since to the best of the authors' knowledge previous studies on the drivers of energy have ignored the potential role of the service sector to energy consumption.

The rest of the paper is organized as follows. Section 2 deals with the empirical strategy, data type and source, and the method employed in the analysis. Section 3 discusses the empirical results and Section 5 concludes the paper with summary and policy recommendations.

## 2. Empirical strategy and data

This section deals with the methodological issues of the study under sub sections of Theoretical and empirical specification, Estimation Strategy, and Data source and description.

### 2.1. Theoretical and empirical specification

Demand for fossil fuel at the national level has been modeled as a function of price and income in the literature (see 31–32]. For convenience, we assumed that the demand function takes the following multplicative form:

$$F_{it} = AP_{it}^{\beta_1} Y_{it}^{\beta_2} e_{it}^{\varepsilon_{it}} \quad (1)$$

Where $F$ is fossil fuel consumption, $A$ is constant term, $P$ is price of fossil energy and $Y$ stands income.

The $\beta s$ are the parameters to be estimated, $e$ raised to epsilon is the stochastic term, $t$ is the time period and $i$ stands for the individual countries.

However, because both residential and non-residential sectors use energy, it is important to take into consideration other variables in addition to price and income that may have influence on fossil fuel consumption at the national level. One of such variables is trade openness. The effect of trade on fossil fuel consumption can be positive or negative. Trade openness can increase fuel consumption in three main ways as argued by Sardosky [35]. First, energy including fossil fuel is involved in the production of manufactured export goods and the transportation of both manufactured goods and raw materials for export. Second, after imported goods have arrived at the port, the transport system which relies on (fossil) energy would have to distribute the goods to the various parts of the country, and thirdly importation brings into the country goods such as automobiles and other manufacturing machines that use fossil fuel. However, trade openness can reduce (fossil) fuel consumption when high efficient equipments that consume less energy are made available to individuals and firms.

Another variable worth considering is urbanization. Urbanization is argued to increase energy consumption in diverse ways. For instance, urban centres are associated with the concentration of manufacturing firms that depend on energy especially fossil fuel. Such centres also experience heavy vehicular traffic and vehicular movements in and out of the centres which increase fuel consumption. Again, urbanization increases the demand for infrastructure which relies on energy for construction; and lastly, urbanization does impact energy demand through private consumption patterns since individuals become wealthier in such centres and do acquire energy intensive machines [36–40].

We also include industrial efficiency to our explanatory variables. Because the level of industrialization thrives on energy, it is argued to positively affect fossil energy consumption. This is because, a key feature of industrialization is the use of machines that rely on fossil fuel to operate. Consequently, as industries expand in their production activities more fuel would be needed to power these machines [41] than does traditional agriculture or basic manufacturing [42]. However, since firms do change their technological characteristics in the long-run to become efficient with their energy consumption [43] industrial efficiency does reduce fossil fuel consumption.

The economies of Ghana, Kenya and South Africa have seen an expansion in the service sectors contributing greatly to their respective economic growth. This sector also relies on fossil fuel for operation and an expansion in its size suggests more fossil fuel would be consumed. Like the industrial sector, firms in the service sector are expected to change their technological characteristics in the long-run to become efficient with their energy consumption thereby reducing energy consumption.

Consequently, we model demand for fossil fuel consumption for each of the three countries as a function of price of fossil energy, income, trade, urbanization, industrial energy efficiency and efficiency of the service sector. Equation (1) is thus modified to take into account the several other factors described earlier and it is expressed in Equation 2:

$$F_{it} = AP_{it}^{\beta_1} Y_{it}^{\beta_2} U_{it}^{\beta_3} T_{it}^{\beta_4} N_{it}^{\beta_5} S_{it}^{\beta_6} e_{it}^{\varepsilon_{it}} \tag{2}$$

Where $T$ represents trade; $U$ represent urbanization; $N$ stands for industrial energy efficiency; and $S$ represents energy efficiency of the service sector.

Taking the natural log of each variable in Equation (2) gives:

$$\begin{aligned} \ln F_{it} = {} & \alpha + \beta_1 \ln P_{it} + \beta_2 \ln Y_{it} + \beta_5 \ln U_{it} \\ & + \beta_4 \ln T_{it} + \beta_5 \ln N_{it} + \beta_6 \ln S_{it} + \varepsilon_{it} \end{aligned} \tag{3}$$

Where ln is natural logarithm operator, $\alpha = \ln A$.

### 2.2. Estimation strategy

We begin our investigation into the determinants of fossil energy consumption for Ghana, Kenya and South Africa by testing for the unit root of the series. We used the Augmented Dickey-Fuller (ADF) and the Phillips-Perron tests respectively developed by Dickey and Fuller [44] and Phillips and Perron [45] for the stationarity test.

Next, is to examine the long-run relationship among the variables for each country. To do so, the cointegrating estimators namely, the Phillips and Hansen [25] Fully Modified OLS (FMOLS) and Park [26] Canonical Cointegrating Regression (CCR) models are employed. These models are chosen over others like the more commonly used ARDL cointegration technique and the maximum likelihood based approach because they are more robust to the problems of serial

correlation and endogeneity. Also these models are robust to both non-stationarity and endogenous regressors. Following Adom and Kwakwa [52], the Fully Modified OLS estimator is given as in the equation below:

$$\phi_{FME} = \left( \sum_{t=1}^{T} Z_t Z_t^{'} \right)^{-1} \left( \sum_{t=1}^{T} Z_t Y_t^{+} - T\hat{J}^{+} \right) \quad (4)$$

where $y_t^{+} = y_t - \hat{\lambda}_{ox}\,\hat{\lambda}_{xx}^{-1}\Delta x_t$ is the correction term for endogeneity, and $\hat{\lambda}_{ox}$ and $\hat{\lambda}_{xx}$ are the kernel estimates of the long-run covariances, $\hat{j} = \hat{\Delta}_{ox} - \ddot{\lambda}_{ox}\hat{\lambda}^{-1}{}_{xx}\hat{\Delta}_{xx}$ 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.

The approach by Park [26], that is the canonical cointegration regression, is similar to the FMOLS. The CCR estimator is shown below:

$$\hat{\phi}_{CCR} = \left( \sum_{t=1}^{T} Z_t^{*} Z_t^{*1} \right)^{-1} \sum_{t=1}^{T} Z_t^{*} Y_t^{*} \quad (5)$$

where $Y_t^{*} = (X_t^{*1}, D_t^{'}),\ X_t^{*} = X_t - (\hat{\sum}^{-1}\hat{\Lambda}_2)\,\hat{v}_t$ and $Y_t^{*} - \hat{\sum}^{-1}\hat{\Lambda}_2\,\hat{\beta} + [\hat{\eta}_{22}^{-1}\hat{\omega}_{21}]'\,\hat{v}_t$ denotes the transformed data, $\hat{\beta}$ is an estimate of the cointegrating equation coefficients, $\hat{\Lambda}_2$ is the second column of $\hat{\Lambda}$ and $\hat{\sum}$ denotes estimated contemporaneous covariance matrix of the residual.

Stock and Watson [46] DOLS is also estimated to check for robustness of the results.

### 2.3. Data source and description

The study used annual times series data for all the variables namely, fossil fuel consumption, income, price, efficiency of the industrial sector, urbanization, trade openness and efficiency of the service sector for each of the three countries. The period of study span from 1975–2013 and it is because of availability of data for the countries under consideration. All the data were sourced from the World Development Indicators [20] of the World Bank except price which was from Energy Information Administration. The dependent variable, fossil fuel consumption is measured as the fossil energy consumption as percentage of total energy consumption. The study uses price of crude oil as a proxy for the price of fossil fuel. From the literature, price is expected to negatively affect fossil fuel consumption. The income variable is measured by real annual per capita income. Income is expected to have a positive effect on consumption of the fossil fuel. Trade is measured as the sum of import and export as share of GDP and its effect is uncertain based on the literature. Urbanization is expected to increase fossil fuel consumption and in this study it is measured as the annual population in the largest city. Both efficiencies of the industrial and service sectors are expected to reduce fossil energy consumption. Industrial efficiency is measured as the ratio of the valued added to GDP by the industrial sector to fossil fuel consumption. Similarly, the efficiency of the service sector is measured as the ratio of the value added to GDP by the service sector to fossil fuel consumption.

## 3. Empirical results and discussion

This section discusses the results of the study under sub sections of unit root test of series, cointegration test and long-run determinants of demand for fossil fuel.

### 3.1. Unit root and cointegration tests

The study employed the Phillip-Perron (PP) and Augmented Dickey-Fuller (ADF) tests to ascertain the stationarity of the variables fossil fuel consumption, income, price, urbanization, trade openness, industrial efficiency and efficiency of the service sector. The results have been reported in Table 1 below. From the ADF and PP tests results, all variables are non stationary at their levels. However, based on the first difference, all variables become stationary rendering the variables as integrated of the order one or I(1) for each country under study. The unit root test results imply that regression analysis to establish the relationship between the fossil energy consumption and its regressors chosen for this study could be embarked upon without generating any spurious results.

The co-integration test is carried out to determine whether long-term relationships exist among the variables. The study used the Engel-Granger and Phillip-Ouliaris tests which allow a single co-integrating relationship to be estimated. The results of the co-integrating tests for Ghana, Kenya and South Africa reported in Table 2 indicate there is a long-run relationship between the fossil fuel consumption and the explanatory variables for each country. This implies a long-run relationship exists among the variables and thus offers evidence that price, income, efficiency of

**Table 1: ADF and PP Unit root test of variables for Ghana, Kenya and South Africa**

| | Ghana | | Kenya | | South Africa | |
|---|---|---|---|---|---|---|
| **Variable** | **PP-test** | **ADF-test** | **PP-test** | **ADF-test** | **PP-test** | **ADF-test** |
| | | | **Variables in levels** | | | |
| *lnF* | –0.9582 | 0.1897 | –2.1366 | –2.0495 | –1.4712 | –1.4781 |
| *lnP* | –1.2739 | –1.1550 | –1.2739 | –1.1550 | –1.2739 | –1.1550 |
| *lnY* | –0.9568 | –1.3469 | 0.2884 | 0.2878 | –1.7679 | –1.7929 |
| *lnT* | –1.0514 | –1.2924 | –2.3810 | –2.2345 | –2.3486 | –1.7928 |
| *lnU* | –1.3371 | –1.0398 | 0.0476 | 0.0179 | –1.7985 | –1.7970 |
| *lnN* | 0.9801 | 14.6951 | 1.4363 | –1.8177 | –1.3768 | –2.0975 |
| *lnS* | 0.67995 | 0.5034 | –0.9782 | –1.4895 | –0.5824 | –1.7712 |
| | | | **Variables at first differences** | | | |
| *DlnF* | –9.7586*** | –7.2557*** | –5.4686*** | –5.4429*** | –6.7816*** | –6.8096*** |
| *DlnP* | –6.0697*** | –6.0645*** | –6.0697*** | –6.0645*** | –6.0697*** | –6.0645*** |
| *DlnY* | –4.2812** | –4.8110*** | –8.1775*** | –7.9888*** | –6.3778*** | –6.1204*** |
| *DlnT* | –4.0884*** | –4.1322*** | –5.9587*** | –5.9620*** | –5.2747*** | –5.1715*** |
| *DlnU* | –6.1548*** | –5.6214 | –1.8889 | –4.1894** | –0.9354*** | –1.4298 |
| *DlnN* | –9.4488*** | –9.1160*** | –5.6403*** | –5.6401*** | –9.1333*** | –7.1354*** |
| *DlnS* | –2.0940 | –9.0084*** | –3.8223** | –3.6968*** | –3.8845** | –4.0869** |

***, **, * respectively represents 1%, 5% and 10% level of significance

**Table 2: Co-integration results of series for Ghana, Kenya and South Africa**

| | Ghana | | Kenya | | South Africa | |
|---|---|---|---|---|---|---|
| **Test** | **tau-stat** | **z-stat** | **tau-stat** | **z-stat** | **tau-stat** | **z-stat** |
| Engel-granger | –6.206** | –101.533*** | –4.500** | –65.506*** | –4.635* | –133.48 |
| Phillips-Ouliaris | –5.461** | –26.321 | –6.144** | –29.566 | –5.451 | –59.235 |

Note: ***, **, * respectively represents 1%, 5% and 10% levels of significance

industrial sector, efficiency of service sector, trade and urbanization are the long-run forcing variables explaining fossil energy consumption in Ghana, Kenya and South Africa.

### 3.2. Long-run determinants of fossil energy consumption

The long-run impact of price, income, trade openness, urbanization, industrial efficiency and efficiency of the service sector on fossil fuel demand are analysed for Ghana, South Africa and Kenya using the FMOLS, CCR and DOLS regression methods. The regression results for Ghana, South Africa and Kenya are presented in Table 3, 4 and 5 respectively.

*3.2.1. The effect of price on fossil energy consumption*

Price was expected to significantly have a negative relationship with fossil energy consumption for each country. However, we obtain a negative and significant effect of price on fossil consumption for the Kenyan economy but insignificant effect for Ghana and South Africa. In the case of Kenya, a one percent increase in the price of fossil fuel will reduce fossil fuel consumption by 0.0236–0.0346 percent. This suggests that a higher price displaces consumption, making the rich to invest more in efficient energy appliance and the poor cutting down on their energy use [47] in Kenya. The inelastic price effect we found for Kenya corroborates those established in earlier studies in the literature. For instance, Tsirimokos [32] found a negative and inelastic price effect for ten IEA countries, Altinay [48] also established an inelastic price effect on demand for crude oil in Turkey and Zarimba [31] found similar effect for the South African economy. The outcome that price has not significantly influenced fossil fuel consumption in South Africa over the period of

**Table 3: Long-run estimates for Ghana**

| | FMOLS | | CCR | | DOLS | |
|---|---|---|---|---|---|---|
| **Variable** | **Coefficient** | **Std. Error** | **Coefficient** | **Std. Error** | **Coefficient** | **Std. Error** |
| *ln P* | 0.0253 | (0.0431) | 0.0263 | (0.0454) | –0.0680 | (0.0530) |
| *ln Y* | 0.0921* | (0.0475) | 0.0842* | (0.0449) | 0.1205* | (0.0629) |
| *ln N* | –0.5370*** | (0.0706) | –0.5026*** | (0.0629) | –0.4781*** | (0.1021) |
| *ln S* | –0.2944*** | (0.0863) | –0.3110*** | (0.0753) | –0.1479*** | (0.1365) |
| *ln T* | 0.2318*** | (0.0547) | 0.2079*** | (0.0548) | 0.3041*** | (0.0889) |
| *ln U* | 1.0378** | (6.8453) | 1.0248*** | (0.4719) | –0.3220 | (1.1505) |
| *Constant* | –12.8673* | (6.8453) | –12.5472* | (6.7258) | 4.7313 | (15.9381) |

Note: ***, **, * respectively represents 1%, 5% and 10% levels of significance

**Table 4: Long-run estimates for South Africa**

| | FMOLS | | CCR | | DOLS | |
|---|---|---|---|---|---|---|
| **Variable** | **Coefficient** | **Std. Error** | **Coefficient** | **Std. Error** | **Coefficient** | **Std. Error** |
| *ln P* | 0.0011 | (0.0047) | –0.0025 | (0.0058) | 0.0565 | (0.0106) |
| *ln Y* | 0.0397*** | (0.0070) | 0.0407*** | (0.0093) | 0.0441*** | (0.0071) |
| *ln N* | 0.2945*** | (0.0567) | .3031*** | (0.0605) | 0.1711** | (0.0715) |
| *ln S* | –0.0961* | (0.0471) | –0.1382** | (0.0527) | 0.0057 | (0.0943) |
| *ln T* | –0.0448*** | (0.0146) | –0.0464** | (0.0149) | –0.0474** | (0.0474) |
| *ln U* | 0.0717** | (0.0312) | 0.1071*** | (0.0349) | 0.0523 | (0.0491) |
| *Constant* | –0.6543 | (0.8382) | –0.4724 | (1.2185) | –0.0577 | (0.0349) |

Note: ***, **, * respectively represents 1%, 5% and 10% levels of significance

**Table 5: Long-run estimates for Kenya**

| | FMOLS | | CCR | | DOLS | |
|---|---|---|---|---|---|---|
| **Variable** | **Coefficient** | **Std. Error** | **Coefficient** | **Std. Error** | **Coefficient** | **Std. Error** |
| *ln P* | –0.0236* | (0.0055) | –0.0262*** | (0.0024) | –0.0349* | (0.0169) |
| *ln Y* | 0.1176*** | (0.0056) | 0.1075*** | (0.0053) | 0.2072*** | (0.0376) |
| *ln N* | 0.0152** | (0.0147) | 0.0564*** | (0.0183) | 0.4403** | (0.1737) |
| *ln S* | –0.7907*** | (0.0127) | –0.8072*** | (0.0013) | –1.2502*** | (0.1657) |
| *ln T* | –0.0451*** | (0.0065) | –0.0335*** | (0.0082) | 0.0406 | (0.0537) |
| *ln U* | 0.3443*** | (0.0140) | 0.3206*** | (0.0128) | 2.5920*** | (0.6853) |
| *Constant* | –1.3471*** | (0.2193) | –1.0101*** | (0.2116) | –31.399*** | (9.1690) |

Note: ***, **, * respectively represents 1%, 5% and 10% levels of significance

study contradicts earlier paper on fossil energy consumption in South Africa by Ziramba [31] which recorded a significant negative effect. The current result may differ from Ziramba [31] due to the differences in the time span and the different estimation techniques of the two studies. Ziramba [31] employed the Johansen Cointegration approach for data that covered 1980–2006 period which is quite shorter than the period this study employs. The additional explanatory variables added to price and income in this study could also be a contributory factor to the differences in the price effects for the South African economy. The insignificant effect we obtain for Ghana is in line with observation in that it appears demand for energy no more depends on price because energy is also becoming a necessity in the country and irrespective of the level of the price, households and industries still demand energy, although amidst complaints.

*3.2.2. The effect of income on fossil energy consumption*

Real per capita income is found to be positive and statistically significant for all the three countries

consistent with a priori expectations. We record that for the Ghanaian economy there will be about 0.0842–0.1205% increment in the consumption level of fossil fuel following a 1% increment in the income level. For the economy of South Africa, a 1% increase in income level will cause fossil fuel consumption to also increase by about 0.0397–0.0441% while a 1% increase in income level will cause fossil fuel consumption to also increase by about 0.1075–0.2072% in Kenya. From these estimations, fossil fuel can be classified as a normal good in Ghana, Kenya and South Africa. In other words, an increase in the level of income results in a corresponding increase in fossil energy consumption although by lesser magnitude than the increase in income. The positive effect of income on fossil fuel consumption suggests that as per capita income increases in these countries, citizens and firms are able to afford appliances that rely on fossil fuel to operate thereby increasing the consumption of fossil energy. For instance, from the abysmal performance in the late 1970s and early 1980s Ghana's economy grew from a rate of 4.8% (in 1987) to 15% (in 2011) suggesting an increase in the overall wellbeing of citizens over the last three decades. This in a way has contributed to the country's ability to reduce by half the people living in poverty. With such increase in income and reduction of poverty, individuals demand for items that thrives on energy has also increased contributing to the rising level of fossil fuel consumption.

According to the Driver and Vehicle Licensing Authority (DVLA) of Ghana, there was about 50% increment in the number of registered vehicles between 2000 and 2010 alone. The effect of such development is the rising trend of fossil fuel consumption. Kenya has also recorded important strides in its economic growth. From a negative 2.01% rate of per capita income in 1984, the country registered a 5.7% growth in per capita income for year 2013. Such development has increased the demand for fossil fuel in the country. Similarly, the South African economy has performed impressively well in the sub region over the years and has thus received the reputation for being among the richest economies in Africa. The economic performance in terms of growth in per capita income has increased from US$ 5053.1 in 1972 to US$ 6090.4 in 2013 on the back of a thriving mining sector hence an increase in the demand for fossil fuel consumption over the period. Studies abound on the income elasticity effect on fossil fuel (coal, gasoline and natural gas) consumption. A review of such studies indicates that generally, income has a long-run inelastic effect on fossil consumption. The current study then lends support to the inelastic effect of income of fossil fuel consumption that the literature suggests. The results of Altinay [48] estimation of elasticities of demand for crude oil in Turkey show a positive and an inelastic long-run income effect. Also, Ackah and Adu [18] established an inelastic income effect of gasoline demand in Ghana. Ziramba [31] also found the long-run effect of income on crude oil to be inelastic and positive for the South African economy. Hughes et al., [49] had positive inelastic income effect for coal demand in the US. Lim et al. [28] had positive and inelastic demand for diesel in Korea and Sultan [33] study on demand for gasoline in Mauritius found inelastic and positive effect of income. The few studies that had elastic income effect include Tsirimokos [32] research on demand for crude oil for ten IEA countries and Ramanathan [27] paper on demand for gasoline in India.

#### *3.2.3. The effect of efficiency of industrial and service sectors on fossil energy consumption*

The technological characteristic of the industrial sector (industrial efficiency) is found to have a negative effect on fossil fuel consumption in Ghana but the opposite rather holds for South Africa and Kenya. This variable happens to be the one with the greatest impact on the consumption of fossil energy in South Africa but the second most significant variable in Ghana and Kenya. For the Ghanaian economy, a one percent increase in the efficiency of the industrial sector will reduce fossil fuel consumption by 0.4781–0.5370 percent. However, a one percent increase in the efficiency level of the industrial sector will increase fossil fuel consumption by 0.1711–0.3031 percent and 0.0152 and 0.0564 percent respectively for the South African and Kenyan economies. This means that industrial efficiency has an inelastic effect on fossil fuel consumption in all the three countries. The results suggest that over the period of study, Ghana's industrial sector has invested in efficient technologies for their operations which have reduced the amount of fossil energy consume to produce an output. The positive effect of the industrial efficiency on fossil in South Africa and Kenya implies that as industrial firms become more efficient in their operations, they tend to use more energy than before. Such a situation in the literature is known as the backfire rebound effect,

commonly known as the Jevons paradox. A review of the literature on the industrial efficiency elasticity revealed that the focus of such studies has been on electricity consumption. Authors like Lin [50] found a significant and negative inelastic effect of industrial efficiency for Chinese electricity consumption. Zuresh and Peter [51] also had similar results for electricity consumption in Kazakhstan. Findings by Adom and Bekoe [43; 53] on electricity consumption in Ghana were also negative and inelastic. However, Keho [54] recorded a positive impact of the industrial sector on energy consumption in South Africa.

A significant negative relationship is established between the technical characteristics of the service sector and consumption of fossil fuel for Ghana, South Africa and Kenya. From the results, a one percent increase in the efficiency of the service sector will decrease fossil fuel consumption by 0.1479–0.3110% in the Ghanaian economy; 0.0961–0.1382% in the economy of South Africa and 0.7907–1.2502% in the Kenyan economy. The service sector for many decades has particularly been the backbone of the Kenyan and South African economies offering the greatest contribution to the GDP of the two countries [20]. In the case of Ghana, the sector became prominent following the commercial production of oil in 2011. It is now the second largest contributor to the country's GDP next to the industrial sector. The negative effect of the service sector efficiency recorded for the three countries suggests that as the sector invests in efficient technology for production, their usage of fossil fuel decreases than before. It also implies that the negative effect the financial sub sector has on the consumption of fossil energy [55–58] outweighs the potential positive effects from the other components of the sub sector. This argument is premised on the fact that the service sector in Ghana, Kenya and South Africa consisting of sub sectors such as hotels and restaurants, transport and storage, financial and insurance activities, education and health has the financial services as the leading sub sector for Kenya and South Africa while it occupies the third position in Ghana's service sector. The relative dominance of the financial activities affords firms and individuals the opportunity to access credit to acquire more energy efficient equipments reducing the use of energy per output of service produced. This therefore reinforces the idea that the technological feature of the service sector plays a major role in managing the rising level of fossil fuel consumption.

#### *3.2.4. The effect of urbanization and trade on fossil energy consumption*

The level of urbanization is shown to have an elastic and positive effect on fossil fuel consumption for the countries under study. A 1% increase in the rate of urban population will increase consumption of fossil energy by about 1.0248–1.0378% in the Ghanaian economy; and 0.3206–2.590% increase for the Kenyan economy and 0.0717–0.1071% in the economy of South Africa. This outcome is not surprising in the sense that over the period under study, urban population for the three countries has increased massively. For instance, figures from WDI [20] show Ghana's urban population has seen a tremendous increase from 2,575,314 in 1971 to 13,660,790 people in 2013. This thus has partly accounted for the positive effect on the consumption of fossil fuel. The reason is urban towns in Ghana are characterized by heavy vehicular traffic and movement of vehicles that rely on fossil energy. Ghana's urban centres have also witnessed rapid infrastructural development made possible by using fossil fuel in the process of construction and other activities. These have contributed to the positive effect urbanization has on the consumption of fossil energy in the country. Like Ghana's experience, urban population in Kenya increased from 1,256,443 people in 1971 to 3,926,810 people in 1990 and then to 10,990,845 people in 2013. Urban centres in the country have also been associated with vehicular traffic and rapid infrastructural development there by contributing to energy consumption. The urban population for the South African economy grew from 10,819,530 people in 1971 to 33,908,100 people in 2013.

In addition, records indicate that over 80% of South Africa's GDP come from the cities and large towns. Again, it is reported that 75% of all net jobs created in South Africa between 1996 and 2012 were from the urban centres. Thus, the urban centres in South Africa have become the hub of industries that rely on fossil fuel and also the destination of many people in search of jobs [59]. The positive effect of urbanization on fossil fuel consumption obtained in this study gives support to earlier arguments by [36–40]. Other studies on the demand for electricity by Adom et al. [60] had similar positive results for the urbanization. Also Kwakwa and Aboagye [61] had similar results for aggregate energy consumption; while Adom and Kwakwa [52] had a similar effect on energy intensity for Ghana. Also, Holtedahl and Joutz [62] found the effect of

urbanization to be elastic for electricity consumption in Taiwan and for the Chinese economy.

The effect of trade is found to be positive for Ghana but negative for Kenya and South Africa. The negative effect of trade openness recorded for South Africa and Kenya suggests that opening up to trade has led to the promotion of efficiency in the usage of fossil fuel in the two countries. High energy efficient equipments that consume less energy have been made available to the South African and Kenyan households and firms through trade. On the other hand, the positive effect of trade openness on fossil fuel consumption for Ghana indicates opening up to trade has increased the consumption of fossil fuel for the country. Previous studies including Kwakwa [23], Sadorsky [35] and Cole [63] reported positive effect of trade on energy consumption.

## 4. Conclusion and policy implications

Concerned about the high emission of carbon from fossil fuel consumption that contribute to climate change and global warming, as well as the rising levels in the consumption of fossil fuel but inadequate supply and future energy security, the study investigated the determinants of fossil fuel consumption for three Sub-Saharan African countries namely Ghana, Kenya and South Africa using annual time series data over the period of 1975–2013. The demand for fossil consumption for each of the countries was modelled as a function of price, income, trade, urbanization and the technical characteristics of the industrial and service sectors. Results from the FMOLS, CCR and DOLS estimators revealed income, urbanization, trade, efficiency of the service and industrial sectors are the long-run drivers of fossil fuel consumption for Ghana and South Africa. In the case of the Kenyan economy, price in addition to the variables mentioned earlier for Ghana and South Africa were found to influence fossil fuel consumption. On the direction of impact, Ghana's fossil fuel consumption was determined positively by income, trade and urbanization; and negatively by industrial efficiency and efficiency of the service sector. For Kenya, fossil fuel consumption was positively affected by income, industrial efficiency and urbanization; but negatively affected by trade, price and efficiency of the service sector. Lastly, for the South African economy, our results showed urbanization, industrial efficiency and income increase fuel consumption while price and trade reduce fossil fuel consumption.

The findings above suggest efforts should be geared towards strengthening the energy efficiency system in each of these countries as income has significant effect on fossil consumption. Achieving higher economic growth and development in the years ahead has been the concern for many countries including Ghana, Kenya and South Africa. For instance, Kenya plans to achieve 10% annual economic growth in order to eliminate absolute poverty by 2030. Ghana has also set for herself 40 year development plan and South Africa has the vision 2030. The goal of such growth and development agenda among other things is to reduce poverty of the citizens. Since higher economic growth and development translate into higher income, it is important for policy makers and governments to factor the fossil fuel consumption effect into such (growth and development) agenda and design appropriate policies to both meet fossil fuel demand or/and reduce fossil fuel demand.

Also, the negative effect of price suggests Kenya may be vulnerable to price shocks. Thus, appropriate measures should be put in place to handle any future shock. Again, because the effect of price changes on fossil fuel consumption is inelastic it is possible for authorities in the economy to reduce the subsidies on fossil energy. Since it has the least effect for the Kenyan economy it is essential that other policies apart from price related policies are given attention. At the industrial level, energy efficiency needs to be promoted in Ghana to help reduce the amount of fossil fuel consumed for their activities. This is because even though industries rely on energy for their operation, there is also the need to promote efficiency to ensure that the industrial sector is efficient in its fossil energy usage. In this regard, it is important for the government of Ghana to help reduce the obstacles or impediments that hamper industrial firms' ability to adopt energy efficient technologies in their operation. This would require the government follows national policy frameworks geared towards equipping industries to be energy efficient. Regarding the South African and Kenyan economies, more efforts are needed in order to make the industrial sector reduce consumption of fossil fuel. Intensive education on energy savings may come at handy for the economies in this regard.

Also adequate measures should be put in place to decentralize growth and other lucrative activities in Ghana, South Africa and Kenya to reduce the population pressure in the urban centres so as to manage the high level of fossil fuel consumption in such urbanized areas.

As it stands now the urban centres in Ghana, South Africa and Kenya have received the attention of governments and corporate bodies when it comes to developmental issues more than rural areas. Other non urban towns should get similar attention. In addition to the above point, attention needs to be given to educating the urban dwellers on efficient energy consumption to reduce the demand. This is because, urbanization, whether good or bad, has come to stay. We may not be able to prevent its growth but we can find a way to live with it.

On trade, the South African and Kenyan economies need to promote and strengthen existing measures which have led to efficiency in the usage of energy through trade. Furthermore, the results for trade imply it is needful for each country to factor the effect trade openness has on fossil fuel consumption in their trade liberalization discussions. Specifically, it is essential that tariff and non-tariff barriers on products that do not promote energy efficiency is raised and vice versa.

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