Ghanaian Journal of Economics, Vol. 4, December 2016

Energy consumption efficiency in Sub- Saharan Africa: evidence and policies

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Abstract

Energy-based inputs continue to feature prominently in all economic activities and the linkages between energy inputs and economic expansion has received considerable attention in the literature. The aftermath of the oil price shocks in the 1970s coupled with the unreliable and insufficient supply of energy resources has spurred a great shift of emphasis from mere energy consumption to a thorough investigation into efficient consumption or utilization of energy-based resources and the factors underlying the behaviour of energy intensity. This quest is particularly important against the evidence that in many Sub Saharan African (SSA) countries, energy supply has not only been very insufficient to meet the every growing demand but has also been uncertain and unreliable. In addition, since every growth process requires some energy consumption, it is vital that energy resources are consumed in more efficient manner given that shortages could threaten the sustainable development of an economy. Using the system Generalized Method of Moments analysis on a panel dataset for 36 SSA countries over the period 1980-2015, this study examines how some key macroeconomic parameters explain the observed rising trend in energy intensity in SSA. It is established among others that, energy consumption efficiency is a function of the extent of openness of an economy to external commerce and domestic price developments. In particular, greater openness to trade and higher domestic prices tend to reduce energy intensity. Further, the results show that while the industrial and services sectors have adverse effect on energy consumption efficiency, the reverse is true for the agricultural sector. We discuss some policy options.

Key words: *Energy consumption efficiency, macroeconomy, foreign direct investment, trade openness, disaggregated growth, income*

1. Introduction

Energy-based inputs continue to feature prominently in all economic activities and the linkages between energy inputs and economic expansion has received considerable attention in the literature. Kwakwa and Aboagye (2014) revealed that energy resources are increasingly becoming the most important and indispensable input for both production and consumption. Researchers generally assert that though the direct link between energy and development might have not been very pronounced in the literature because growth only translates to development if properly channeled, the relevance of energy to economic growth cannot be overemphasized. In fact, households need energy resources for lighting, cooking and entertainment. Energy has also been recognized as a key input in achieving the Millennium Development Goals (see Garg and Halsnaes, 2008; Mensah and Adu, 2013). Sahu and Narayanan (2011) has further argued that energy-based resources are now recognized as part of the most essential and indispensable inputs necessary for sustainable development.

The aftermath of the oil price shocks in the 1970s spurred a great shift of emphasis from mere energy consumption to a thorough investigation on efficient consumption/utilization of energy-based resources and to ascertain the factors underlie the behaviour of energy intensity (see Blanchard and Gali, 2010). This quest is particularly important against the evidence that in many developing countries such as those in SSA; energy supply has not only been very insufficient to meet the every growing demand (Kwakwa and Aboagye, 2014) but also has been uncertain and unreliable. To the extent that the growth process requires some energy consumption, it is vital that energy resources are consumed in more efficient manner since shortages could threaten the sustainable development of an economy. Further, against a milieu of concerns about climate change, peak oil, and energy security issues, reducing energy intensity has gained much popularity in contemporary growth agenda as it is often advocated as a way to at least partially mitigate these impacts (Sadorsky, 2013).

However, recent data (International Energy Agency, 2015) reveal that while countries in the developed world are seeking for moves towards decline in energy intensity, in many developing regions world the contrary is observed (see also International Energy Agency, 2007, and Worrell, 2011). This empirical analysis is crucially relevant to examine the demand side factors underlying the rising energy intensity observed in developing countries as well as discovering factors which could be usefully harnessed to put downward pressure on energy intensity.[1] The

[1] *In the literature of energy economics, energy intensity is the widely used indicator for energy consumption efficiency and has been extensively used to analyze trends in energy consumption efficiency. Energy intensity simply is the ratio of energy consumption to Gross Domestic Product (GDP). Though in this paper energy intensity is used interchangeably with energy consumption efficiency, a rise in energy intensity implies a fall in energy consumption efficiency and the converse is also true.*

findings of this study could highlight the extent to which the structural and output compositions of countries tend to rely on energy resources and thus influence energy use efficiency (Yang, 2000). It will also help to ascertain the effects that different sectoral growth have on energy consumption efficiency (Lean and Smyth, 2013; Sari *et al*., 2008). Such empirical evidence could potentially shape the formulation and implementation of policies aimed at improving the performance and reliability of the energy sector as well as the tackling the demand side of the sector in ways that would promote sustainable economic growth *inter alia*.

The main findings of this study are as follows: inflation, education and trade openness tend to reduce energy intensity in SSA. The contrary evidence is however established for FDI, urbanization, population growth, income and industrialization (i.e. industrial activities). Additionally, compared to West African countries, at higher levels of economic growth, there is a greater likelihood for energy intensity to decline in countries in Southern African and East African countries. Finally, the industrial and services sectors are found to increase energy intensity in SSA while growth agricultural (sector) activities is found to enhance energy use efficiency (i.e. reduce energy intensity). This implies that SSA industrial and services sectors are energy intensive sectors.

Section 2 reviews the various theoretical and empirical aspects of the link between energy intensity and the macroeconomy. In section 3, an empirical model based on the dematerialization hypothesis and the Environmental Kuznet Curve (EKC) hypothesis is specified for a panel data for 36 SSA. The results and discussion are presented in section 4 while section 5 provides conclusions and highlights some policy implications of the study.

2. Literature Review

2.1 Review of Theoretical literature

The theory of energy consumption efficiency or energy intensity takes its roots from the hypothesis of dematerialization (inspired by the concept of "dematerialization" in Chemistry) according to which there is a reduction in material and energy consumption along the path of economic growth. Recalde and Ramos-Martin (2012) reveal that this hypothesis is argued to support the Environmental Kuznets Curve (EKC), which assumes the existence of an inverted-U shaped relationship between economic growth and environmental degradation. The EKC hypothesis implies that environmental degradation increases with economic activity up to a turning point after which income increases tend to improve environmental quality. To some extent through inference, the EKC hypothesis is based on the concept of intensity of use, which means that the consumption of energy and materials can be mainly explained by income (economic growth). At the theoretical level, the EKC has three main effects: **scale** effects, **composition** effects and **technology** effects and since the EKC hypothesis is assumed to reflect the concept of intensity of use, energy use intensity could also be explained by these same three effects.

The scale effect represents an increase in energy consumption (and environmental degradation) as a result of more economic activity while the composition effect denotes structural changes which results in changes in the share of each economic activity out of the total economic activity, from agriculture (with low energy intensity in most developing countries), to industrial activities (higher energy intensity), and finally back to a low energy intensive activity as services (Mielnik and Goldemberg, 1999; Ramos-Martin, 2001). The technology effect refers a fall in energy use per unit of output as a result of higher technology development as income levels of a country grows much higher. A joint result of these three effects implies that energy intensity should be much lower in developed economies while developing economies experience higher energy intensity (Recalde and Ramos-Martin, 2012). This conclusion is consistent with Mielnik and Goldemberg (1999) who reveal that lower energy intensity is attributed mainly to radical shifts from high energy intensity sectors to lower intensity ones. Although this theory forms the basis of most studies on energy intensity, it is not without challenges. However, it has largely guided many empirical studies on energy consumption intensity (see Ramos-Martin, 2001; Recalde and Ramos-Martin, 2012).

2.2 Empirical literature

Many factors have been cited in the literature to influence energy intensity at the country level as well as firm and household levels. These structural composition of output (i.e. agricultural sector, industrial sector and services sector); macroeconomic parameters (i.e. inflation, exchange rate, income level, level of investment); demographic factors (i.e. population growth, level of secondary school enrolment and urbanization); growth policies (i.e. FDI and trade openness). Other equally important determinants of energy intensity are energy prices, climate, technological innovation, energy policies and actions of national, state, and local governments. We discuss some of these in turn.

2.2.1 Energy price levels and/or general price levels

Like any other commodity, energy prices have been a major influence on energy demand, and therefore energy intensity (Fisher-Vanden *et al*., 2004). The price of energy usually differs significantly from country to country. For instance, electricity prices differ considerably due to the energy requirements of fixed capital (e.g., commercial buildings), the types of technologies in use, fuel availability, the ability to move electricity across large areas (prior to recent innovations in electricity markets), and regulatory requirements. Also, the general price levels in a country could explain variations in energy consumption efficiency. For instance, higher general price levels reduce purchasing power and thereby reducing the amount of energy consumption (and many other commodities). Empirically, Fan, Liao, and Wei (2007) examined energy consumption efficiency in China before the 1992 market reforms and afterwards and found that the own-price elasticity for energy was positive prior to 1992 and negative afterwards, providing further support that the 1992 market reforms are providing the necessary incentives for firms to reduce energy use in response to higher energy prices. Also, Fisher-Vanden *et al*. (2004) find that rising energy prices contributed significantly to the decline of firm-level energy intensity, with 54.4% of the decline in aggregate energy-use explained by rising energy costs. This conclusion is in line with that of Hang and Tu (2007), Kleijweg *et al*. (1989), Fan, Liao, and Wei (2007), Hang and Tu (2007) and He and Wang (2007).

2.2.2 Urbanization and Population growth

All things equal, increasing population exerts an upward pressure on energy resources and infrastructure. High urban population require massive energy consumption. However, the increased production may lead to economies of scale and thereby increasing both energy demand and reducing energy intensity. Sadorsky (2013) found that while urbanization was not a significant determinant of energy intensity in the static sense, it had significant dynamic effects (also see Mishra *et al*., 2009; Krey *et al*., 2012; Poumanyvong and Kaneko, 2010; Parikh and Shukla, 1995).

Also, as a population becomes larger, energy use rises substantially as more people now than previously require energy for various economic activities. In this way, citizens could realize the need to consume the available energy efficiently to potential energy shortages and its concomitant adverse effects and thus, energy intensity may rise. Also, the infrastructural needs of a country increases as its population expands. The construction of these additional infrastructure such as construction of, roads, hospital, schools, markets, housing etc and the purchase of new vehicles requires the use of energy-consuming equipments (such as excavators, caterpillars, bulldozers,). The use of computers and many other household energy-driven appliances may also rise as population grows.

2.2.3 Industrialization, Research and development

Industrialization refers to the introduction and application of new, modern and sophisticated equipments and techniques to the production of existing and new goods and services (Sadorsky, 2013). Usually, industrial activities use more energy than does traditional agriculture or manufacturing implying that industrialization has a positive impact on energy intensity. Samouilidis and Mitropoulos (1984) studied the effects of industrialization on energy intensity in Greece and found the long-run elasticities of industrialization of energy intensity in the range of 0.90 to 1.96 while short-run elasticities in the range 0.17 to 0.46. Similarly, Poumanyvong and Kaneko (2010) using panel data techniques on 99 countries covering the period 1975 – 2005, found that the impact of the share of industrial activity in the economy on energy consumption is positive, but statistically significant for only the low- and middle income groups.

Research and development (R&D) activities have also contributed to declines in industrial energy intensity particularly at the firm level. Fisher-Vanden (2009) revealed how the Chinese government has undergone the process of privatizing R&D institutes since the late 1990s. It is expected that this increase in R&D expenditures will lead to more efficient production processes and, therefore, lower energy intensity. Also, Garbaccio, Ho, and Jorgenson (1999) find that technical change rather than structural change explains most of the decline in China's energy intensity from 1987–1992. Using logarithmic mean Divisia index techniques to examine changes in energy use per unit from 1980–2003, Ma and Stern (2008) also find technical change to be the most important factor explaining energy intensity decline.

2.2.4 Economic growth / Income

Damette and Seghir (2013) argued that the energy-income nexus literature was initiated by the seminal work of Kraft and Kraft (1978) who examined the causal link between energy consumption and economic growth for the USA for the period 1947-1974 found a unidirectional causality relation from GNP to energy consumption. Jumbe (2004) revealed that the result of the Kraft and Kraft study carries an implicit notion that the low level of energy dependence enabled the USA to pursue energy conservation policies. Also, Metcalf (2008) studied 46 continental states of the United States of America, excluding North Dakota and Wyoming between 1970 and 2001. Their state level analysis revealed that rising per capita income and higher energy prices have played an important part in lowering energy intensity. He further argued that income predominantly influence energy intensity through changes in energy efficiency rather than through changes in economic activity. Per the findings of his study, Metcalf (2008) concluded that some policy interventions were needed to achieve the Bush Administration goal of an 18 percent reduction in carbon intensity by the end of this decade. Cheng (1999) also examines the relationship between energy consumption, economic growth, capital and labour by way of establishing the cointegration as well as direction of causality using Johansen cointegration and Hsiao's version of causality test. He concludes that the direction of causality runs from economic growth to energy consumption both in short as well as long run but there was no evidence of energy consumption causing economic growth either in the short run or long run. Contrarily, Parikh and Shukla (1995) used a pooled data set on developed and developing countries from 1965–1987 to investigate the impact of economic growth on energy intensity. The study revealed that the income elasticity varies between 0.25 and 0.47 for the total energy intensity models. Galli (1998) using Fixed Effects and Random Effects on 10 Asian economies over the period 1973–1990 found some evidence of a non-linear relationship between energy intensity and income for the Fixed effects specification but no statistically significant evidence of this relationship in the Random effects specification.

2.2.5 Trade openness and Foreign Direct Investment

Trade, which comprises of export and imports of goods and services, potentially leads to productivity gains via stronger competition for domestic firms due to the presence of foreign owned firms and rivalling imports. Such productivity gains are likely to influence energy intensity. Hubler (2009) studied energy intensity effect of trade in China argued that imports directly improve productivity, especially if the imported goods have better characteristics than the domestically produced goods. Imports indirectly create productivity spill-overs via imitation of the imported products and via improved application of methods adopted together with the imported goods. Cole (2006) investigated the relationship between trade energy intensity in a panel of 32 developed countries for the period 1975–1995. The elasticities obtained ranged from −1.1 to −0.1 depending on the specification of the regression model implying that greater openness to trade in these countries had improved energy efficiency/intensity during the period between 1975 and 1995.

Fisher-Vanden *et al*. (2004), in turn, suggested that foreign ownership, which facilitates technological transfer, decrease energy intensity. However, it is also important to know that greater export of energy intensive products and primary products could increase industrial energy intensity. Also, Sahu and Narayanan (2011) studied the determinants of energy intensity of Indian manufacturing for cross sectional data of 2007. Using an econometric approach the study identified FDI to explain significant variation in energy intensity across the firms.

3. Methodology and Data

3.1. Theoretical framework

Empirical analysis into energy consumption efficiency or intensity can be usually traced to concept of material consumption which is captured in the chemistry concept of dematerialization. The seminal work of Grossman and Krueger (1993) which was largely inspired by Simon Kuznets earliest study on economic growth and inequality in 1995 is one of the pioneering works that attempted to apply the dematerialization concept, though in modified form, through the use of the EKC hypothesis. In particular, Grossman and Krueger (1993) examined the linkages between environmental degradation and economic growth in the North American Free Trade Area (NAFTA) within the Environmental Kuznets Curve. Guided by Grossman and Krueger (1993) various empirical studies have examined the economic growth-environment nexus within the Environmental Kuznets Curve framework. It is worth-mentioning that in recent times, empirical studies on the nexus between environmental degradation and economic growth continue to be guided principally by the Environmental Kuznets Curve hypothesis.

Although the study takes some inspiration from the EKC based on Grossman and Krueger (1993), the entirely empirical analysis is principally guided by the dematerialization hypothesis. The dematerialization hypothesis has been put succinctly as follows: At low levels of development, material consumption is very high both in quantity and intensity of environmental degradation is limited to the impacts of subsistence economic activity on the resource base and to limited quantities of biodegradable wastes. However, as economic development accelerates with the intensification of agriculture and other resource extraction and the take-off of industrialization, the rates of material consumption begin to exceed the rates of material/resource regeneration. At higher levels of development, structural changes towards information-intensive industries and services, coupled with increased environmental awareness, enforcement of environmental regulations, better technology and higher environmental expenditures, result in leveling off and gradual decline of material consumption. In this way, the dematerialization hypothesis predicts a positively monotonic curvature for energy intensity if an economy is at its low levels of development (i.e. where material consumption is very high).

Conceptually, since all energy-based resources (such as fossil, electricity, etc.) are typical materials that are consumed in various economic activities and that every economic activity entails the consumption of some energy-based resources, empirical examination into energy consumption efficiency could be principally guided by the dematerialization hypothesis. In this way, the dematerialization hypothesis is said to have applied when at low levels of development, consumption of energy material is very high and increases substantially as economic development accelerates with the intensification of agriculture and other resource extraction and the take-off of industrialization. Then at higher levels of development, structural changes towards information-intensive industries and services, coupled with increased environmental awareness, enforcement of environmental regulations, better technology and higher environmental expenditures, result decline of energy material consumption.

Adopting a suitable model for the empirical analysis of energy intensity or energy consumption efficiency is theoretically comparable to the evaluation of loss functions or cost functions. That is, reducing energy intensity or increasing energy consumption efficiency follows similar procedures for loss and cost minimization. Thus, thus current study, in attempt to establish a conceptual or theoretical framework to guide the empirical estimation of the relevant models, adopts similar theoretical framework researchers have developed to understand cost and loss minimization.

Taking cognizant of the objectives of this paper, the starting point involves the modeling energy intensity from the concept of cost minimization, assuming the following simple Cobb-Douglas cost function:

$$C(P_K,P_L,P_E,P_M)=A^{-1}PK^{\alpha K}PL^{\alpha L}PE^{\alpha E}PM^{\alpha M}Q$$

where C is cost,

Q is the quantity of output,

PK is the price of capital input,

PL is the price of labor input,

PE is the price of energy input,

PM is the price of material input,

αX is the elasticity of input X (X=capital, labor, energy, material),

and $\Sigma\, \alpha X = 1 X = K,L,E,M$.

From Shepherd Lemma condition, the factor demand for an input is equal to the derivative of the cost function with respect to the input price. Hence, deriving the factor demand for energy:

$$E = \frac{\alpha_E A^{-1} P_K^{\alpha_K} P_L^{\alpha_L} P_E^{\alpha_E} P_M^{\alpha_M} Q}{P_E} \qquad \text{(a)}$$

If we assume $P_Q = \dfrac{P_K^{\alpha_K} P_L^{\alpha_L} P_E^{\alpha_E} P_M^{\alpha_M} Q}{P_E}$, then the above formula [i.e. equation (a)] can be rewritten as:

$$\frac{E}{Q} = \frac{\alpha_E A^{-1} P_Q^{P_E}}{P_E}$$

Taking the log of both sides, we obtain the following:

$$\ln\left(\frac{\mathrm{E}}{\mathrm{Q}}\right) = \alpha_1 + \alpha_2 \ln\left(\frac{\mathrm{P_E}}{\mathrm{P_Q}}\right) + \alpha_3 \mathrm{Z_{it}} + \varepsilon$$

where

■/■ is energy intensity, measured as the ratio of energy consumption to Output (GDP)

$\frac{P_E}{P_Q}$

Z captures all other factors determining changes in energy intensity.

In attempting to better understand the variation in energy intensity changes among countries empirically, a considerable number of factors (all captured by 'Z') have been cited in the literature to influence energy intensity at the country level. These factors include but not limited to structural composition of output (i.e. Agricultural sector, Industrial sector and Services sector); macroeconomic parameters (i.e. Inflation, exchange rate, income level, level of investment); demographic factors (i.e. population growth, level of secondary school enrolment and urbanization); growth policies (i.e. FDI and trade openness). Other equally important determinants of energy intensity are energy prices, climate, technological innovation, energy policies and actions of national, state, and local governments.

3.2. Specification of empirical model

The conceptual framework underlying the study has revealed a number of factors that explain energy intensity (also see previous paragraph). Therefore, to examine the macroeconomic determinants of energy intensity in SSA while following the review of both theoretical and empirical aspects of energy intensity and the works of Jones (1991) and Sadorsky (2013), an empirical model is specified as given by equation (1) below.

$$EI_{it} = \beta_1 + \beta_2 URB_{it} + \beta_3 IND_{it} + \beta_4 Y_{it} + \beta_5 TOP_{it} + \beta_6 FDI_{it} + \beta_7 FX_{it} + \beta_8 INF_{it} + \beta_9 SSE_{it} + \beta_{10} PG_{it} + \varepsilon_{it} \quad (1)$$

Equation (1) links energy intensity (EI) to general price levels (INF), exchange rate (FX), urbanization (URB), industrial activities (IND), population growth (PG), secondary school enrolment (SSE), income (Y), Foreign Direct Investment (FDI) and trade openness (TOP).

To understand econometrically how the three broad sectors of the economy (i.e. sectoral components of aggregate growth/income namely agricultural sector, industrial sector and services sector) tend to influence energy intensity in SSA, another empirical model is specified as given by equation (2) below

$$EI_{it} = \beta_1 + \beta_2 URB_{it} + \beta_3 TOP_{it} + \beta_4 FDI_{it} + \beta_5 AGRIC_{it} + \beta_6 IND_{it} + \beta_7 SERV_{it} + \beta_8 FX_{it} + \beta_9 INF_{it} + \beta_{10} SSE_{it} + \beta_{11} PG_{it} + \varepsilon_{it} \quad (2)$$

In equation (2) above, EI is linked to the agriculture sector (AGRIC), industrial sector (IND) and services sector (SERV) alongside with other control and standard variables such as general price levels (INF), exchange rate (FX), urbanization (URB), population growth (PG), secondary school enrolment (SSE), Foreign Direct Investment (FDI) and trade openness (TOP).

A final equation is specified to examine how the state of developments in the four sub-regions of SSA affects the level of energy intensity. This is given by equation (3) below

$$EI_{it} = \beta_1 + \beta_2 URB_{it} + \beta_3 IND_{it} + \beta_4 Y_{it} + \beta_5 TOP_{it} + \beta_6 FDI_{it} + \beta_7 Sdummy * Y_{it} + \beta_8 Edummy * Y_{it} + \beta_9 Cdummy * Y_{it} + \beta_{10} FX_{it} + \beta_{11} INF_{it} + \beta_{12} SSE_{it} + \beta_{13} PG_{it} + \varepsilon_{it} \quad (3)$$

The rationale of model 3 is to explore the performance of energy intensity in the four main sub-regional blocks in SSA so as to better understand the dynamics/behaviour of energy intensity across the sub-regional blocs based on their state of development.

By this the study is able to assess whether the state of development of a particular sub-region in SSA has any systematic influence on how efficient energy resource inputs are consumed. This analysis is motivated by the fact that it is often argued that since the World War II, SSA economies have undergone various reforms which have largely modified their economic structure. For instance, countries in Southern Africa have more formalized labour market, and relatively higher per capita income. Given this, countries in relatively developed sub regions such as those in Southern Africa are more likely to have lower energy intensities than counterpart countries in other sub-regions. To econometrically evaluate whether the state of development of a sub-region influence its energy conservation and consumption efficiency behaviour, the sub regional dummies (i.e. S. dummy for Southern African countries, E. dummy for East African countries and C. dummy for Central African countries) are interacted with income (Y) serving as a proxy for the state of development in a sub-region).

In all the three models, a positive coefficient on a variable means that increases in such a variable worsens energy intensity or worsens energy consumption efficiency while a negative coefficient improves energy intensity. β*'s* are parameters, and it = country i at time, t. Also, natural logs of the variables are taken in order to obtain their elasticity coefficients and also to make the variable less sensitive to outliers.

3.3 Data sources and sample

The study uses unbalanced panel annual dataset from World Bank covering 35 SSA countries[2] from 1980-2015. Data on all variables are obtained from the World Development Indicators (WDI) of the World Bank (see http://data.worldbank.org/data-catalog/world-development-indicators). In the WDI, there hardly exist sufficient data on the relevant variables under study for many of the SSA countries. This is the main reason why the study uses unbalanced panel annual dataset covering 1980-2015 for 35 SSA. Though the panel dataset used is unbalanced it has considerably consistent data for all the 35 countries sampled for the study. In this way, both the sample size and period are dictated by data availability.

Energy intensity is measured as units of energy per unit of GDP (constant 2005 PPP). This indicator was obtained from the Sustainable Energy for all (SE4ALL) database of the World Bank. GDP per capita is used as a proxy of income. The choice and measurement of GDP per capita is justified on the grounds that income levels affect energy demand/consumption and thus can directly influence efficient consumption of energy resources. We also include trade openness (the sum of exports and imports of goods and services measured as a share of GDP); foreign direct investment, inflation, exchange rate, urbanisation and secondary school enrolment as control variables.

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[2] *See Appendix I for the list of the 35 SSA countries sampled for this study. Appendix II also provides exact year range you have used for each country*

4. Data analysis and discussion of results

4.1 Stationarity or unit root test

Prior to the empirical estimation and discussions of results, the stationarity properties of the variables are examined. As a measure of robustness, two tests (i.e. ADF and PP procedures) are employed to examine the stationarity characteristics of the variables. The study first tested for unit root in level variables (log levels) taken cognizance of the trend and intercept characteristics of the each variable. The Akaike Information Criterion -AIC is used to select optimal lag. An optimal lag length of one (1) is selected by the AIC. The results of the ADF and PP unit root tests are presented in Table 1. Both tests reject the null hypothesis that all the panels contain unit roots at 10%. Thus the evidence is that both tests show that all the variables are stationary in level implying the variables are integrated of order zero [i.e. I(0)]. This conclusion that the long run relationships between the energy intensity and the set of explanatory variables could be estimated directly without facing the problem of spurious or unrelated regressions and further implies that testing for potential existence of cointegration may be less useful given that a cointegration test is required when level variables are non-stationary (see Costantini and Martini, 2009; Baltagi and Kao 2000; Pedroni, 1999, Pedroni, 2004).

Table 1: Unit root test

Variables	Fisher ADF (Inverse χ2)		IPS (W-t-bar stat)	
	Statistic	Prob.	Statistic	Prob.
Energy consumption efficiency	65.11	0.007	-4.171	0.000
Income	92.82	0.000	5.374	0.000
Inflation rate (CPI)	78.03	0.000	-3.191	0.003
Exchange rate	38.11	0.099	-2.372	0.034
FDI (% of GDP)	54.44	0.020	-2.445	0.019
Trade (% of GDP)	48.69	0.097	-3.919	0.072
Population growth	58.03	0.081	-4.110	0.002
Secondary school enrolment	18.45	0.097	-4.004	0.003
Agriculture sector, value added (% of GDP)	43.73	0.044	-2.654	0.005
Industry, sector, value added (% of GDP)	52.69	0.070	-2.731	0.001
Services, sector, value added (% of GDP)	87.66	0.000	-3.949	0.070
Urban (% total population)	59.92	0.079	5.193	0.000

H_0: All the panels contain unit roots/non-stationary
H_1: Some panels are stationary/has no unit

4.2 Model estimation and discussion of findings

The underlying empirical model of the study is estimated using the two-step system Generalized Method of Moment (GMM) developed by Arrelano and Bover (1995). The choice of the system GMM is justified on two major grounds. Foremost, the technique is able to overcome endogeneity and collinearity of regresssors which characterize the basic model of this paper. Secondly, the system GMM technique is able to overcome econometric problems such as cross-sectional dependence of countries and multi-correlation which are prevalent in macro panel models (Arrelano and Bover, 1995). Furthermore, aside the I(0) nature of the variables the GMM technique produces efficient parameter estimates than many of the fundamental panel estimators / techniques such as Ordinary Least Squares (OLS), Random Effects (RE) and Fixed Effects (FE) particularly in instances of where the underlying model suffers from endogeneity and multicollinearity.

The major diagnostic tests for system GMM estimation are first and second-order autocorrelation test and a Sargan test statistics of over-identification of instruments employed (Baltagi, 2008; Arrelano and Bover, 1995). The test for contemporaneous correlation or cross-sectional dependence is carried out using the Pasaran Cross sectional Dependence (CD)[3] test, suitable for a panel with the time dimension less than the cross-sectional dimension.

4.2.1 Macroeconomic analysis of energy intensity

In line with our first objective on the macroeconomic analysis of energy intensity, corresponding to equations 1, the results of the system GMM estimations in Table 2. It is evident that inflation, secondary school enrolment (serving as a proxy for education or human capital) and trade openness have a reducing effect on energy intensity. The contrary evidence is established for FDI, urbanization, population growth, income and industrial activities. Exchange rate though has a negative effect on energy intensity, albeit its coefficient is not statistically significant.

In particular, the positive elasticity coefficients on urbanization and population imply that urbanization and population have increasing (i.e. unfavourable or adverse) effect on energy intensity in SSA. A 1% proportionate increase in urban population worsens energy intensity by about 0.018% while a 1% rise in overall population growth also results in about 0.09% proportionate rise in energy intensity and the converse is also true. This finding is intuitively justified on the grounds that, it is often argued that rapid urbanization and rising population growth are associated with such

[3] *A CD probability value greater than 10% shows that there is not enough evidence for cross-sectional dependence among the cross-sectional units in the model. Moreover, the absolute value of the off-diagonal elements suggests a weak correlation between the error terms. The GMM can then be used in the regression analysis. Otherwise, it would have given inconsistent results if cross-sectional dependence was detected (Sarafidis and Robertson, 2006).*

consequences such as increased pressure on existing urban facilities, infrastructure, and a rapid rise in the demand for goods and services. To produce enough goods and service and provide adequate infrastructure to meet the rising demands of the additional population in urban centres there is the need to expand existing and/or create new facilities. This situation coupled with an increase in the production of goods and service in response to the demand of the rising population results in massive energy consumption with attendant consequences for energy intensity. In many SSA countries, there is some evidence of rapid urbanization and high population growth and thus it is not surprising at all to find both urbanization and population growth to increase the level of energy intensity in the region. This conclusion is in sharp contrast with the findings of Mishra et al. (2009) in New Caledonia who found that urbanization has a negative impact on energy use in New Caledonia; Poumanyvong and Kaneko (2010) on low-income countries and Sadorsky (2013) in the long run dynamic model but agrees with the conclusions of Parikh and Shukla (1995) and Poumanyvong and Kaneko (2010) on middle-income countries.

Similarly, industrialization (i.e. industrial activities) has a significant positive elasticity coefficient implying an increasing impact on energy intensity as expected. Specifically, a 1% proportionate increase in industrialization (i.e. industrial activities) increases energy intensity proportionately by about 0.29%. A plausible economic explanation for this relationship between industrialization (industrial activities) and energy intensity could be that, often and usually, industrialization relies extensively on energy utilization through the use of energy-consuming machines and equipment and other related sophisticated technology. These machines and technology though require energy, they also facilitate production activities tremendously which may eventually lead to a fall in energy intensity. However, these sophisticated and advanced technologies are scarcely employed in the industrial activities undertaken in the region. As a consequence, energy intensity keeps on rising in the face of industrialization (i.e. rise in Industrial activities) in SSA. This finding confirms the conclusions of Samouilidis and Mitropoulos (1984) who reported that the effects of industrialization on energy intensity in Greece in both the long-run ranges from 0.90 to 1.96 while short-run elasticities ranges 0.17 to 0.46. Similarly, it is consistent with findings of Poumanyvong and Kaneko (2010) in 99 countries they studied that the share of industrial activity in the economy on energy intensity is positive for low and middle income groups.

Table 2: Macroeconomic analysis of energy intensity

Regressors	Coefficient	Standard Error	Z-Statistic
Energy consumption efficiency (-1)	-0.3093	0.6336	-0.48816
Income	0.3329	0.0891	3.736251
Inflation level	-0.0093	0.0021	-4.42857
Exchange rate	-0.0844	0.5022	-0.16806
Industrial activities	0.1922	0.0476	4.037815
Trade openness	-0.3299	0.0012	-274.917
Foreign Direct Investment	0.1891	0.0291	6.498282
Population growth	0.0128	0.0076	1.684211
Urbanization	0.1099	0.0229	4.799127
Secondary school enrolment	-0.0198	0.0129	-1.53488
Constant	0.2114	0.024	8.808333
Adjusted R-Squared	*0.4988*		
Prob.>F	*0.0000*		
AR (1) test (p-value)	*0.250*		
AR (2) Test (P-value)	*0.191*		
Cross sectional dependence	*0.3724*		
Sargan test	*122.15*		

More so, income has a positive elasticity coefficient implying that energy intensity rises as the economy grows. From Table 2, a 1% proportionate increase in economic growth increases energy intensity proportionately by about 0.49%. This could be attributable to the fact that as income increases, citizens are able to afford appliances, gadgets, vehicles, among other commodities they consider luxury or superior almost all of which expend considerable energy use to work desirably. The end effect is worsening energy efficiency in both productive and consumptive economic activities. This finding disagrees with the argument raised by Metcalf (2008) who maintained that rising per capita income has played a significant role in improving energy intensity and that income predominantly influences energy intensity through changes in energy efficiency rather than through changes in economic activity. However, this finding is consistent with Parikh and Shukla (1995) and Harris and Prakash (2012) who found an unambiguous unidirectional causal relationship running from electricity consumption to economic growth in the short run with no causal relationship running from economic growth to electric consumption both in the short and long runs.

Openness to trade is found to significantly reduce energy intensity in SSA. In particular, a 1% proportionate increase in trade openness reduces energy intensity proportionately by about 0.32%. This could possibly be attributable to the fact that, trading activities within the region and between other regions and even the world economy at large do not rely extensively on energy and/or trading activities make use of highly advanced and sophisticated technology so that the net effect is that, energy intensity is lowered as trade openness increases. This finding stands in accord with the conclusion of Hubler (2009) and Cole (2006) who conducted similar empirical investigation in China and 32 developed countries for the period 1975–1995 respectively and found a negative elasticity coefficient for trade openness in relation with energy intensity.

FDI is significant with a positive impact on energy intensity. The elasticity coefficient on FDI implies that a 1% proportionate increase in FDI increases energy intensity proportionately by about 0.21%. This finding appears quite unexpected especially considering the fact FDI provides an avenue for the transfer of advanced technology from developed economies to developing ones, which in turn is expected to enhance productivity in developing regions such as SSA and eventually improve energy consumption efficiency. However, when one takes into account the fact that more than half of the FDI that come to the region goes into the mining and extractive sectors, the finding becomes less surprising. The reason being, the mining sector is highly capital-intensive and as such requires a considerable amount of energy and coupled with the evidence that the human capital base of many of these SSA countries is usually not up to the task of manning these highly sophisticated machines and equipment inter alia, the destructive effect of FDI on energy intensity become very evident. This finding however contrasts that of Hubler (2009), Eskeland and Harrison (2003), He and Wang (2007) and Fisher-Vanden et al. (2004) and many other related studies.

Secondary school enrolment (serving as a proxy for education) is also significant with a negative and enhancing impact on energy intensity. Its elasticity coefficient implies that a 1% proportionate increase in secondary school enrolment reduces energy intensity proportionately by about 0.0096%. This finding is expected owing to the fact that when people get educated especially up to the second cycle, they become very conscious of the hazardous effects of misusing energy resources. Though, it is also debated that these educated ones will eventually get wealthier and will demand goods and services which are energy consuming, the findings established by this study attest to the fact that perhaps the improving effect of the former far outweighs the worsening effect of the latter and thus resulting in an improving net effect of secondary school enrolment and energy consumption efficiency in SSA.

Finally, as expected both inflation level and exchange rate have negative coefficients (but the coefficient on exchange rate is not statistically significant) indicating that energy intensity is reduced in the region as inflation increases. This implies that a higher inflation rate which potentially reduces the value of money and the purchasing power of the populace can make people extremely conscious especially in the consumption of vital and essential commodities such as energy.

This confirms the findings of Fan, Liao, and Wei (2007), Dargay *et al*. (1983) and Fisher-Vanden *et al*. (2004) which concluded that rising energy prices contributed significantly to the decline of firm-level energy intensity, with 54.4% of the decline in aggregate energy-use explained by rising energy costs. Exchange rate is not statistically significant implying it does not drive energy consumption efficiency in SSA even though at the theoretical level, higher exchange rate is most likely to enhance energy intensity as it can potentially cause higher energy prices.

4.2.2 Energy intensity effect of sub-regional state of economic development

To what extent do disparities in sub-regional economic development affect energy intensity? The second objective of this study examines this very question. Four (4) dummies are used for Southern Africa, Central Africa, East Africa and West Africa by interacting each dummy with income (i.e. income is used as a proxy for the state of development in a sub-region). For the sake of analysis West Africa is used as the reference category. The result of the how the state of economic development of the various sub-regional blocs in SSA influence moves towards energy use efficiency is presented in Tables 3.

It is palpable from the results presented in Table 3 that all the sub-regional dummies (interacted with income as a proxy for the state of economic development) are statistically significant but with varying signs and weights while the other regressors maintain their signs as before.

Table 3: Energy intensity effect of sub-regional state of economic development

Regressors	Coefficient	Standard Error	Z-Statistic
Energy consumption efficiency (-1)	-0.4793	0.6336	-0.75647
Income	0.1087	0.021	5.17619
Inflation level	-0.0682	0.091	-0.74945
Exchange rate	-0.4331	0.9892	-0.43783
Foreign Direct Investment	0.1638	0.0961	1.704475
Trade openness	-0.2582	0.1418	-1.82087
Population growth	0.9127	0.5196	1.756543
Urbanization	0.7426	0.0828	8.968599
Secondary school enrolment	-0.0345	0.0054	-6.38889
SADC	-0.0119	0.0103	-1.15534
EAC	0.0727	0.017	4.276471
CEMAC	0.1348	0.0937	1.438634
Constant	0.5196	0.742	0.70027
Adjusted R-Squared	*0.508*		
Prob.>F	*0.008*		
AR (1) test (p-value)	*0.238*		
AR (2) Test (P-value)	*0.401*		
Cross sectional dependence	*0.502*		
Sargan test	*11.512*		

In particular, the coefficients are negative for Southern Africa and East Africa but positive for Central Africa. This stands to reason that compared to West Africa, there is a greater likelihood of economic growth enhancing energy consumption efficiency in Southern Africa and East Africa. This effect is more pronounced for Southern Africa than for East Africa. However, for Central Africa, the effect of economic development is a movement towards a decline in energy use efficiency. The most plausible explanation for this conclusion could be that the economic growth process in Central Africa is more energy intensive than in Southern Africa, East Africa and West Africa: the converse of which is also valid.

4.2.3 Sectoral effects of energy consumption efficiency in SSA

Finally, the paper examines how growth of the three broad sectors of the economy (i.e. disaggregated components of economic growth) impact on energy intensity in SSA. The results are presented in Table 4.

It is evident that the activities of industrial and services sectors tend to increase energy intensity which is an indication of a fall in energy consumption efficiency while for agricultural (sector) activities, the contrary was established. The other regressors maintained their signs as before. This agrees with Fisher *et al* (2004), who found that sectoral shift (i.e., structural change) can explain almost 50% of the decline in total energy intensity over the period 1997-1999.

Table 4: Sectoral effects of energy consumption efficiency in SSA

Regressors	Coefficient	Standard Error	Z-Statistic
Energy consumption efficiency (-1)	-0.721	-0.421	1.712589
Income	0.3329	0.0891	3.736251
Inflation level	-0.0718	0.0281	-2.55516
Exchange rate	-0.1009	0.2011	-0.50174
Foreign Direct Investment	0.2018	0.062	3.254839
Trade openness	-0.0997	0.0128	-7.78906
Population growth	0.1014	0.4019	0.252302
Urbanization	0.0104	0.0017	6.117647
Secondary school enrolment	-0.0033	0.1901	-0.01736
AGRIC	-0.0318	0.0051	-6.23529
INDUSTRY	0.4549	0.0102	44.59804
SERVICE	0.0323	0.0776	0.416237
Constant	0.029	0.9127	0.031774
Adjusted R-Squared	*0.4938*		
Prob.>F	*0.000*		
AR (1) test (p-value)	*0.191*		
AR (2) Test (P-value)	*0.217*		
Cross sectional dependence	*0.717*		
Sargan test	*18.99*		

5. Conclusions and policy

The crucial importance of energy has gained much attention in contemporary growth agenda in many developing economies given its linkages with sustainable development. This study, using a panel dataset on 36 SSA countries over the period 1980-2015, examined how the macroeconomy tends to influence energy intensity as well as the link between energy consumption efficiency and economic growth

The findings of the study show that increasing economic growth/income worsens energy intensity in SSA countries. From a policy perspective, it gives the indication that policy instruments that increase per capita income in SSA should be critically evaluated for energy consumption efficiency consideration. Attention needs to be given to the industrial and services sectors of the economic growth process. The reason being that, the sectoral analysis revealed the industrial and services sectors have a rising effect on energy intensity. In line with this, promoting sustainable growth requires critical shift towards more efficient energy based technologies to reduce energy intensity.

The empirical results further reveal that increases in industrialization (i.e. activities of the industrial sector) and the services sector worsen energy intensity in SSA. This conclusion does not however imply that, the region should discard its policies to promote industrial growth. The essential issue at stake relates to how best to minimize the destructive effect of industrialization on energy intensity in the region. Minimizing these destructive effects may require a considerable number of research and development (R&D) activities to identify the optimal growth-energy intensity mix for the region. To this end, considerable attention and emphasis to the link between industrial energy intensity and key reform parameters, such as privatization, enterprise restructuring and power sector reforms ought to be given attention.

Finally, the authors acknowledge that, ideally, energy prices should have featured as a prominent determinant of energy intensity due to its importance in influencing energy consumption and hence energy intensity. However, due to inadequate dataset on energy prices, the variable is omitted from the specifications. This is considered as a potential weakness of the study. However, we expect that the regressors included should render some useful insights on the topic. Further research addressing this weakness is considered very essential.

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Appendix I: List of the 36 SSA countries sampled for the study

Angola***	Congo, Dem. Rep.*	Lesotho***	Nigeria****	Swaziland***
Benin****	Congo, Rep.*	Liberia****	Rwanda**	Tanzania**
Botswana***	Cote d'Ivoire****	Madagascar***	Senegal****	Togo****
Burkina Faso****	Ethiopia*	Malawi*	Sierra Leone****	Uganda**
Burundi**	Gabon*	Mali****	South Africa***	Zambia***
Cameroon*	Gambia, The****	Mauritania****	Sudan**	Zimbabwe***
Cape Verde****	Ghana****	Mauritius		
Central African Rep*	Kenya**	Niger****		

, **, * and **** correspond to countries in CEMAC, EAC, SADC and ECOWAS respectively.*

Appendix II: Measurement of variables

Variable	Definition and Measurement
Energy intensity (EI)	Natural log of energy intensity (energy use in kg of oil equivalent per GDP (constant 2005PPP)
Income (Y)	Natural log of real per capita GDP (GDP per capita, PPP (constant 2005 international dollars),
Industrial sector (INDUSTRY)	Natural log of industrialization (industry, value added as a % of GDP).
Agricultural sector (AGRIC)	Natural log of Agriculture, value added (% of GDP).
Services sector (SERVICE)	Natural log of Service/GDP (services, value added as a % of GDP).
Exchange rate (FX)	Natural log of nominal exchange rate
Inflation level (INF)	Natural log of inflation level (Consumer Price Index)
Secondary school enrolment (SSE)	Natural log of level of secondary school enrolment
Urbanization (URB)	Natural log of urbanization (measured by the fraction of the population living in urban areas)
Population growth	Natural log of annual population growth rate
Foreign Direct Investment (FDI)	Natural log of the share of FDI (net inflows) in GDP
Trade openness (TOP)	Natural log of (export + import)/GDP

Source: World Development Indicators (2015) and International Energy Agency (2015)