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A Disaggregated Analysis of Energy Demand in Sub-Saharan Africa

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ABSTRACT

Adequate energy is required in Sub-Saharan African (SSA) countries to promote economic growth and development. The purpose of this study is to identify and analyse the determinants of disaggregated energy demand in SSA. Using reliable macroeconomic and energy data collected from publicly available databases over the period 1980-2013 for selected countries in the region, we estimate fixed and random effects panel data models to examine the determinants of electricity, diesel, petrol, kerosene, solid biomass and liquefied petroleum gas consumption. We find that income, urbanization, economic structure and population are significant determinants of energy demand in SSA. Important implications flow from these findings.

Keywords: Energy Consumption, Income, Sub-Saharan African
JEL Classifications: C33, Q41, Q43

1. INTRODUCTION

Energy is an integral part of a modern economy due to the critical role it plays as a factor employed in the production of goods and services, when combined with capital and labour. It is also the main factor behind global warming due to greenhouse gas (GHG) emissions. While an annual increase of 3% in energy consumption is expected in developing countries, only a 0.9% annual increase is expected in developed economies (Keho, 2016). This may explain why the past decade has seen a surge of energy demand studies in developing countries, including Sub-Saharan Africa (SSA). Such a surge of interest in the modeling and estimation of energy demand in SSA is also motivated by other compelling reasons.

First, the SSA population accounts for 13% of the global population but it makes up only 4% of the total global energy consumed (IEA, 2014). Second, the majority of people in SSA (over 1 billion) live in rural areas but this trend is changing, with an increase in urban population from 22.1% in 1980 to 38% in 2015 (World Bank, 2015). This rural-urban migration is likely to have significant implications for both the level and mode of energy consumption in SSA. Third, the region is home to ten countries with the highest fertility rates in the world (PRB, 2013), growing at an annual population growth rate of 2.7% (World Bank, 2015). Lastly, the primary energy consumed is from solid biomass sources such as fuel wood and charcoal, which account for more than three quarters of the SSA energy mix (IEA, 2014). Also, two out of three households in the region are not connected to the power grid (David et al., 2014).

Against this backcloth, especially when considering cash constraints and the expected future growth of energy consumption in developing countries, it is reasonable for policy makers and planners to be interested in evidence that can guide decision making. It follows that in addition to information on present energy consumption patterns, knowledge of the significant determinants of energy demand is a critical tool for both investment and planning decisions in SSA.

Although a number of studies have investigated the relationship between energy consumption and economic growth in SSA or the causality between the two, to the best of our knowledge, there is no single study that provides an up-to-date empirical analysis of disaggregated energy demand by energy types in SSA.

We investigate the determinants of energy demand in SSA through a disaggregated analysis of six energy types: Electricity, diesel, petrol, kerosene, solid biomass and liquefied petroleum gas (LPG) consumption, a level of disaggregation that constitute a significant advance on what has been done before. Moreover, we include relatively under-researched variables in our analysis, including the degree of urbanization, population and economic structure, to reflect the current energy and socio-economic dynamics in SSA. Prior studies on energy consumption in some SSA countries like Ghana, included degree of urbanization, population and economic structure in their analysis. The authors stated their importance in reflecting both the current energy and socio-economic dynamics in the SSA countries analyzed (Adom et al., 2012; Mensah et al., 2016). The data is based on a panel data set over the period from 1980 to 2013, covering 12 SSA countries, namely: Benin, Botswana, Cameroon, Congo, Democratic Republic of Congo, Ethiopia, Nigeria, Senegal, South Africa, Sudan, Togo and Zambia (the data period and sample of countries included were dictated by data availability).

The findings can aid the development of an appropriate policy framework for meeting the energy need of consumers in the region while also enabling informed investment decisions in the development of interregional capital intensive gas systems across SSA.

The rest of the paper is organized as follows. Section 2 presents a synthesis of related literature. Section 3 presents the data and model used in the empirical analysis. Section 4 presents and discusses the econometric results. The final section summarizes the main findings and highlights some policy implications.

2. A SYNTHESIS OF RELATED LITERATURE

2.1. Energy Sources in SSA: Some Stylized Facts

The vast amount of renewable and non-renewable energy sources in SSA have been identified by researchers and reports published by both private and public organizations in the region and globally. A consensus exists around the view that the available energy resources are in abundance and could be employed to more than satisfy both the present and future energy need in the region (Kebede et al., 2010; KPMG, 2013; Onyeji, 2014). A special report by the International Energy Agency on Africa's energy outlook (IEA, 2014) states that the proven oil, gas and coal reserves in the region would be sufficient to meet energy demand for 100, 600 and 400 years, respectively.

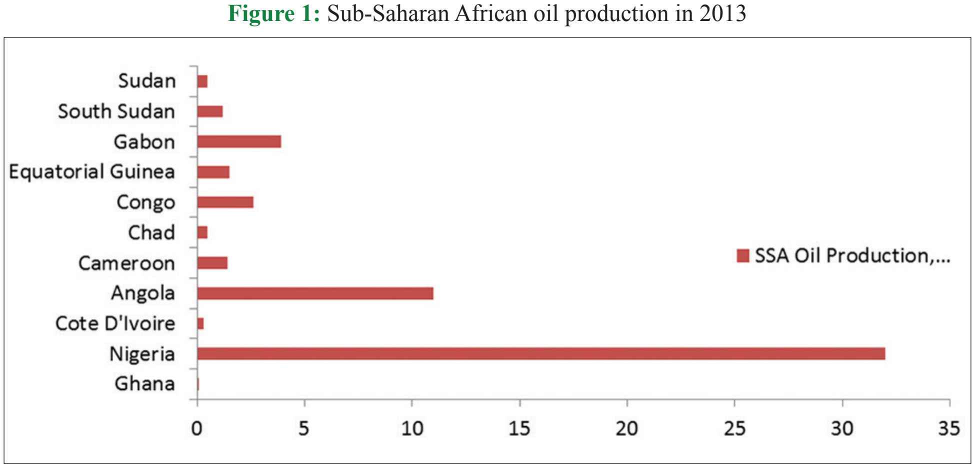
The SSA region holds about 6% of the world's total natural gas resource (IEA, 2014). The share of the gas reserve in the global percentage is due to an increase of 80% in the new gas reserves discovered within the last few years. The close relationship of the gas to oil, has led to several decades of waste of the gas through gas flaring in the exploration process of crude oil. Recent awareness about the commercial and environmental impact of gas flaring, notably by regulations from the global gas flaring reduction partnership, have led to a reduction in the amount of gas flared in recent years.

Most of the proven coal reserves are in the Southern part of SSA. The known 36 billion tonnes reserves are in South Africa, Mozambique, Botswana, Tanzania, Zambia, Swaziland and Malawi. Whilst South Africa has 90% of the reserve and on a global basis, it has the ninth largest recoverable coal deposit (EIA, 2013).

Nigeria is the leading oil producer in the region, followed by Angola with Ghana, producing the lowest amount of oil (Figure 1). In 2013, the top three oil producers in SSA were Nigeria, Angola and Gabon. They produced 32 billion barrels, 11 billion barrels and 3.9 billion barrels of oil, respectively (IEA, 2015). These countries are favored by the layout of the Gulf of Guinea, which is the main oil basin in the region, Although Nigeria has the highest number of reserves, the oil basin extends from the North-Western part of Angola from Guinea, to Nigeria, Ghana, Ivory Coast, Democratic Republic of Congo, Congo (Brazzaville), Gabon, and Cameroon (KPMG, 2013).

The river systems in Africa are among the largest in the world and account for about 13 percent of the total hydropower potential available globally (IEA, 2014). Several studies agree that solid

Figure 1: Sub-Saharan African oil production in 2013



Source: IEA data, 2015

biomass - a key renewable energy source in the region - is the dominant domestic fuel for cooking, drying and heating in SSA (Kebede et al., 2010; Brew-Hammond, 2007; Karekezi, 2002). This may be explained by the high use of traditional biomass by the majority of the population in the residential sector, and also the availability of forest resources. SSA has one of the best solar energy potentials in the world. This stems from a geographical location near the equator, which provides the region 320 days of sunshine (in most countries) per annum. The irradiance level varies across sub-regions, with the Southern sub-region having the highest level of 2500 KWh per m^2/day.

Most of the wind power potential lies in the Horn of Africa, the Eastern part of Kenya, the side of the West and Central Africa located around the borders of the Sahara desert, and some areas in the Southern part of the region. A feasibility study on the SSA wind power potential by the African Development Bank (AfDB, 2013), found that Somalia has the highest potential, followed by Sudan, Mauritania, Madagascar, Chad and Kenya, all with a high on-shore wind power.

Considering that energy sources are unequally distributed across SSA countries, regional integration and cooperation of energy supply may help to reduce the financial burden on individual countries of building their own infrastructure. In addition, it offers the governments in the SSA region the opportunity to invest in the cheapest and cleanest sources of energy.

2.2. A Brief Review of the Empirical Literature

Energy models can be classified into static or dynamic, Univariate or multivariate, top down or bottom up, identity versus structural or market-share based approaches and forecasting models (Jebaraj and Iniyan, 2006; Urban et al., 2007; Swan and Ugursal, 2009; Suganthi and Samuel, 2012). Pesaran et al. (1998) argue that structural engineering, end-user approach and econometric approaches provide the best frameworks for the estimation of energy demand. In this paper, we used the econometric approach for the analysis of the consumption of six main energy types in SSA.

Table 1 presents a schematic summary of the estimated price and income elasticities from some of the main studies on energy demand in developing countries. To fully implement an effective energy demand management strategy in SSA, it is paramount to understand first the impact of economic and non-economic factors on energy demand (consumption) in SSA. The present study seeks to fill this gap in the literature by providing an up-to-date empirical analysis of the determinants of electricity, diesel, petrol, kerosene, solid biomass and LPG consumption in SSA using a comprehensive and theory-based model that also includes variables typically neglected in prior empirical literature such as the degree of urbanization, population and economic structure, to reflect the current energy and socio-economic dynamics in SSA.

It is clear from Table 1 that, with few exceptions, most of the previous studies have estimated energy demand of single countries at either aggregate level or for few, mostly single energy sources such as electricity or petrol. This choice is clearly inadequate to reflect the pattern of energy consumption by energy type, especially given the rather peculiar energy mix in developing countries. In the main, price and income have emerged as the most important determinants of energy demand, similarly to the findings for developed countries. Yet very few studies aimed at developing a comprehensive model that includes most variables that could be reasonably expected to exert a significant influence on energy demand, have taken into proper account the socio-economic conditions and state of development of the developing countries under study by also including variables such as the degree of urbanization, population and economic structure, to reflect the current energy and socio-economic dynamics in SSA. As shown in Table 1, the reported price and income elasticities generally display a negative and positive sign, respectively, as expected a priori, but the magnitude of the estimated coefficients tends to differ, quite considerably in some cases. It remains unexplained whether such differences stem from country specific factors of the countries investigated or inherent differences in the studies themselves. Some of these results have either confirmed or contradicted earlier findings in the literature and, overall, the results obtained appear to depend on the variables used in estimation, the study period and the methodology employed.

3. EMPIRICAL MODEL AND DATA

3.1. Empirical Model

Following the typical log-linearized model employed in previous studies, we specify the energy demand function for each energy type as follows:

Gasoline

$$\ln G_{it} = \alpha_0+\alpha_1 Y_{it}+\alpha_2 \ln POP_{it}+\alpha_3 \ln URB_{it}+\alpha_4 \ln ES_{it}+u_t \tag{1}$$

LPG

$$\ln LPG_{it} = \beta_0+\beta_1 Y_{it}+\beta_2 \ln POP_{it}+\beta_3 \ln PURB_{it}+\beta_4 \ln ES_{it}+\xi_t \tag{2}$$

Diesel

$$\ln D_{it} = \gamma_0+\gamma_1 Y_{it}+\gamma_2 \ln POP_{it}+\gamma_3 \ln PURB_{it}+\gamma_4 \ln ES_{it}+\zeta_t \tag{3}$$

Solid biomass

$$\ln BE_{it} = \delta_0+\delta_1 Y_{it}+\delta_2 \ln POP_{it}+\delta_3 \ln URB_{it}+\delta_4 \ln ES_{it}+\upsilon_t \tag{4}$$

Electricity

$$\ln EC_{it} = \psi_0+\psi_1 Y_{it}+\psi_2 \ln POP_{it}+\psi_3 \ln URB_{it}+\psi_4 \ln ES_{it}+\rho_t \tag{5}$$

Kerosene

$$\ln K_{it} = \phi_0+\phi_1 \ln Y_{it}+\phi_2 \ln POP_{it}+\phi_3 \ln URB_{it}+\phi_4 \ln ES_{it}+\pi_t \tag{6}$$

Where $\ln G_{it}$ is the natural log (ln) of gasoline consumption in country i at time t; $\ln LPG_{it}$ is the ln of LPG in country i at time t; $\ln D_{it}$ is the ln of diesel consumption in country i at time t; $\ln BE_{it}$ is the ln of biomass energy consumption in country i at

Table 1: Empirical results of selected energy demand studies in developing countries

Author	Energy type	Long-run price elasticity	Long-run income elasticity	Period	Country
Alter and Syed (2011)	Aggregate	−0.19	0.32	1970-2010	Pakistan
	Residential	−0.42	0.18		
	Industrial	−0.21	0.06		
	Commercial	−0.30	0.00		
	Agricultural	−0.14	0.72		
De Vita et al. (2006)	Energy	−0.34	1.27	1980-2005	Namibia
	Electricity	−0.30	0.59		
	Petrol	−0.86	1.08		
	Diesel	−0.11	2.08		
Atakhanova and Howie (2007)	Aggregate	−0.04	0.37	1960-2007	South Africa
	Residential				
	Service				
	Industrial				
Iwayemi (2008)	Energy	−0.11	0.81	1977-2006	Nigeria
	Petrol				
	Diesel				
	Kerosene				
Abdullahi (2014)	Petrol	−0.23	0.11	1978-2010	
	Diesel	−0.30	0.17		
	Kerosene	−0.20	0.10		Nigeria
	Fuel oil	−0.18	0.27		
	LPG	−0.58	0.64		
Kumar (2008)	Energy	−0.30	1.00	1970-2005	Fiji
Ackah (2014)	Gas aggregate	−1.81	1.95		
	Residential	−0.52	0.53	1989-2009	Ghana
	Industrial	−6.3	3.70		
Arisoy and Ozturk (2014)	Industrial	−0.014			Turkey
	Residential	−0.0223		1960-2008	
Adom and Bekoe (2013)	Electricity		2.12	1971-2008	Ghana
Amusa et al. (2009)	Electricity	−11.41	1.67	1960-2007	South Africa
Adom et al. (2012)	Electricity		1.6	1975-2005	Ghana
Mensah (2014)	LPG	−0.28	0.45	1992-2012	Ghana
Mensah et al. (2016)	Petrol	−0.55	1.32	1979-2013	Ghana
	Diesel	0.32	3.56		
	LPG	−0.26	2.77		
	Kerosene	−0.48	−3.63		
	Biomass	−0.76	−0.59		
	RFO		1.74		
	Electricity		2.71		
Lundmark et al. (2001)	Electricity	0.51	0.86	1980-1996	Namibia
Akinboade et al. (2008)	Petrol	−0.47	0.36	1978-2005	South Africa
Al-Azzam and Hawdon (1999)	Energy	−0.08	0.98	1968-1997	Jordan

time t; $\ln EC_{it}$ is the ln of electricity consumption in country i at time t; $\ln K_{it}$ is the ln of kerosene consumption in country i at time t. Likewise, lnY, lnURB, lnPOP and lnES stand for the ln of income, urbanization, population and economic structure in country i at time t. The demand elasticities are measured by the parameters (α, β, γ, δ, ψ, ϕ) while the white noise errors are denoted by (u, ξ, ζ, v, ρ, π).

3.2. Data

Due to data constraints at higher frequency, we use annual time series. Data were collected for 12 countries in SSA from 1980 to 2013. GDP is expressed as real GDP per capita in US dollars (2005 base year), taken from the World Bank database. The urbanization series, also collected from the World Bank, is defined as people living in urban areas in a country as a proportion of the total population. Economic structure is derived from real value added in industry divided by the real value added in the service sector. All energy consumption data are obtained from the International Energy Agency. Energy consumption is computed as the sum of the energy used by all the sectors in the economy, measured in thousand tons of oil equivalent.

The following 12 countries in SSA are analyzed: Benin, Botswana, Cameroon, Congo, Democratic Republic of Congo, Ethiopia, Nigeria, Senegal, South Africa, Sudan, Togo and Zambia. The study employed two linear panel econometric techniques: Fixed effects (FE) and random effects (RE) models.

Figures 1 and 2 in Appendix A display the plots of the analyzed energy types, that is, diesel, petrol, biomass, kerosene, LPG and electricity consumption data in each of the 12 countries in our sample. Visual inspection of Figures 1 and 2, suggests that there appear to be no major or persistent structural breaks in the analyzed series. Figure 2 (Appendix A) shows the scatter plots of the relationship between the energy types consumption against income in SSA. The chart shows a clear positive relationship between the plotted variables for diesel, petrol, biomass, kerosene, LPG and electricity, as expected a priori. While a negative relationship is found between biomass consumption and income, as one would expect. This suggests the existence of a long run relationship between the variables in question, a pattern that should find confirmation in our regression analysis results.

4. EMPIRICAL RESULTS

Table 2 presents the descriptive statistics of the variables analyzed. The mean value of the log of population has the highest log mean value of 16.42 while the income variable has a log mean value of 6.65. It is evident from Table 2 that we have a weakly balanced panel, in most models. The method we employed for the analysis is robust and works well even with few missing values.

It is evident from the estimated correlation coefficients (Appendix Tables 1-5 in Appendix B) that there is no problematic issue of multicollinearity among the variables in all the energy type models under consideration. Since none of the coefficient values is higher than 0.75 using Tabachnick and Fidell's (2007) cut-off line, we do not have a multicollinearity problem.

Table 2: Descriptive statistics

Variable	Mean	Standard deviation	Minimum	Maximum	Observed
lnIncome					
Overall	6.65	1.00	4.74	8.92	407
Between		0.12	6.45	6.95	
Within		0.10	4.85	8.66	
lnUrban					
Overall	1.34	0.40	0.09	2.66	408
Between		0.17	1.15	1.62	
Within		0.36	0.07	2.42	
lnEconomy					
Overall	−0.44	0.76	−1.70	1.49	406
Between		0.10	−0.67	−0.26	
Within		0.75	−1.96	1.45	
lnPop					
Overall	16.42	1.28	13.81	18.97	408
Between		0.27	15.96	16.85	
Within		1.25	14.09	18.58	
lnKero					
Overall	3.80	1.73	0.00	7.82	404
Between		0.20	3.46	4.16	
Within		1.72	−0.13	7.90	
lnBiomass					
Overall	11.67	1.62	8.93	15.23	406
Between		0.22	11.31	12.07	
Within		1.61	8.92	14.91	
lnDiesel					
Overall	5.85	1.30	1.95	9.15	406
Between		0.36	5.38	6.56	
Within		1.25	2.42	8.83	
lnLPG					
Overall	2.78	1.64	0.00	6.14	351
Between		0.46	2.14	3.57	
Within		1.58	−0.59	6.16	
lnPetrol					
Overall	5.49	1.56	2.30	9.05	406
Between		0.37	5.04	6.16	
Within		1.52	2.61	9.31	
lnElect					
Overall	7.71	1.73	4.23	12.25	406
Between		0.44	7.02	8.57	
Within		1.68	4.84	12.18	

4.1. Electricity

Electricity is used across all sectors of an economy, from residential and manufacturing to the service sector. This makes it an important energy required for socio-economic development. Results from the two models analyzed reveal that income, urbanization, economic structure and population are significant factors behind energy consumption in SSA. Population has the highest impact, then income, economic structure and urbanization, in that order, in both the FE and RE model. The Hausman test is performed to choose the appropriate model for electricity consumption in SSA. According to the test results, the FE model is most appropriate since the chi-squared critical value (P = 0.000) is lower than the test statistic for the individual effect model (P = 0.05). Hence, we can safely accept the hypothesis that the FE model is preferable.

According to the FE model (Table 3), the income elasticity of electricity is positive, inelastic and strongly significant. That is, a 1% increase in income increases electricity consumption by approximately 0.55%. The urbanization elasticity is against our a priori expectations. There is no increase in electricity consumption associated with an increase in the degree of urbanization. Instead, we find that a unit increase in urbanization reduces electricity consumption by 0.11%, and the estimated coefficient is statistically significant at the 1% level. The results also show that population is a key and significant factor behind electricity consumption in SSA. Specifically, a 1% increase in population size is expected to lead to a 1.54% increase in electricity consumption. Likewise, the positive elasticity of economic structure implies that an increase in industrial output increases electricity consumption in SSA. For each percentage increase in industrial output, electricity consumption increases by 0.09%.

These results are broadly consistent with those obtained by Adom et al. (2012) who estimated the long run income elasticity of Ghana to be 1.59, Expo et al. (2011), who reported an income elasticity of electricity of 0.58 in Ghana, and De Vita et al. (2006) who reported 0.59 as the income elasticity of electricity in Namibia. Clearly, the income elasticity of electricity demand is inelastic and positive in the long run in SSA. Kebede et al. (2010) also found a positive relationship between electricity demand and population in SSA the negative relationship found between electricity demand and urbanization, differs from some published studies in related literature (Holtedahl and Joutz, 2004; Adom et al., 2012) but is consistent with the findings by Adom and Bekoe (2013). Considering that most of the SSA countries analyzed are in the low income group, it is suggested that the negative sign of the urbanization coefficient may be due to "urban compaction" (Poumanyvong and Keneko, 2010). This hypothesis suggests that countries which lack access to public infrastructure may need more energy if the number of access areas increases. This explanation is in line with our findings, as most public services like rail lines, well equipped hospitals, uninterrupted power supply, to name but

Table 3: Estimation results from fixed effects model

Regressors	Dependent variable					
	Electricity	Diesel	LPG	Kerosene	Biomass	Petrol
Income	0.545***	0.470***	0.884***	0.735***	−0.036	0.548***
	(11.96)	(5.46)	(5.65)	(9.14)	(−1.30)	(6.35)
Urbanization	−0.113***	−0.214**	−0.364***	0.688***	0.087***	−0.229***
	(−3.10)	(−3.11)	(−4.35)	(3.49)	(3.91)	(−3.32)
Economic structure	0.089***	0.029***	0.755***	−0.049	−0.028	0.164**
	(2.60)	(3.54)	(6.28)	(−0.52)	(−1.10)	(2.53)
Population	1.537***	1.156***	1.623***	0.976***	0.886***	1.176***
	(34.10)	(13.58)	(12.00)	(17.52)	(32.27)	(13.79)
Constant	−20.951***	−15.880***	−28.942***	−18.066***	−2.773***	−17.088***
	(−25.40)	(−10.19)	(−13.50)	(−13.88)	(−5.52)	(−10.94)
Observations Hausman test statistic	404	404	385	402	402	404
	(54.02***)	(19.59***)	(15.18**)	(4.14)	(6.25)	(8.27)

Note: *, ** and *** significance levels of 10%, 5% and 1%, respectively t and z statistic are in parenthesis. The Hausman (1978) test is performed after the fixed effects regression, to select the appropriate model for the analysis

Table 4: Estimation results from random effects model

Regressors	Dependent variable					
	Electricity	Diesel	LPG	Kerosene	Biomass	Petrol
Income	0.585***	0.567***	1.029***	0.691***	−0.036	0.630***
	(12.74)	(7.94)	(8.16)	(9.01)	(−1.32)	(7.92)
Urbanization	−0.121***	−0.235***	−0.391***	0.585***	0.089***	−0.227***
	(−3.22)	(−3.47)	(−4.65)	(3.38)	(4.03)	(−3.32)
Economic structure	0.085**	0.174**	0.662**	−0.021	−0.021	0.159***
	(2.41)	(2.85)	(5.71)	(−0.22)	(−0.99)	(2.51)
Population	1.487***	1.002***	1.400***	0.960***	0.896***	1.115***
	(33.37)	(15.83)	(13.19)	(18.17)	(33.10)	(14.98)
Constant	−20.39***	−13.998***	−26.332***	−17.356***	−2.931***	−16.638***
	(−24.07)	(−11.21)	(−13.17)	(−13.93)	(−5.49)	(−16.638)
Observations	404	404	385	402	402	404

Note: *, ** and *** indicates significance levels of 10%, 5% and 1%, respectively, t and z statistic are in parenthesis

a few, which are obtainable in most of the big cities in the world, are not readily available in most of the urban cities in SSA.

4.2. Diesel

For diesel consumption in SSA, our results show positive elasticities for income, economic structure and population. A negative elasticity is reported for the relationship between diesel consumption and the degree of urbanization in SSA, in both the FE and RE models (Tables 3 and 4). According to the results of the Hausman test, the FE model is preferable for our analysis. When income rises, there is more demand for diesel from both residential and industrial sectors of the economy, because diesel is used as fuel in power generating sets across most SSA countries. It is also used in automobiles and trucks in the transport sector. Thus, an increase in income, population size and industrial output will increase diesel consumption. The effect is found to be around 0.47%, 1.16% and 0.03%, respectively.

Our results corroborate those by De Vita et al. (2006) for Namibia, and Abdullahi (2014) for Nigeria. Abdullahi (2014) suggests that the upward trend in diesel demand in Nigeria could be linked to manufacturing, telecommunication and high income household segments of the economy. This is the case for most of the countries in SSA, even South Africa, due to failure of the respective governments to upgrade or replace the installed power plants since the 1960s. Contrary to our expectation, we did not find a positive relationship between diesel demand and the degree of urbanization. The observed negative relationship may be partly due to the deindustrialization that is occurring in most of SSA cities, due to poor infrastructure. If the number of manufacturing firms reduces, then the amount of diesel consumed in urban areas will also be affected because most of the diesel consumed is used by firms' diesel generators, machineries, equipment and trucks.

4.3. LPG

Our results from both FE and RE models show robust elasticities with respect to income, economic structure and size of the population. The results from the FE model will be discussed, as it was selected as the preferred model on the basis of the Hausman test. As expected, a positive relationship is found between income and LPG consumption, estimated to be 0.88. This means that a 1% increase in consumers' income will lead, on average, to a 0.88% increase in LPG consumption in SSA. A possible explanation for the positive income elasticity may be that as income increases, consumers move away from traditional energy types like biomass and kerosene to a more modern energy type. This result is consistent with the "energy ladder" hypothesis, which predicts that as the income of households increases, they move up the energy ladder by stepping up from the use of traditional energy to the use of modern energy sources like LPG (Mensah et al., 2016). A positive relationship is also found between LPG demand and population size, with an estimated elasticity of 1.62, which seems plausible when acknowledging the emergence of a new middle income class in SSA. Increasingly more consumers might be able to afford to use LPG in homes for cooking. Also, an increase in population would mean an increase in market size for firms that use LPG in their production activities such as those in the hospitality sector. Increased industrial output is also estimated to increase LPG consumption by 0.76, while an increase in the degree of urbanization is found to reduce LPG consumption by 0.37%. Earlier empirical studies with similar findings include Abdullahi (2014), Mensah (2014), Ackah (2014), Akinboade et al. (2008), Alves and Bueno (2003), with reported income elasticities ranging from 0.36 to 1.95. The value of our estimated coefficient sits comfortably within this range.

4.4. Kerosene

SSA consumers in rural and urban areas use kerosene for cooking and lighting purposes. Our results give evidence of a positive and significant income, population and degree of urbanization elasticities of 0.61, 0.90 and 0.09, respectively. The results of the RE model are analysed, as it was chosen on the basis of the results of the Hausman test. The positive income elasticity could be attributed to the move towards more efficient energy source like kerosene from traditional biomass like charcoal and firewood, as consumers' income increases. The relatively inelastic result also suggests that as kerosene is the cheapest form of modern cooking fuel, consumers are less responsive to changes in price because it is an essential good to them. Studies with similar results include Iwayemi (2008) and Abdullahi (2014) in Nigeria.

The positive relationship between kerosene demand and the degree of urbanization is likely to be due to the fact that when consumers move from rural areas to urban centers, they switch from traditional sources like firewood to kerosene cooking stoves. Even for slum dwellers the use of firewood may not be appealing because of the compacted style of living, and consumers may be able to afford small cooking stoves that use kerosene in the available living space. Besides, with more awareness of the adverse health implications associated with the use of biomass sources for cooking in main cities, most households prefer to use kerosene stoves, which are relatively more affordable in most SSA cities.

4.5. Solid Biomass

Solid biomass sources such as fuel wood and charcoal are major components of the energy mix in SSA, making up more than 75% of the total energy consumed in the residential sector (Lambe et al., 2015). Also, four out of five people rely on fuel wood for cooking in SSA (IEA, 2014). The RE model selected by Hausman's test is analyzed. Our results reveal that the degree of urbanization and population are the main significant drivers of biomass consumption in SSA, with associated elasticities of 0.09 and 0.90, respectively. The rapid rate of urbanization and population growth has not been matched with the availability of energy required in SSA. Coupled with widespread poverty, especially in the rural areas, most of the low income earners rely on the use of solid biomass for cooking. A low income level is prevalent in most of the cities and even lower income levels characterize rural areas. Hence, a rapid population growth rate would lead to an increase in the number of people using solid biomass for cooking.

Considering that both elasticities are relatively inelastic. These results may be rationalized by the fact that low income people consume biomass, and most of them are less responsive to changes in prices because biomass is the cheapest form of energy available. Moreover, most of the people in the rural areas collect the firewood directly from the forest or farms. This finding is corroborated by Kebede et al. (2010) who also reported a positive relationship between the consumption of traditional fuel wood and population in SSA. Our result is in agreement with that by Mensah et al. (2016), which showed that urbanization is one of the significant factors that determine biomass demand in Ghana. Mensah et al. (2016) also showed that income is a significant driving force of biomass demand in Ghana. This differs from the findings presented in this study. Income was found to have a negative and insignificant relationship with biomass demand in SSA. The negative sign is as expected given that consumers with more income could plausibly be expected to demand less biomass and move towards the use of modern energy like kerosene and LPG. However, a possible explanation for the statistically insignificant result may be linked to this being a cross-country study; our results being based on a cross-country average while the study by Mensah et al. (2016) is a single-country study.

In general, therefore, it seems that the high proportion of urban poor, high level of unemployment and shortage in modern energy types like LPG and electricity may have led to the use of different forms of biomass among the low income earners who are unable to afford the use of generators or modern cooking stoves.

4.6. Petrol

The RE model was chosen by the Hausman's test, which is therefore used to analyze petrol consumption in SSA. The results reveal that all the variables are statistically significant with the expected sign, except for urbanization. According to the results, a 1% increase in consumers' income leads to a 0.63% increase in petrol consumption in SSA. However, a 1% increase in the degree of urbanization reduces petrol consumption by 0.23%. Our positive income elasticity for petrol demand is consistent with the findings of previous energy demand studies in the literature. These include Mensah et al. (2016) with an income elasticity of 1.32 for petrol demand in Ghana, Abdullahi (2014), who reported an income elasticity of 0.11 for Nigeria, Iwayemi (2008) who reported an income elasticity of 0.75 for Nigeria, Akinboade et al. (2008) who reported an income elasticity of 0.36 for South Africa, and De Vita et al. (2006) who also found an elasticity of 1.27 for petrol demand in Namibia.

The negative link between petrol demand and urbanization may be due to the fact that rural migrants move slowly from the use of solid biomass to modern energy. The switch is slow as rural migrants are low skilled workers, initially live in slums, and likely to be unable to afford to buy a vehicle or even a small power generating set until after some time. This slow transition may explain the negative elasticity because some of the rural migrants may even become worse off in the city, at least initially, and their standard of living will reduce due to the reduced disposable income. However, their disposable income may improve over time but the modernization towards green and efficient energy sources will take time, and an even longer time before they are able to acquire petrol using equipment. This is supported by published statistics that indicate that SSA has the highest proportion (65%) of slum dwellers in Africa (AfDB, 2012). The result of the negative impact of the degree of urbanization on petrol demand is in contrast with that unveiled by Mensah et al. (2016) who reported a positive link between petrol demand and urbanization in Ghana.

Also, a percent increase in industrial output increases petrol consumption by 0.16%, while population increases it by 1.12%. Since there is inadequate power supply in the region, most commercial and residential consumers rely on the use of power generating sets to alleviate the inadequacy in supply. The two main fuels used in fueling the generating sets are petrol and diesel. Another logical explanation for this result is that an increase in industrial output will result in more transportation services. Since most of the studied countries do not have an efficient public transport system in operation, they rely mostly on vehicles, vans, cars and trucks for transport and haulage. Therefore, an increase in industrial output will lead to an increase in petrol demand in SSA. The positive relationship found between population and petrol demand in this study is supported by one of the findings of Kebede et al. (2010), who found a positive relationship between population and traditional energy demand.

5. CONCLUSIONS

This paper presents a comprehensive analysis of energy consumption in SSA by estimating the main determinants of six energy types in 12 countries in the region, other than focusing on a single energy type or single country in SSA, as done in most previous studies in the empirical literature. The study examined the determinants of electricity, diesel, LPG, kerosene, biomass and petrol demand in SSA, using linear panel model techniques of fixed and RE. Our results indicate that income, the degree of urbanization, economic structure and population are significant factors driving electricity, diesel, LPG and petrol demand (consumption) in SSA. For kerosene: Income, urbanization and population are the key demand determinants. We also found that urbanization and population are the two main drivers of biomass consumption in the region.

For all the analyzed energy types, population has the highest elasticity. Therefore, it is the first main driver of energy consumption in SSA. Rising income increases the demand of all energy types in the region, except solid biomass. Therefore, governments and policymakers should ensure the availability of stable and reliable supply of energy to meet the growing demand.

Our findings appear to have important policy implications for a developing region such as SSA. First, SSA countries are on path of increasing population and rate of urbanization. To reduce the impact of increased energy use on the environment, a good energy efficiency policy must be put in place across the region. First and foremost, there is need for stringent energy conservation policies through effective energy efficiency practice, to ensure that the increase in energy use does not lead to more GHG emissions and that the electricity produced is well utilized. For instance, the government should ensure that appliances and gadgets sold to consumers comply with recommended energy efficiency standards by the relevant agencies. SSA countries can reduce their overall carbon emissions by investing in cleaner sources of power generation techniques using the vast renewable sources available across the region.

Second, as a long term plan towards sustainable energy supply, there is the need to promote regional integration and cooperation of energy supply to meet the need of consumers in SSA. The International Energy Agency (Africa Energy Outlook, 2014) suggested regional integration and cooperation of energy supply as one of the ways to provide the needed energy in SSA. Also, by investing in regional energy generation, SSA countries could benefit from economies of scale, lower investment costs and wider choice. The capital needed for the projects can be generated from both private and public sources, since consumers will demand for modern energy, if it is made available to them at reasonable prices. Similarly, availability of gas in every country through increased trade and construction of cross-country gas pipelines, may lead to generation of more power in the countries concerned, and also serve as a backup plan in situations where hydroelectric power stations are affected by drought, whilst also providing gas for residential and other sectors in the countries.

Third, oil and gas producing countries should use their supply to cater for domestic needs to improve economic conditions and export surplus when needed. This may be required for some years to increase energy supply, especially electricity and LPG to the required level. This approach may also be necessitated by the recent decline in global energy prices and increased global use of renewable energy, which may make export less attractive. This approach may also reduce the shortage of gas experienced in some power plants across the region, most notably in Nigeria. In the same way, governments should provide subsidies for poor households to make LPG more affordable to them and to reduce the use of solid biomass in the residential sector. Furthermore, in countries with proven oil and gas reserves, an appropriate and stable regulatory environment should be provided to encourage international and private investors to participate in timely commercialization of the fields.

Fourth, countries with fossil fuels should invest in their refineries to ensure reliable and affordable oil products for consumers. Considering the high costs associated with the importation of refined fuel, construction and maintenance of working refineries will reduce such costs and time. This may also require the construction of pipelines across the region to transport refined products to where it is needed in a timely manner.

Finally, to reduce high use of biomass in the residential sector, incentives should be provided for firms to develop affordable charcoal “improved stoves” to cater for low income earners in the countries. This will also reduce high rate of deforestation experienced across the region, time spent by girls and women in collecting firewood and associated respiratory infections caused by emissions in firewood use.

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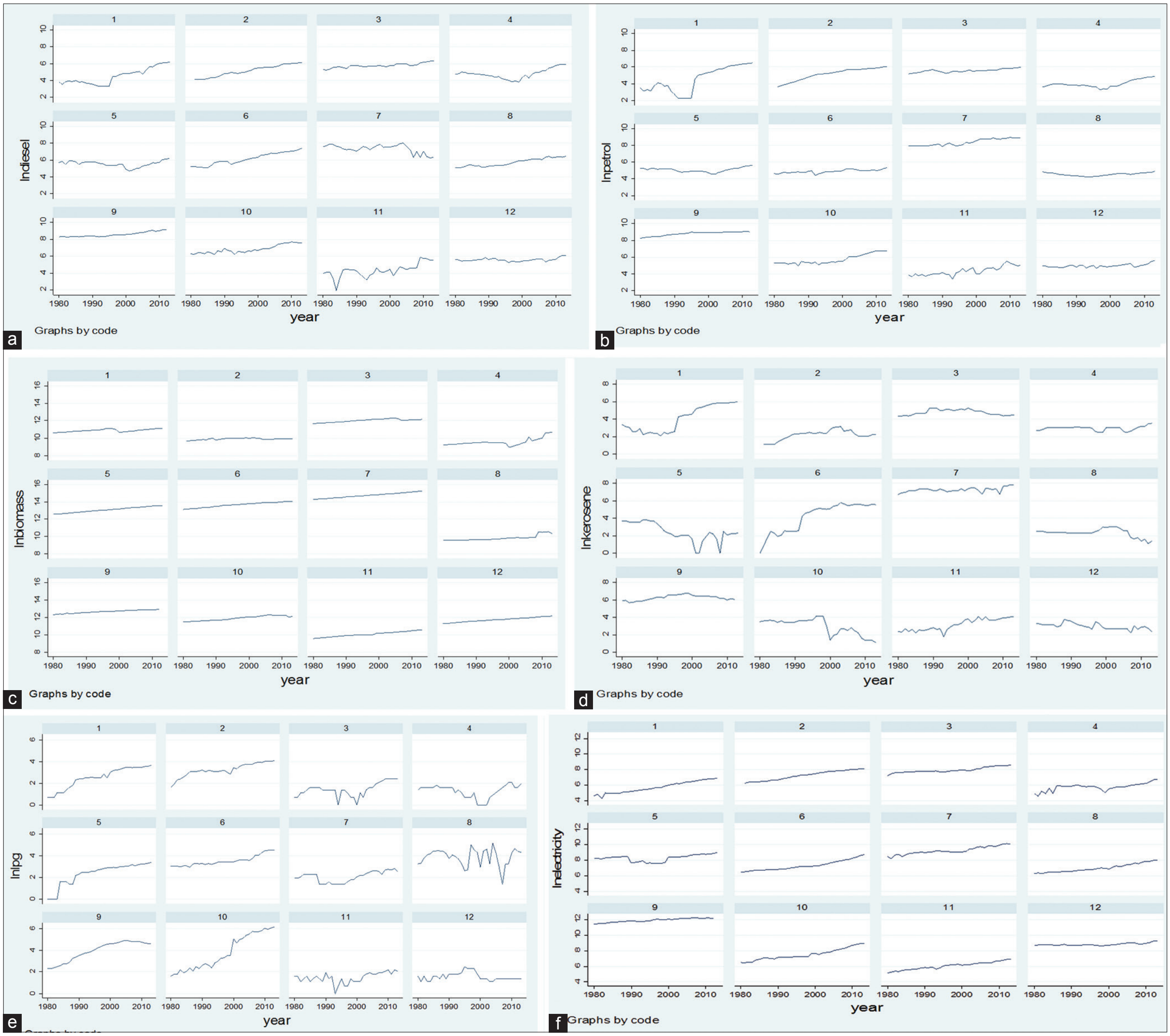
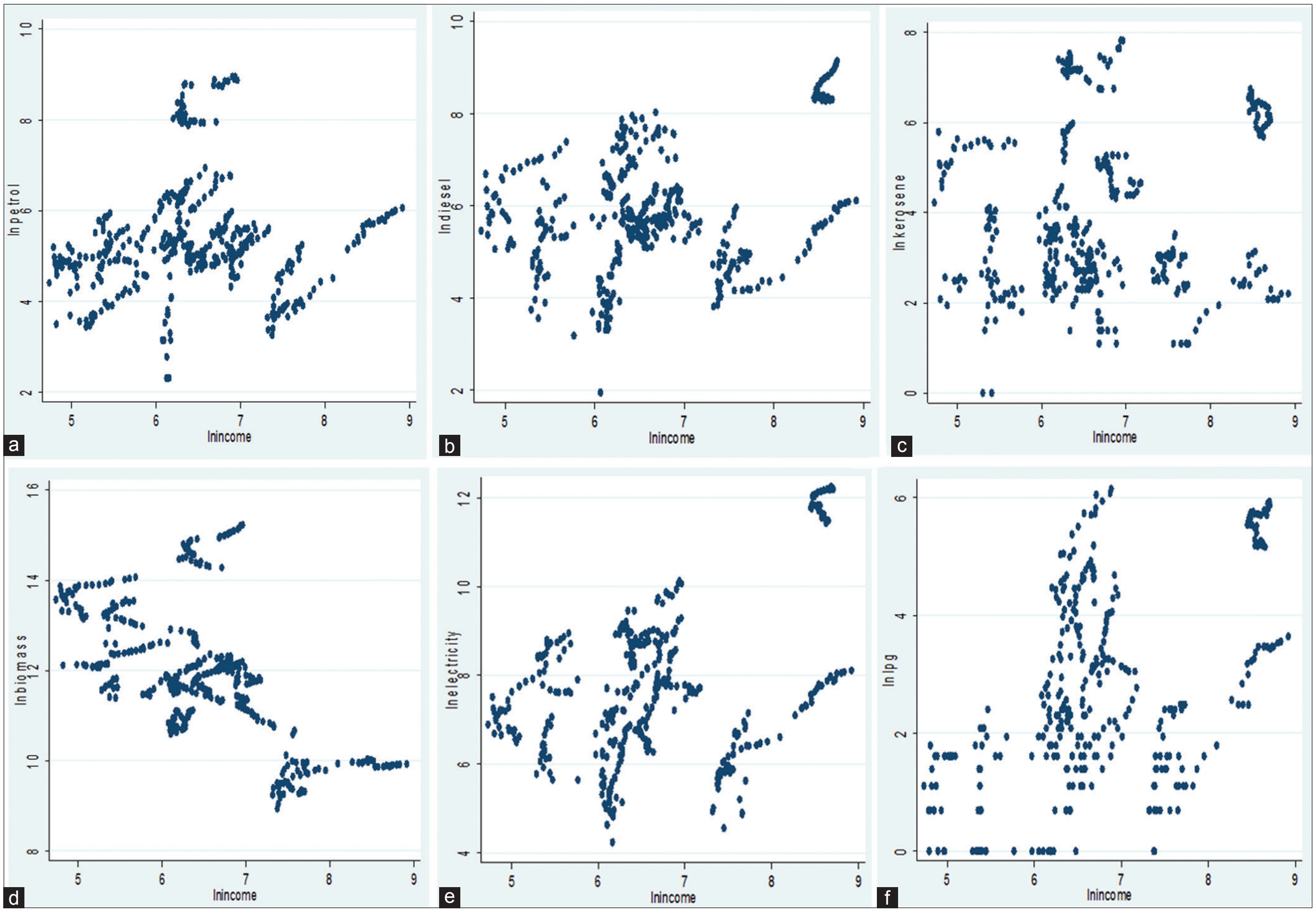
APPENDIX A

Appendix Figure 1: (a-f) Plots of energy consumption series for the analyzed energy types in Sub-Saharan African. 1-12 on the plots represent: Benin, Botswana, Cameroon, Congo, Democratic Republic of Congo, Ethiopia, Nigeria, Senegal, South Africa, Sudan, Togo and Zambia energy consumption data by type, respectively



Appendix Figure 2: (a-f) Scatter plots of energy consumption by energy type and income in Sub-Saharan African



APPENDIX B

Appendix Table 1: Correlation matrix of the variables in diesel demand model

	lnIncome	lnUrban	lnEconomy	lnPopulation	lnDiesel
LnIncome	1.00				
lnUrban	−0.30	1.00			
lnEconomy	0.33	0.11			
lnPopulation	−0.32	0.02	1.00	1.00	
lnDiesel	0.32	−0.25	−0.01	0.70	1.00

Appendix Table 2: Correlation matrix of the variables in petrol demand model

	lnIncome	lnUrban	lnEconomy	lnPopulation	lnPetrol
LnIncome	1.00				
lnUrban	−0.30	1.00			
lnEconomy	0.33	0.11	1.00		
lnPopulation	−0.32	0.02	−0.01	1.00	
lnPetrol	0.40	−0.18	0.18	0.64	1.00

Appendix Table 3: Correlation matrix of the variables in LPG demand model

	lnIncome	lnUrban	lnEconomy	lnPopulation	lnLPG
LnIncome	1.00				
lnUrban	−0.30	1.00			
lnEconomy	0.31	0.19	1.00		
lnPopulation	−0.31	0.05	−0.09	1.00	
lnLPG	0.48	−0.25	0.02	0.44	1.00

Appendix Table 4: Correlation matrix of the variables in electricity demand model

	lnIncome	lnUrban	lnEconomy	lnPopulation	lnElectricity
lnIncome	1.00				
lnUrban	−0.30	1.00			
lnEconomy	0.33	0.11	1.00		
lnPopulation	−0.32	0.02	−0.01	1.00	
lnElectricity	0.40	−0.33	0.09	0.62	1.00

Appendix Table 5: Correlation matrix of the variables in kerosene demand model

	lnIncome	lnPopulation	lnUrban	lnEconomy	lnKerosene
LnIncome	1.00				
lnPopulation	−0.32	1.00			
lnUrban	−0.30	0.02	1.00		
lnEconomy	0.33	−0.01	0.11	1.00	
lnKerosene	0.13	0.59	0.02	0.13	1.00