Electricity crisis and the effect of CO2 emissions on the infrastructure-growth nexus in Sub Saharan Africa

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Abstract

Sub Saharan Africa (SSA) has the greatest proportion of its population without access to electricity, especially those in rural communities. Efficiency of the power sector is another obstacle, characterised by rise in the ratio of electricity transmission and distribution (RETDL) and high levels of electricity-related CO2 emissions. We analyse the extent of electricity shortage, efficiency, key sources and opportunities for SSA in comparison with other regions. Two Stage Least Squares (2SLS) is used to examine the economic growth effects of electricity consumption (stock) and RETDL (quality), and how electricity-related CO2 emissions alter the growth contributions of both electricity consumption and RETDL. Our analysis indicate that SSA is mainly coal energy driven and coal has been the major cause of high levels of electricity-related CO2 emissions. The percentage of electricity from renewable sources (excluding hydro) is very low in SSA. However, the region presents a great opportunity from its abundant renewable resources that can be exploited. Furthermore, electricity consumption has a positive impact on economic growth whereas the RETDL exerts a negative pressure on growth. High levels

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of electricity-related CO2 emissions lower the growth contributions of electricity consumption and exacerbates the negative growth impact of electricity quality. Policy implications are discussed.

1 Introduction

Sub Saharan Africa (SSA) is a region of over 950 million people but also with the poorest access to electricity in the world (Avila *et al*, 2017). The World Development Indicators reveal that CO2 emissions from electricity and heat production (CO2EM), and the ratio of electricity transmission and distribution losses (RETDL) have been rising in SSA over the past decades, implying deterioration in efficiency of the power sector. Consequently, poor electricity access is believed to remain the key obstacle to most businesses and economic growth in several SSA countries (DIE, 2016), while potential threats from greenhouse gases is associated with substantial negative impact in SSA given persistent rise in CO2EM in the region (Gao and Zhang, 2014). CO2 emissions cause environmental problems and to mitigate their consequences, many nations have signed the Kyoto Protocol and pledged to lessen their emissions (Esso and Keho, 2016).

Recently, with increased focus on the Sustainable Development Goals (SDGs), studies on the impact of electricity consumption and CO2 emissions on economic growth remain vital to inspire energy policy and academic research. Interest in the potential nexus between electricity consumption, CO2 emissions and growth is traced back to the 1970s when scholars begun to notice the probable connection between these variables (Mezghani and Haddad, 2017). Several studies have empirically tested the environmental Kuznets curve (EKC) that hypothesizes environmental quality and economic growth nexus. The EKC suggests that environmental degradation initially increases and then declines as growth per capita continues to rise. Since then plenty of literature investigated the cointegration between electricity, CO2 emissions and growth (for example, Gao and Zhang, 2014; Asongu *et al*, 2015; Ahmad *et al*, 2016), and/or the direction of causality between these variables (for example, Cowan *et al*, 2014; Esso and Keho, 2016; Salahuddin *et al*, 2015).

Despite considerable amount of extant studies, firstly, accounting for electricity quality is still lacking and remains a serious gap in the empirical literature. Secondly, measuring both the nature and size of the influence of electricity-related CO2 emissions on the growth contribution of electricity stock (quantity) and quality is another angle that has not been properly interrogated in the literature. Given these gaps, we investigate the economic growth effects of both electricity stock and quality. While most existing research is on the direct impact of CO2 emissions on economic growth, to the best of our knowledge, we are unaware of studies that examine the nature and size of CO2EM's influence on the growth contribution of both electricity stock and quality. Electricity consumption per capita is used as a proxy for our stock variable while the RETDL is the quality variable. Addressing these major concerns in our view will help illuminate trajectories of energy policy in SSA, especially in the light of the serious shortage of electricity and high levels of CO2 emissions from electricity and heat production.

The rest of the study is organised as follows: Section two gives a brief literature survey. Section three provides an overview of the electricity shortage and efficiency in SSA. Section four presents our approach for the influence of electricity-related CO2 emissions on the growth contributions of electricity stock and quality. Section five discusses the key findings of the study. Finally, the conclusions and policy implications are provided in section six.

2 Brief review of literature

It is imperative to highlight briefly the Environmental Kuznets Curve (EKC) hypothesis that involves the connection between economic growth and environmental quality. We cannot go into detail since the validation of the EKC is not the concern of this study. The concept of the EKC emerged from the work of Grossman and Krueger (1991) on the environmental impacts of a North American Free Trade Agreement (NAFTA). The EKC was named after Kuznets (1955) who postulated an inverted U relationship between income inequality and economic development (see also Stern, 2003).

The EKC hypothesizes the relationship between growth in per capita income and environmental degradation which is believed to be inverted U-shaped. The notion behind this theory is that in the early stages of development when primary production is the key, there are plenty of natural resources and partial generation of waste due to less economic activity (Kaika and Zervas, 2013). As economic development progresses with industrilisation taking place, there is significant depletion of resources and accumulation of wastes. A positive link between growth per capita and environmental degradation occurs in this phase. However, based on this theory, further economic development is expected to overcome environmental degradation that took place in the initial stages of economic growth and hence producing an inverted U-shaped relationship between growth per capita and environmental degradation. In other words, at higher levels of economic development associated with enforcement of environmental regulations, environmental awareness, higher environmental expenditures and improved technology, environmental degradation declines (see Panayotou, 1993). The implication of the EKC hypothesis is that economic development is not a threat to global sustainability (Stern *et al*, 1996). In other words, if this inverted U-shaped curve holds, then instead of being an environmental risk (as claimed by environmentalists), economic development would be the means to ultimate environmental improvement (see Stern, 2004).

Since the inception of the EKC concept, quite a number of empirical studies have investigated the validity of this curve. While others (for instance, Pao and Tsai, 2010; Lau *et al*, 2014; Gao and Zhang, 2014; Farhani and Shahbaz, 2014; Bouznit and Pablo-Romero, 2016; Al-Mulali *et al*, 2016) found the validity of this hypothesis, some (for instance, Stern *et al*, 1996; Vincent, 1997; Coondoo and Dinda, 2008; Ozturk and Al-Mulali, 2015; Lacheheb *et al*, 2015) did not find evidence for the inverted U-shaped relationship between pollutants and income.

Electricity and heat production being among the key sources of CO2 emissions, a body of empirical studies investigated the relationships between electricity, CO2 emissions and growth. Among the recent literature, using the autoregressive distributed lag model and vector error correction model, Ahmad *et al.* (2016) revealed the existence of a long-run cointegrating relationship between energy consumption, CO2 emissions and economic growth, and the validation of the Kuznets curve. Moreover, they found feedback effects between CO2 emissions and growth, and positive nexus between energy and CO2 emissions. Salahuddin *et al.* (2015) examined the link between CO2 emissions, electricity consumption, economic growth and financial development in the Gulf Cooperation Council (GCC). Their results suggested that economic growth and electricity consumption are positively related with CO2 emissions while financial development negatively impact CO2 emissions. They also found evidence for causality from electricity to CO2 emissions, and a two-way causality link between growth and CO2 emissions.

In Saudi Arabia, Mezghani and Haddad (2017) found that huge volatility of electricity consumption tend to have negative impacts on oil GDP and CO2 emissions while it positively impact the non-oil GDP. Additionally, low and high volatility of oil GDP were found to have positive effects on CO2 emissions and electricity consumption. More so, the results of Apergis and Payne (2010) suggested a positive relationship between energy consumption and CO2 emissions, with output showing the EKC hypothesis in the long-run. This includes a one way causal relationship from electricity consumption to real output. Kim and Baek (2011) demonstrated that a rise in energy consumption can damage environment in the long-run. Analysing the Turkish power sector, Atilgan and Azapagic's (2016) findings indicated that fossil fuels are accountable for roughly 88-99.9% of environmental effect related to electricity generation. From economic assessment, their results suggested capital costs of US$69.3billion for 49524 MW of installed capacity in 2010, by which hydro, coal and gas contributed 43%, 31% and 22%, respectively.

Cowan *et al.* (2014) investigated the connection between CO2 emissions, electricity consumption and growth in the BRICS economies. In terms of electricity-growth relationship, they found evidence for the conservation hypothesis in South Africa, feedback hypothesis in Russia and neutral hypothesis in India, China and Brazil. For the CO2 emissions-GDP connection, mixed outcomes were shown, that is, GDP to CO2 emissions (South Africa), CO2 emissions to GDP (Brazil), feedback hypothesis (Russia) and no Granger causality (China and India). In the African context, Bouznit and Pablo-Romero (2016) confirmed the validity of the EKC in Algeria, however, with a turning point attained for a very high growth per capita so that growth continues to increase emissions. Furthermore, there was evidence of increased electricity consumption raising CO2 emissions. The inverted U-shaped hypothesis was also documented in Kais and Sami's (2016) work. In a number of SSA countries, Esso and Keho (2016) found power consumption and growth to be associated with rise in pollution in the long-run.

Based on 30 Chinese provinces, an analysis by Ding and Li (2017) suggested that economic development factors are the greatest drivers for regional emissions compared to structural change factors, energy intensity and social transition. Moreover, urbanisation was found to contribute to emissions via changes in energy use characteristics of business sectors, transportation and urban households, among other factors. Rue du Can *et al.* (2015) indicated that when allocating CO2 emissions based on end-user sectors, the share of buildings sector rises the most from 9% (direct emissions alone) to 31% (including indirect emissions), showing the great share of electricity and heat utilised by this sector.

Finding suitable strategies to reduce CO2 emissions is another key issue. Li *et al.* (2014) found carbon pricing to be an effective measure for lowering CO2 emissions in China, in which the reduction ranges from 6.8% to 11.2% in the short-run. They also mentioned that in the long and mid-term, the effective policy is to target carbon revenue with competitive price of electricity. Wu *et al.* (2016) demonstrated that amending the structure of energy to utilize renewable energy and recycling solid waste can substantially lower CO2 emissions.

3 Overview of electricity shortage and efficiency

3.1 *Electricity shortage*

Among the infrastructure problems, the shortage of electricity is a major hindrance to businesses and household welfare in SSA. Irrespective of considerable rise in the population with access to electricity in SSA, approximately 530 million persons remain without electricity in 2014, very far from the desirable progress (IEA, 2014). Given the data available to us, we use the percentage of people with access to electricity as a proxy for any region's electricity supply. On the demand side, we assume that the total population of a region is the proxy for electricity demand. Consequently, the population without access to electricity represent the supply gap.

It is clear from Figure 1 that since the 1990s the majority of the population in SSA remain without access to electricity. Roughly 77% of the total population had no access to electricity in 1990, this percentage slightly fell to approximately 65% in 2012. The bigger proportion of those without access to electricity are in rural areas, which slightly decreases from 92% of rural population in 1990 to 85% in 2012. Approximately 28% of urban population also remained with no electricity in 2012.

Compared with other regions, SSA has the lowest percentage of total population with access to electricity as indicted on Figures 2 - 4. The same applies in terms of electricity power consumption (kWh per capita). The statistics also indicated that SSA's electricity performance is below the middle income group and the world average.

3.2 *Electricity efficiency*

The problem of electricity is aggravated by poor quality in the production and provision of electricity as demonstrated by the high ratio of electricity transmission and distribution losses, which tend to exert negative pressure on economic growth (see Calderon, 2009; Chakamera and Alagidede, 2017). More so, CO2 emissions from electricity and heat production can be problematic to SSA's potential growth. As depicted in Figure 6, SSA recorded higher ETDL than MENA in 1971 and 1980 but the losses fell slightly below the MENA levels in the subsequent years. However, ETDL in SSA have been better than those experienced by Latin America and Caribbean, and South Asia. Also in the past five decades, SSA's ETDL stay below the low income benchmark while it rose above the middle income level as from 2010. The Euro area, followed by North America have minimal ETDL.

In Figure 7, SSA remains on top of all other regions in terms of CO2 emissions from electricity and heat production since 1971. This is as a percentage of total fuel combustion. Thus, SSA experiences relatively high CO2 emissions than other regions despite consuming relatively small kWh per capita as indicated by Figure 5. Most of the CO2 emissions are from solid fuels (see Figure 10) especially coal consumption.

When it comes to key power sources, the World Development Indicators (WDI) show that coal has always been the major source of electricity production in SSA though its contribution slightly decreases from 67% in 1971 to 54% in 2013. The second main source is hydro whose proportion of total electricity increased between 1971 and 2013. Electricity generated from oil and gas sources is in smaller proportions. As indicated by the WDI, SSA has very small percentage of electricity from renewable sources. This proportion is even worse in MENA, which has greater proportions electricity from gas and oil.

4 The influence of CO2 emissions on electricity growth contribution

This section examines the economic growth contribution of electricity infrastructure (quantity and quality) in SSA while accounting for CO2 emissions from electricity and heat production. The fundamental idea is to reveal the nature and magnitudes of CO2 emissions' influence on electricity growth contribution. First, we formulate an electricity-related CO2 emission index which takes 1990 as the base year and then traces the changes in CO2 emissions in the subsequent years. Second, the CO2 emission index is used to develop two more indices, namely, the modified electricity consumption (MELEC) and the modified RETDL (MRETDL). The two new indices are the stock and quality measures of electricity after accounting for CO2 emissions through multiplication of the stock and quality indices by the CO2 index. MRETDL can be interpreted as a measure of a country's effectiveness and efficiency in the provision of electricity by checking both the electricity-related CO2 emissions and distribution losses experienced. *We assume that CO2 emissions may have additive effect on electricity contribution when huge power consumption generates enormous economic returns enough to counter the negative externalities of emissions, otherwise the electricity growth effect is supressed.*

4.1 *Data issues*

The World Bank Group is the source of the data used in this study, particularly from the World Development Indicators (WDI). The data is for 18 SSA countries over the period 1990-2013[1]. The selection of countries is purely based on data availability for both the time frame in question and the variables of interest. Our electricity stock and quality variables are represented by *electric power consumption (kWh per capita)* and *electric power transmission and distribution losses (% of output)*, respectively. We are interested in *CO2 emissions from electricity and heat production, total (% of total fuel combustion)* as the third focus variable. The dependent variable is *gross domestic product (GDP) per capita (current US$)*. In terms of control variables, this study considers (i) *Domestic credit to private sector (% of GDP)* as proxy for financial depth, (ii) *Inflation, consumer prices (annual %)* as proxy for price stability, and (iii) *Trade (% of GDP)* as a proxy for trade openness. *Urban population (% of total)* is also obtained and used as an instrumental variable in 2SLS. All these are from WDI. We also include a *coastal dummy* (i.e. 1 if a country is not landlocked and 0 otherwise) as a fourth control variable. This is based on the possibility that coastal countries may have an advantage in terms of infrastructure gains.

4.2 *Model and Identification*

To examine the relationship between electricity and growth while accounting for the electricity-related CO2 emissions, we consider the following empirical model:

$$Ingdp_{it} = \alpha_i + \beta_{it} Inelectricty_{it} + \phi'_{it} InZ_{it} + \gamma_t + \varepsilon_{it} \tag{1}$$

(i) *electricity* = ELEC

(ii) *electricty* = RETDL

(iii) *electricity* = MELEC

(iv) *electricity* = MRETDL

where all variables are in natural logarithms (In); based on equation (1), different models are estimated by changing only the electricity variable, that

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[1] Angola, Cameroon, Congo Republic, Cote d'Ivoire, DRC, Ethiopia, Gabon, Ghana, Kenya, Mauritius, Mozambique, Nigeria, Senegal, South Africa, Tanzania, Togo, Zambia, and Zimbabwe.

is, electricity stock (represented by electricity consumption - ELEC, electricity quality (represented by ratio of electricity transmission and distribution losses - RETDL), modified ELEC (MELEC) and the modified RETDL (MRETDL). Note that MELEC and MRETDL are electricity stock and quality measures that accounts for CO_2 emissions. Z is a set of control variables, ε is the disturbance term, and the parameters α, γ stand for intercept and trend included in the models.

Identification problem may arise due to potential endogeneity between electricity infrastructure and economic growth. Infrastructure may also be correlated with other growth determinants and subject to reverse causality. A suitable identification technique is required. Therefore, to overcome this problem we apply the two stage least squares (2SLS) technique, which allows for the use of instrumental variables (see also Wan and Zhang, 2017). Ideally, the instruments will be correlated with the endogenous variable but not correlated with the disturbance terms. However, caution should be taken when applying this approach for weak instruments may affect the estimates. To ensure the validity of our instruments we perform weak instrument test across all models.

4.3 *Cross-section dependence (CD) test*

It is plausible to perform CD test prior to unit root testing because the ’first generation’ unit root tests such as Levin, Lin and Chu (2002), Hadri (2000) and others that assume cross-section independence can produce biased estimates when dependency exist among cross sections (see Cerasa, 2008). Moreover, cross-section dependence may suggest key policy implications vital for decision making at both national and regional levels. It becomes crucial to consider external factors when the regional countries show dependency amongst themselves, and this buttress certain policies being made at the regional level.

In the view of the above, we run cross section dependence test developed by Pesaran (2004). This CD approach is presented as follows:

$$CD\sqrt{\frac{2T}{N(N-1)}\sum_{i=1}^{N-1}\sum_{j=1+1}^{N}\hat{\rho}_{ij}} \tag{2}$$

where $CD \approx N(0,1)$ with T large and $N \to \infty$ under the null hypothesis of no cross-sectional dependence. Consequently, Pesaran’s CD test overcomes the problem of the LM test (an alternative CD test by Breusch and Pagan, 1980), which shows considerable biases when N is large and T is small. Nevertheless, when T is finite the regular central limit theorems cannot be used in the derivation of the CD statistics (Pesaran, 2012). As a result, to handle this obstacle the CD statistic can be written as:

$$CD_{NT}\sqrt{\frac{2}{N(N-1)}\sum_{i=1}^{N-1}\sum_{j=1+1}^{N}\sqrt{T}\hat{\rho}_{ij}} \tag{3}$$

where $\rho_{ij} = T^{-1}\Sigma_{=1}^{T}\zeta_{ii}\zeta_{jt}$ are the scaled residuals.

The presence of cross-section dependence necessitates the use of Pesaran's CIPS unit root test which accounts for cross-sectional dependency.

4.4 *Pesaran CIPS unit root test*

This approach is vital for a number of reasons. Unlike the 'first generation' unit root tests, the CIPS accounts for cross section dependence. Moreover, the 'first generation' unit root approaches may tend to over-reject the null hypothesis of a unit root in the presence of cross-section dependence (see Burret *et al*, 2014). Additionally, several studies reached a conclusion that panel data usually exhibit substantial cross-section dependence in the disturbances due to manifestation of unobserved components and common shocks that make part of disturbance terms (De Hoyos and Sarafidis, 2006).

This method by Pesaran (2007) arguments the standard Augmented Dickey Fuller (ADF) regressions with the cross-section averages of first differences and levels of individual series. It transforms the regular unit root based on the simple averages of the individual cross-sectionally ADF statistics (CADF). The CADF may further be used to have advanced versions of the t-bar tests proposed by Im, Pesaran and Shin (IPS). Cross-sectionally augmented IPS (CIPS) test is therefore presented as follows:

$$CIPS = N^{-1}\sum_{i=1}^{N} CADF_i \tag{4}$$

Subsequently, the CIPS test is fundamentally the simple averages of the individual CADF statistics.

4.5 *Two Stage Least Squares (2SLS)*

Following Bun and Windmeijer (2011), we begin by providing the basic notion behind the 2SLS, which is based on instrumental variables (IV). Assume a model with one endogenous regressor (x_i) and j instruments (z):

$$y_i = \beta_i x_i + \varepsilon_i \tag{5}$$

$$x_i = \beta_i' z_i + \varepsilon_i \tag{6}$$

A 2SLS estimator of β is estimated as follows:

$$2sls\hat{\beta} = \frac{x'Z(Z'Z)^{-1}Z'y}{x'Z(Z'Z)^{-1}Z'x} = \beta + \frac{x'Z(Z'Z)^{-1}Z'\varepsilon}{x'Z(Z'Z)^{-1}Z'x} \tag{7}$$

where x is a vector $(x_{1,\ldots,}x_n)$', y is a vector $(y_1, \ldots y_n)$' and ε is a vector $(\varepsilon_{1,}, \ldots, \varepsilon_n)$.

In this study, electricity is the endogenous regressor and principal variable in equation (1). In order to handle the endogeneity problem, the 2SLS approach first regresses electricity (endogeneity variable) on all explanatory variables in equation (1) (i.e. Z) and on the probable instrumental variables excluded from equation (1). We consider lagged values of urban population (% of total) as an instrument for the electricity infrastructure. Lagged values of this instrument are found in this study to be relatively robust compared to the current values. The use of demographic indicators as external instruments for infrastructure variables is also found in other studies such as Calderon (2009) and Calderon and Serven, 2010[2]. They considered current and lagged values of population density and urban population. Their application of demographic measures was also motivated by other scholars (for example, Canning, 1998; Roller and Waverman, 2001) who demonstrated that much of the variations in infrastructure quantities are described by demographic factors, including urbanization and population density. Among other studies, Karanfil and Li (2014) found urbanization to be a key factor of electricity consumption. To ensure that our estimations are not contaminated by poor instruments, we perform weak instrument test. Having discussed the instrumental issue, the first stage model is as follows:

$$\ln electr_{it} = \lambda_0 + \lambda_1 \ln ubnpop_{it} + \lambda_{it}' \ln Z_{it} + e_{it} \tag{8}$$

where $ubnpop_{it}$ denotes urban population (% of total). In the second stage, the following regression model is estimated:

$$Ingdp_{it} = \alpha_i + \beta_{it}\hat{E}_{it} + \phi_{it}' \ln Z_{it} + \gamma_t + v_{it} \tag{9}$$

where $\hat{E}$ denotes the fitted values from the first stage regression model and $v \equiv \{\varepsilon + \beta(electricity-)\}$ (see also Angrist and Imbens, 1995). The

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[2] The chosen instrument(s) should pass weak instrument test because weak instruments cause the 2SLS estimator to be inconsistent with large standard errors.

2SLS thus can be viewed as an instrumental variable (IV) estimator where instruments are Z and $\hat{E}$.

5 Key findings and discussion

5.1 ***Summary regarding extent of energy crisis, efficiency*** **and** ***key sources***

Analysing the WDIs, the population without access to electricity slightly declines from roughly 77% in 1990 to 65% in 2012. The majority of those with no access to electricity are the rural folks, approximately 85% of rural population in 2012. We also observe that SSA has the lowest access to electricity in comparison to other regions. For instance, only 35% of total population in SSA had access to electricity in 2012 while the MENA had 96% in the same year. In terms of electricity consumption in 2013, it was roughly 488kWh per capita, far less than 2880kWh in MENA[3].

In the area of efficiency, electricity power transmission and distribution losses (% of output) have generally been rising in SSA over the past decades. Compared to other regions, SSA is not the one with the highest distribution losses; it has been below South Asia and Latin America and Caribbean from 1971 and below the MENA since the 1990s. In addition, since the 1970s SSA has experienced higher levels of CO2 emissions from electricity and heat production (% of total fuel combustion) than all other regions. Solid fuel consumption has been the major cause of these emissions. The WDI show that in MENA greater proportions of CO2 emissions are from gas and liquid fuels.

As for the sources of electricity, coal has been the major source of electricity production in SSA. South Africa has the most coal reserves and solely a SSA country with active nuclear power plants. While the MENA region is less dependent on coal, its electricity is mainly from natural gas and oil sources. More so, SSA has greater hydro electricity production than MENA. Proportion of hydropower in MENA fell substantially since 1971 (when it was above SSA level) as the region increased its focus on oil and gas sources. Electricity production from renewable sources (excluding hydro) is still very low in SSA, and it is even lowest in MENA.

This analysis reveals the extreme shortage of electricity in SSA, the poor efficiency associated with electricity transmission and distribution losses and

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[3] In this section we restrict our comparison to just SSA versus MENA given other African countries within the MENA group.

highest levels of CO2 emissions from energy and heat production. The challenges to SSA's electricity development include financing, technical issues and policy mechanisms to advance electricity sector (Avila *et al*, 2017). The authors attributed high transmission and distribution losses to lack of systematic planning for the energy sector. Additionally, other factors such as unreliable rainfall patterns and extended droughts can adversely affect hydropower, leading to more outages. There has been an involvement of independent power producers (IPP) in SSA to help solve the electricity problem. Involvement of the Chinese oil companies in African power sector has been expanding, however, China is not side-lining Western or United States firms or taking over African power sector as popularly portrayed in media (Cooke and Goldwyn, 2015). Cooke and others also maintain that the African continent is an attractive destination in terms of gas and oil investments due to factors such as proximity to the Asian market and being still underdeveloped.

5.2 *Electricity-growth relationship and the influence of CO2 emissions*

5.2.1 *Summary statistics*

Table 1 displays the descriptive statistics for the data. All variables are in natural logarithms. Even though our variables show evidence of skewness, all focus variables, which are logarithms of gross domestic product per capita (L.GDP), electricity consumption (L.ELEC), ratio of electricity transmission and distribution losses (L.RETDL) and CO2 emission index (L.CO2INDEX) have kurtosis less than the threshold of 3. Consequently, these variables are not fat tailed. On the contrary, logarithms of inflation (L.INFL), trade openness (L.TRA) and financial depth (L.FDEP), which are control variables are fat tailed. Excess kurtosis and skewness violate the normality assumption of the data process and may lead to biased estimates especially when the standard OLS technique is used. However, our 2SLS estimator based on the instrumental variable approach overcomes potential problems that may emanate from non-normality. The table also presents the average, standard deviations, maximum and minimum values of the variables. The inflation variable has the highest maximum value indicating that some representative economies recorded extreme levels of inflation in certain periods.

5.2.2 *Cross-section dependence*

Pesaran's CD test results are indicated in Table 2. Except for logs of electricity quality variables (L.RETDL and L.MRETDL) and the L.CO2INDEX, the

CD statistics for the rest of the variables are statistically significant at the 1% level and hence the null hypothesis of cross-section independence is rejected in terms of the variables in question. From a policy perspective, cross-section dependence implies that changes in the variable of interest in one country will affect a similar variable in other regional states. For instance, when electricity consumption (or GDP) increases in South Africa, the consumption of electricity (or GDP) in other countries within SSA is affected as well. This could give credence to the idea of having certain policies for electricity (or economic growth) advancement to be taken at the regional level than individual states. Furthermore, cross-section dependence of electricity consumption might represent implied spillovers from this infrastructure among regional countries. Thus, the representative countries tend to gain from each other's development. However, on the downside, it shows that negative shocks can be easily passed among the regional countries. For instance, electricity infrastructure crisis in one country can affect electricity consumption in other countries especially if the affected economy has been an exporter of electricity to the neighbouring countries. Policy wise, it is imperative to consider this cross-section dependence when formulating domestic policies to account for potential external influences.

Econometrically, strong evidence of dependency among SSA countries for a number of variables entails the importance of applying 'second generation' kind of unit root tests that account for cross-section dependence. In this case, Pesaran's CIPS unit root test is implemented as one of the 'second generation' unit root tests.

5.2.3 *Unit root*

Table 3 exhibits the unit root results based on Pesaran (2007) CIPS test, which is robust and plausible in sight of dependency among cross-sections. We consider both estimations with constant only and constant plus trend in order to exploit potential hidden data features. Consequently, comparisons are made and decide on the models that best fit the data.

It is clear that across all tests (both constant and constant plus trend), most variables (L.FDP, L.ELEC, L.MELEC, L.CO2INDEX, L.UBNPOP, L.TRA and L.INF) are stationary in level except for L.RETDL, L.MRETDL and L.TRA. However, the CIPS test with constant only also suggests that L.TRA is stationary in level. As it is important to work with stationary variables in regressions, we ensure stationary variables are applied in our estimations. Working with stationary variables avoids the likelihood of producing spurious results.

5.2.4 *Electricity growth effects*

In Table 4, electricity stock measures (i.e. L.ELEC and L.MELEC) are the instrumented variables, the instrument is the lagged log of urban population as a percentage of total population (L.UBNPOP) as discussed fully in the previous section. We do the same in Table 5 but in this case, electricity quality measures (i.e. L.RETDL and L.MRETDL) are the instrumented variables. Our choice of this demographic factor as an instrument to our stock and quality measures of electricity infrastructure is not random. We have tried a number of population variables that include total population, population density and urban population growth rate but found L.UBNPOP to be plausible from both the size of correlation with electricity measures and its performance in the regressions. For preliminary checks, the correlation coefficients between L.UBNPOP versus L.ELEC, L.MELEC, L.RETDL and L.MRETDL are 0.62, 0.63, -0.50 & -0.48, respectively. The positive correlations implies that electricity consumption tend to increase as the percentage of urban population increases. The negative correlations entail that the ratio of electricity transmission and distribution losses tend to decline as the population increasingly become urbanised. This might be as a result of short distributional distances, contrary to a sparsely population region or country, thus, urbanisation assist in overcoming geographical obstacles.

L.UBNPOP thus enters in the first stage of each regression. As discussed in section 4.5, the fitted values from the first stage regression automatically appear in the final regression model and hence instrumenting the endogenous variable (electricity measure). Using a similar instrument in these related models ensures that the changes in growth effects are restricted to: (i) the infrastructure variable (i.e. stock or quality) and (ii) the influence of CO2 emissions on electricity impact.

We consider a just-identified model, that is, single endogenous variable and single instrument. In terms of specification tests for a just-identified model, the success of an instrumental variable approach (IV) demands answering two key questions: (i) are the variables endogenous and (ii) are the instruments weak or not? Across all the models (Tables 4 and 5), both the Durbin Chi2 and Wu-Hausaman statistics are highly significant and hence rejecting the null hypothesis that the variables are exogenous. As a result we are correct to treat electricity infrastructure measures as endogenous. Moreover, the F-statistics across all models are significant and hence rejecting the null hypothesis of weak instruments. Consequently, the problem of weak instruments does not affect our estimates. We therefore proceed to discuss the electricity growth impact results.

5.2.5 Stock effects

Table 4 presents the major findings on the growth effects of electricity stock, along with specification tests. As discussed in the previous sub-section, our specification tests suggest that the models are adequate. Electricity stock is represented by the electricity consumption per capita. Model 1 (that includes only the constant) and Model 3 (for constant plus trend) focus on the growth contribution of electricity consumption in SSA before accounting for CO2 emissions from electricity sector. To achieve the key objective of this paper, we further examine the influence of CO2 emissions on the economic growth impact of electricity consumption, which is demonstrated in models 2 and 4, including constant only and constant plus trend, respectively.

A number of striking findings are shown in Table 4. First, all electricity infrastructure variables have the expected sign and significant at the 1% level. Thus, the positive impact of electricity on growth remains even after controlling for CO2 emissions from electricity and heat production. Based on the results from the two cases, the growth contribution of electricity consumption is in the rank between 0.68% and 0.79%. The positive impact of electricity consumption on economic growth confirms the results of other previous studies (for instance, Akinlo, 2008; Arouri *et al*, 2014) that examined African economies. The results reveal the importance of energy use in production processes; it enhances the efficiency of production inputs (see Jumbe, 2004). Electricity also complements other public infrastructures such as telecommunication, transportation, health and education.

Second, the growth effects of electricity consumption decline when CO2 emissions are accounted for as presented by the coefficients of L.MELEC being smaller than those of L.ELEC. Being initially in the range 0.74 % (Case 2) - 0.79% (Case 1), the contribution falls to somewhere between 0.68% (Case 2) and 0.72% (Case 1) after accounting for the CO2 emissions. Consequently, CO2 emissions reduce the growth contribution of electricity stock by roughly between 0.06% and 0.07%. It implies that electricity-related CO2 emissions can adversely affect the effective growth impact of the current electricity consumption in SSA. The relationship between electricity stock and economic growth, thus, should also be analysed thoughtfully with environmental effects in mind. The CO2 emissions from electricity add to excess CO2 which become pollutants with adverse effects on environment, including negative impact on water, health and agricultural production (Ahmad *et al*, 2016). As long-term consequences, CO2 emissions released to the atmosphere lead to ocean acidification, ozone layer depletion, global warming, climate change and altering plant growth. As a result, the costs that are associated with rising CO2 emissions from electricity production can exert negative pressure on GDP growth by impeding the potential growth effect of electricity consumption.

Third, the models that account for CO2 emissions (i.e. Model 2 & 4) have lower standard errors (SE) for the individual coefficients, together with higher R^2 and lower Root MSE than those that do not capture emissions (Model 1 & 3)[4] . The comparison here is made for Model 1 versus Model 2 and Model 3 versus Model 4. Furthermore, for the first stage regression statistics, Models 2 and 4 have higher Partial R^2 than their counterparts (Models 1 & 3). Partial R^2 measures the correlation between the endogenous variable (electricity measure) and the instrument (L.UBNPOP) after restricted the effects the exogenous independent variables. We therefore conclude that accounting for CO2 emissions in the electricity stock - growth nexus improves our models.

Fourth, the models that include both constant and trend (Models 3 & 4) have most of their individual coefficients with lower SE, higher R^2 and lower Root MSE than the equivalent models 1 & 2. In this case, models 4 and 2 are compared against each other while Model 3 is versus Model 1. The conclusion is that the models that include both constant and trend (Case 2) tend to have the best fit. We are right therefore to include deterministic trend, which improves our estimations. The results of the control variables in Tables 4 and 5 are almost similar and we discuss these at once after discussing the quality effects in the next section.

5.2.6 Quality effects

Table 5 presents the impact of electricity quality before accounting for CO2 emissions and after controlling for emissions. All the models pass specification test as previously discussed. A number of key results are shown in Table 5.

First, our electricity quality measures (L.RETDL and L.MRETDL) have negative and significant coefficients. A percentage increase in the ratio of electricity transmission and distribution losses reduces economic growth in the range between -0.57% and -0.65%. Consequently, deterioration in the quality of electricity in most SSA states is adversely affecting growth per capita. The implied negative growth effects from electricity quality in SSA were also demonstrated by Chakamera and Alagidede (2017) (see also Calderon, 2009). Electricity transmission and distribution losses (ETDL) are among the factors that lower electricity access in SSA. Poloamina and Umoh (2013) mention that ETDL do not only lessen power consumption but also lead to

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[4] Root MSE shows the standard error for the estimated model.

loss of revenue in SSA. Avila *et al.* (2017) asserts that the system losses in SSA comprise of technical losses from weakly maintained transmission and distribution networks, including commercial losses from poor revenue collection. Another explanation is that Africa is dominated by costly small-scale power systems that lead to greater transmission and distribution costs, mostly from power losses (Castellano *et al*, 2015). Small power plants lack necessary economies of scale in the production, transmission and distribution of electricity (see AfDB, 2013).

Second, the negative growth effects of electricity quality are intensified once the CO2 emissions are taken into consideration. The negative effects may increase to reach approximately -0.65%. It implies that CO2 emissions from electricity production further hinder the electricity quality growth effects. This is expected given the adverse effects of CO2 emissions we have previously noticed. Therefore, combining the negative effects of electricity distribution losses and CO2 emissions can worsen the negative pressure on GDP growth.

Third, unlike the electricity stock regressions, the models that do not account for CO2 emissions (Models 5 & 7) have lower SE for individual coefficients as well as higher R^2 and lower Root MSE than their counterparts that account for CO2 emissions (Models 6 & 8). Note that we compare models 5 versus 6, and 7 versus 8. Fourth, like the stock models, the quality models that include constant and trend (Models 7 & 8) have relatively small SE for individual coefficients, together with higher R^2 and small Root MSE than their counterparts that excludes deterministic trend (Models 5 & 6). In this case, comparisons are made for models 5 versus 7 and then models 6 versus 8. We reach the final conclusion that including deterministic trend tend to improve our model fit as suggested by rise in R^2 and decrease in standard errors.

Based on the results across all models (both Tables 4 & 5), an increase in inflation levels reduces economic growth (roughly in the range between -0.19% and -0.36%) in SSA as theoretically expected. The negative coefficient of inflation confirms the commonly accepted hypothesis that inflation is harmful to economic growth and is largely consistent with the literature (see Baharumshah *et al*, 2016). This is one of the reasons why inflation targeting has become a key monetary policy regime as most countries are cautious of the detrimental effects of price instability on economic activity and ultimately economic growth. Zimbabwe is one of the SSA states that experienced world records of inflation levels in 2008 that had pushed the country into de facto dollarization. Nguyen *et al.* (2017) demonstrated that exchange rate, monetary variable shocks and domestic supply shocks have been the core drivers of inflation in SSA in the past 25 years but their impact has declined recently. Nevertheless, demand pressure and global shocks have become the key inflation drivers in the past decade.

Moreover, the trade openness coefficients for all quality models are positive (in the range between 0.34% and 0.42%) and highly significant but those for stock models are not significant. Thus, in line with conventional wisdom, there exist a growth enhancing effect of trade openness in SSA countries since 1990. Trade liberation has been facilitated by both integration and specialisation. Various regional communities in Africa (for example, SADC, ECOWAS, COMESA, ECCAS, EAC, among others) play an essential role in the process of integration among member states, with trade agreements being among the key components of these regional blocs[5]. SSA countries heavily specialise in primary commodities such as mineral and agricultural products that are exported mostly to Europe, and also facilitated through various multilateral and bilateral trade agreements. However, the connection between trade openness and growth may not be linear in SSA as demonstrated in Zahonogo's (2017) recent work[6].

Financial depth coefficients across all models are negative and four out of eight models are significant at the 1% level. The level of financial development in SSA implies negative growth effects. This observation was also observed by Chakamera and Alagidede (2017) in a Generalized Method of Moments framework (see also Gries *et al*, 2009; Kodongo and Ojah, 2016). Possibly a good ratio of the credit provided especially to individuals (mainly as unsecured personal loans) is used to finance consumption instead of investment (Kodongo and Ojah, 2016). Financial and banking systems of SSA are essentially fragile and hence cannot effectively ensure a sound allocation of investment funds. The absence of efficient and deep financial markets hinders both economic growth and poverty alleviation in SSA (Gulde *et al*, 2006).

Another concern is that coastal countries may have an advantage in terms of infrastructure gains as compared to landlocked countries. Coastal dummy have positive impact on growth per capita (see also Ran, 2005). Coastal economies may yield greater benefits from their superior access to transportation network with the external markets than the inland economies. The trend coefficients are not only significant but also improve our models. Finally, the constants have high positive and significant coefficients, which may suggest growth effects explained by other factors (e.g. total factor produc-

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[5] SADC stands for Southern African Development Community. COMESA stands for Common Market for Eastern and Southern Africa. ECOWAS stands for Economic Community of West African States. ECCAS stands for Economic Community of Central African States. EAC stands for East African Community.

[6] A threshold may exist below which large openness is beneficial to growth and above which the trade liberalisation growth effect falls.

tivity -TFP) rather than those considered in this study.

6 Concluding remarks and Implications

We investigate the relationship between electricity stock (electricity consumption) and quality (RETDL) in 18 SSA countries over the period 1990-2013. The investigation is done before and after accounting for electricity-related CO2 emissions to detect the influence of these emissions on the growth contribution of electricity stock and quality. Our results show evidence of cross-section dependence among SSA economies in terms of L.GDP, L.ELEC, L.MELEC, L.INF, L.TRA, L.FDP and L.UBNPOP but not for L.RETDL, L.MRETDL & L.CO2EM. Electricity consumption shows positive growth contribution in SSA and this contribution declines when the effects of CO2 emissions are accounted for. Electricity quality developments (as represented by change in the RETDL) suggest negative growth effects in SSA. The negative growth effects will be worse once the CO2 emissions are taken into consideration. Consequently, CO2 emissions from electricity and heat production reduce the growth effects from electricity stock and quality. Furthermore, accounting for CO2 emissions tend to improve the adequacy of our regression models. Also in terms of model choice, the models that include constant plus trend have the best fit for our data. Inclusion of deterministic trend enhances the electricity - growth nexus.

The findings of this paper provide important policy implications. The fact that electricity power generation from renewable sources (excluding hydro) is still very low in SSA (second lowest from MENA), it should be a major concern for respective governments, and appropriate policies to promote renewable energy production are called for. Solar energy has not assumed a major role in Africa but its gaining ground (IEA, 2014). Despite the fact, the region is endowed with abundant renewable resources. Africa at large has more than 20% of world's hydro resources and a number of countries in the continent experience long hours of sunshine with considerable radiation to be utilised, including wind resources mainly along the Western, Northern and Southern African coastlines (AfDB, 2009). The risk of climatic change, however, is an obstacle to the renewable sources such as hydro, wind and solar (see Avila *et al*, 2017).

Because of large coal reserves in SSA, the countries should also continue exploiting this endowment. We have already discussed earlier that SSA is greatly dependent on electricity production from coal. The use of coal brings some key advantages including its wide distribution, reliability, affordability and being the least subsidised (see World Coal Association, 2012). The

World Coal Association also applauded its convertible ability to liquid fuel (coal liquefaction) as has been in South Africa since 1955. Nevertheless, coal sources have been the greatest emitters of CO2 emissions and hence suitable policies should be considered to minimise these emissions. We support the recommendation by the World Coal Association (2012) that policy makers should seek to improve the efficiency of most aged and inefficient coal plants as well as considering CO2 capture and storage technologies that handle CO2 emissions not only from coal but the entire electricity sector.

Policy wise, as part of SDGs strategies, it could be relevant to consider also the sizes of CO2 emissions' influence on the growth effects of electricity stock and quality in the calculations of carbon taxes (carbon pricing). We demonstrated that CO2 emissions from electricity production reduce electricity growth contribution. Countries are mostly heterogeneous in terms of electricity growth effect and the impact of emissions. Some countries might be in a phase where rising emissions from electricity entail minimal negative effects on the electricity growth contribution, in the opinion of EKC hypothesis. Therefore, where carbon pricing is applicable, considering both the sizes of CO2 emissions and their influence on electricity-growth contribution seems plausible. It ensures a carbon pricing approach that is designed to minimise emissions without excessively discouraging the benefits from electricity sector[7]. The problem is worse if CO2 emissions from electricity production reduce the positive contribution of electricity in huge proportions, which may require a reasonable carbon penalty. Additionally, resources that are equivalent to the potential growth loss implied by rising emissions can be used in efforts that are meant to create a friendly environment. However, policy makers should bear in mind that stringent environmental standards on emissions may have substantial implications on power production (IEA, 2014). The power sector should consider better combination of power sources that minimise environmental degradation without hurting growth.

Positive growth effects of electricity consumption warrants the importance of electricity infrastructure. However, from a policy perspective, we believe that the electricity sector may attain its economic growth potential when the critical power shortages are reduced. Appropriate planning and substantial investment is highly required to promote economic development. Moreover, the greater proportion of people without access to electricity may represent an opportunity to be exploited when these people become future consumers of energy, especially in productive activities such as agriculture in

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[7] Though theoretically sound, it might be difficult in practice to measure with accuracy the influence of electricity-related CO2 emissions on the growth contribution of the energy sector. However, from a policy-making position, it helps to penalise each sector of the economy according to the size of emissions and its growth contribution.

rural areas. Increased access to electricity can also help alleviate the unemployment challenge in SSA as others would become self-employed in various small business projects (e.g. barbershops and saloons, poultry, carpentry, internet cafe, among others). It is important for the countries in SSA to increase small-scale off-grid systems in a decentralised manner to reduce the percentage of population without access to electricity, especially in rural communities. This can reduce reliance on centralised grid systems that hardly reach the rural areas. It is also important to ensure affordable electricity prices. Electricity prices in SSA are among the highest in the world.

Furthermore, the respective governments in SSA need to improve the efficiency of the energy sector to minimise the ratio of electricity transmission and distribution losses, which imply negative growth effects. While small-scale power plants (e.g. solar, small-scale hydropower) can improve the supply of electricity even in remote areas as off-grid systems, they lack economies of scale to reduce generation costs and losses. To enhance efficiency in the transmission and distribution of energy, proper planning and implementation, skilled personnel, adequate research and development are among the key factors. Appropriate measures to deal with electricity pilferage (which is part of ETDL as non-technical loss) are also essential in SSA. Large power plants are also believed to be cost-effective unlike the small-scale power systems that dominate Africa (see AfDB, 2013).

Based on control variables, the positive coastal effect may imply that coastal economies gains from their favourable transport infrastructure connection with external markets, which might translate to becoming favourable investment destinations (see Ran, 2005). Again, SSA countries have benefited from trade openness in general and hence we support policies that are designed to further promote trade liberalisation. These include regional communities and various bilateral and multilateral trade agreements, which facilitate regional integration in SSA. Given that inflation has had negative effects in SSA since 1990, inflation targeting may remain one of the key approaches to ensure price stability. However, it also demands discipline and less political pressure to avoid a "time inconsistency" problem that arises when policymakers adopt discretionary monetary policies (for example, expansionary monetary policy) based on favourable short-term outcomes (for instance, increased investment) but neglect the undesirable long-term effects (for example, high inflation). More so, financial development in SSA is very poor. Banks and stock markets in the region are weak in terms of facilitating investment funds while a significant proportion of credit especially to individual borrowers is used for consumption than investment purposes. Bolstering financial sector may require substantial effort from the respective governments to attract investment in this sector, including proper supervision.

Finally, it is concluded in this study that SSA countries require substantial funds to address both the critical shortage of electricity and enhancing efficiency of the energy sector. We recommend the representative countries to increase the participation of individual power producers (IPP) rather than relying on the public sector. Attracting adequate investment (especially from external sources) in the power sector may also demand improvement of institutional quality in SSA, including " ease of doing business" indicators and reduction of corruption. While carbon pricing (or taxes) may help in lowering CO2 emissions and their adverse influence on growth contribution of electricity sector, this strategy may further worsen electricity crisis in SSA and hence the use of carbon capture technologies might be better. A detailed cost and benefit analysis (CBA) is needed when choosing the best strategy to improve environmental quality while staying cautious of each strategy's impact on electricity production and ultimately economic growth.

Further studies may investigate the influence of CO2 emissions on electricity stock and quality from a time series perspective for the effects of these emissions may differ across individual countries. Non-dependency in terms of electricity efficiency indicators (L.RETDL, L.MRETDL and L.CO2EM) may imply heterogeneity across individual SSA countries in terms of efficiency. Consequently, in the presence of heterogeneity, the countries may need slightly different policy prescriptions when addressing electricity efficiency.

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Table 1: Descriptive statistics

Variable	*Obs*	*Average*	*Std.Dev*	*Min*	*Max*	*Skew*	*Kurt*
L.GDP	432	6.662	1.094	4.612	9.353	0.562	2.543
L.ELEC	432	5.428	1.244	3.075	8.529	0.675	2.979
L.RETDL	432	-2.744	1.646	-6.600	0.480	-0.569	2.500
L.CO2INDEX	432	0.193	0.155	0.000	0.541	0.423	2.038
L.FDP	407	2.677	0.995	-1.618	5.076	-0.230	4.744
L.TRA	422	4.153	0.569	1.412	5.187	-1.568	7.122
L.INF	431	3.263	1.074	-1.159	10.103	2.746	15.171

Note: Data for 18 SSA countries considered over the period 1990-2013. The L.CO2INDEX is the log of electricity-related carbon emission index, formed using the starting year (1990) as a base year and hence trace changes in these emissions from 1990 to 2013.

Table 2: Cross-Section (CD) Dependence test

Variable	*CD-test*	*corr*	*abs(corr)*
L.GDP	46.36***	0.765	0.768
L.ELEC	17.23***	0.284	0.529
L.MELEC	14.01***	0.231	0.468
L.RETDL	-0.39	-0.006	0.405
L.MRETDL	-0.53	-0.009	0.399
L.CO2INDEX	-0.55	-0.009	0.47
L.UBNPOP	39.82***	0.657	0.87
L.FDP	14.25***	0.246	0.405
L.TRA	11.92***	0.199	0.378
L.INF	15.67***	0.259	0.342

Notes: Under the null hypothesis of cross-section independence. L.UBNPOP is urban population (% of total). L.MELEC=L.ELEC x L.CO2INDEX; L.MRETDL = L.RETDL x L.CO2INDEX (thus, both stock and quality variables account for electricity-related CO2 emissions.

Table 3: Pesaran unit root test

	Constant		Constant & Trend	
Variable	*Level*	*1st Diff*	*Level*	*1st Diff*
L.GDP	-2.587***	-5.169***	-3.302***	-5.230***
L.ELEC	-2.315**	-4.541***	-2.826**	-4.562***
L.MELEC	-2.309**	-4.638***	-2.754**	-4.830***
L.RETDL	-1.541	-4.568***	-2.241	-4.495***
L.MRETDL	-1.520	-4.563***	-2.251	-4.546***
L.CO2INDEX	-2.472***	-4.941***	-2.701**	-5.004***
L.UBNPOP	-2.115*	-1.089	-2.713**	-4.501***
L.FDP	-4.795***	-7.707***	-2.289***	-5.691***
L.TRA	-2.646***	-5.881***	-0.883	-3.634***
L.INF	-4.808***	-14.864***	-6.024***	-13.189***

Note: Dynamic lags criterion decision based on Portmanteau (Q) test for white noise with maximum lag set at 4. L.UBNPOP is the first lag values of urban population as a percentage of total population. For L.TRA, L.FDP, L.INF the CADF test (another version by Pesaran) is performed since CIPS couldn't perform due to the nature of missing observations. Constant: Critical values (level of significance) are -2.07 (10%), -2.15 (5%) & -2.32 (1%). Constant plus Trend: Critical values (level of significance) are -2.58 (10%), -2.67 (5%) & -2.83 (1%). H0: homogeneous non-stationary, rejected when Statistic < Critical value.

Table 4: Electricity Stock

	Case 1: Constant		Case 2: Constant and Trend	
Variable	*Model 1*	*Model 2*	*Model 3*	*Model 4*
L.ELEC	0.789***	----	0.744***	----
	[0.050]	----	[0.048]	----
L.MELEC	----	0.723***	----	0.680***
	----	[0.045]	----	[0.043]
L.TRA	0.082	0.115	0.029	0.058
	[0.081]	[0.077]	[0.082]	[0.079]
L.FDP	-0.128***	-0.165***	-0.219	-0.185
	[0.049]	[0.049]	[0.144]	[0.141]
L.INF	-0.275***	-0.288***	-0.198***	-0.199***
	[0.040]	[0.038]	[0.038]	[0.037]
COASTAL DUMMY	0.730***	0.659***	0.733***	0.675***
	[0.115]	[0.110]	[0.113]	[0.109]
CONSTANT	2.649***	2.925***	2.140***	2.285***
	[0.309]	[0.298]	[0.290]	[0.280]
TREND	----	----	0.033***	0.032***
	----	----	[0.005]	[0.005]
Obs	385	385	382	382
R-squared	0.653	0.677	0.688	0.704
Root MSE	0.654	0 .630	0.619	0.604
Post-estimation checks				
(1) First-stage regression key statistics				
Adjusted R-squared	0.712	0.749	0.4656	0.4633
Partial R-squared	0.501	0.539	0.3542	0.357
(2) Endogeneity tests				
Durbin (score) chi2	28.219	19.584	16.642	14.687
	(0.000)	(0.000)	(0.000)	(0.000)
Wu-Hausman F	29.897	20.259	17.035	14.955
	(0.000)	(0.000)	(0.000)	(0.000)
(3) Weak instruments test				
F - statistic	80.566	443.569	205.663	208.478
	(0.000)	(0.000)	(0.000)	(0.000)

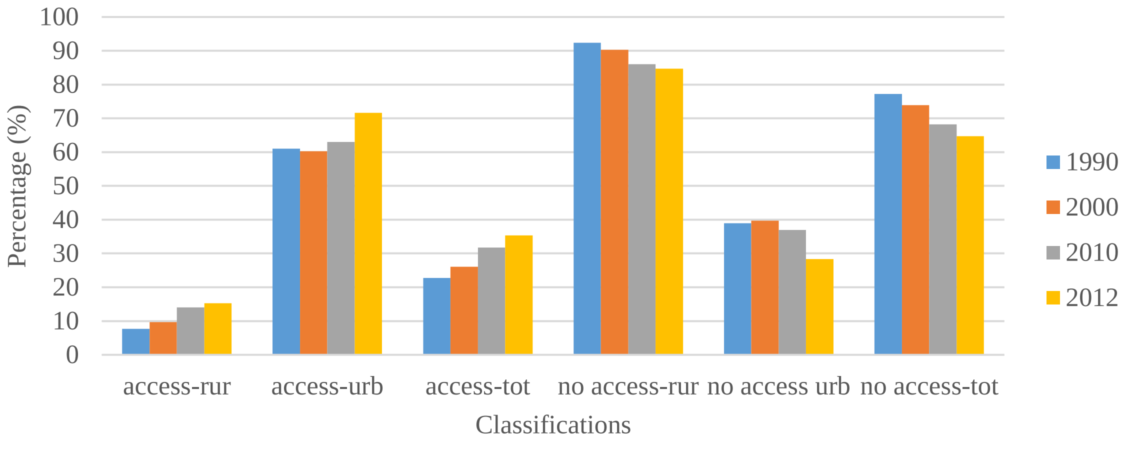
Note: 2SLS estimates based on Stata 13. Electricity stock measures are endogenous variables (i.e. L.ELEC and L.MELEC). Endogeneity tests have the null hypothesis that the variables are exogenous. The weak instrument test has the null hypothesis that the instruments are weak. [ ] and ( ) represent standard errors and p-values, respectively. *** denotes significant at 1% level

Table 5: Electricity Quality

	Case 1: Constant		Case 2: Constant and Trend	
Variable	*Model 5*	*Model 6*	*Model 7*	*Model 8*
L.RETDL	-0.606***	----	-0.567***	----
	[0.048]	----	[0.044]	----
L.MRETDL	----	-0.651***	----	-0.610***
	----	[0.055]	----	[0.050]
L.TRA	0.418***	0.413***	0.346***	0.343***
	[0.089]	[0.094]	[0.087]	[0.091]
L.FDP	-0.062	-0.024	-0.448***	-0.495***
	[0.058]	[0.059]	[0.176]	[0.185]
L.INF	-0.360***	-0.354***	-0.300***	-0.307***
	[0.051]	[0.053]	[0.045]	[0.047]
COASTAL DUMMY	0.850***	0.924***	0.819***	0.879***
	[0.145]	[0.155]	[0.139]	[0.148]
CONSTANT	3.867***	3.711***	3.486***	3.460***
	[0.395]	[0.413]	[0.327]	[0.344]
TREND	----	----	0.039***	0.040***
	----	----	[0.006]	[0.007]
Obs	385	385	382	382
R-squared	0.462	0.404	0.542	0.494
Root MSE	[0.814]	[0.857]	[0.751]	[0.789]
Post-estimation checks				
(1) First-stage regression key statistics				
Adjusted R-squared	0.526	0.475	0.347	0.334
Partial R-squared	0.372	0.337	0.306	0.291
(2) Endogeneity tests				
Durbin (score) chi2	69.914	78.027	36.805	42.667
	(0.000)	(0.000)	(0.000)	(0.000)
Wu-Hausman F	83.874	96.080	39.876	47.026
	(0.000)	(0.000)	(0.000)	(0.000)
(3) Weak instruments test				
F - statistic	224.714	192.554	165.355	153.506
	(0.000)	(0.000)	(0.000)	(0.000)

Note: Electricity quality measures are endogenous variables (i.e. L.RETDL & L.MRETDL). See Table 4 footnotes.

Figure 1: Access to electricity



Note: access-rur, access-urb, access-tot stand for percentage of population with access to electricity in rural areas, urban areas and total, respectively. no access-rur, no access-urb, no access-tot stand for percentage of population without access to electricity in rural areas, urban areas and total, respectively.

Figure 2: Access to electricity, total (% of population)

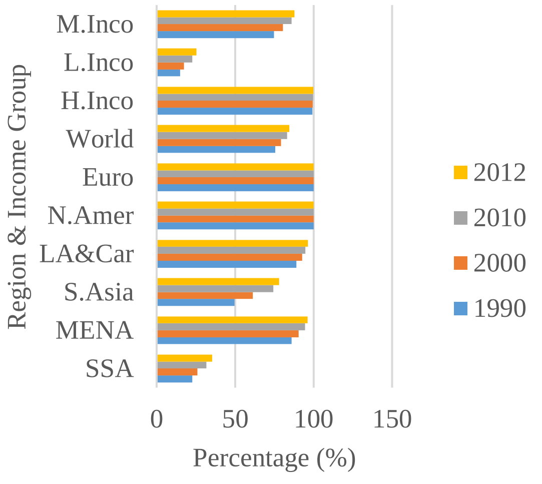
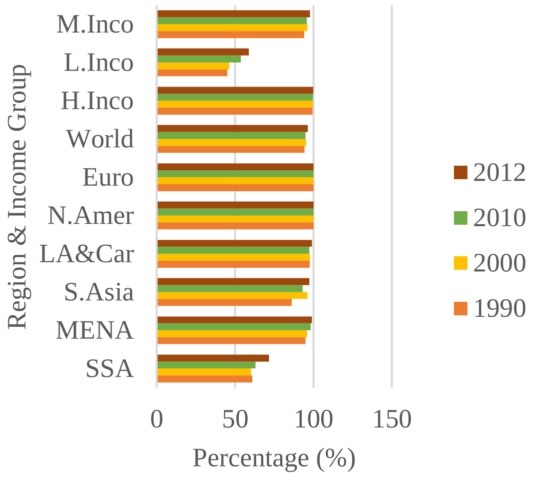


Figure 3: Access to electricity, urban (% of urban population)



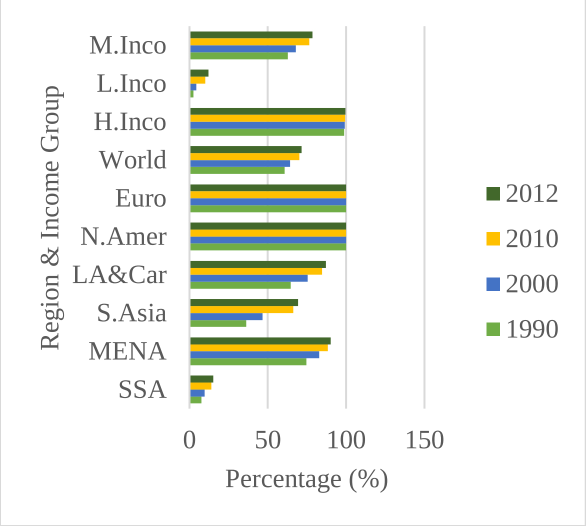


Figure 4: Access to electricity, rural (% of rural population)

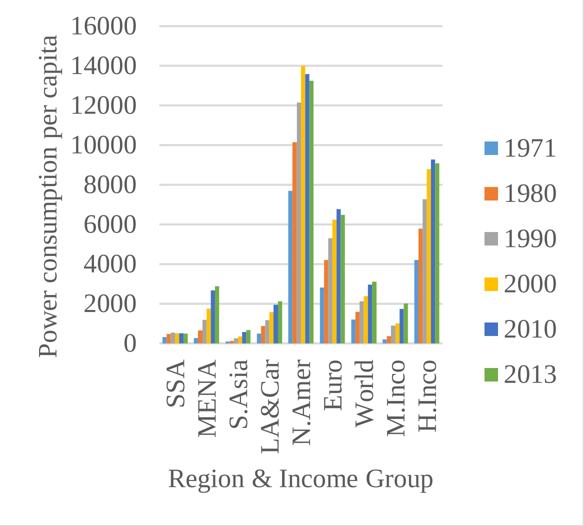


Figure 5:Electricity power consumption (kWh per capita)

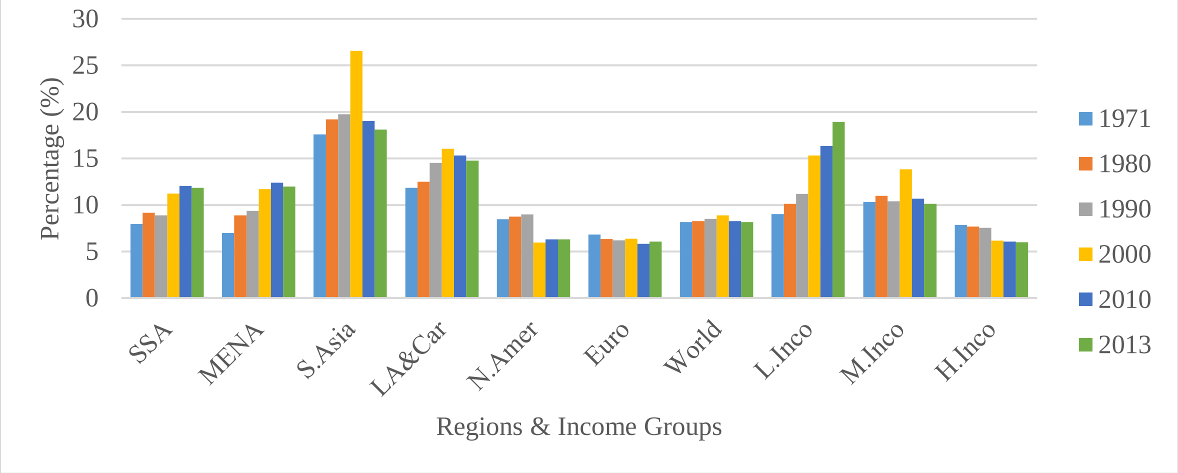


Figure 6: Electricity power transm & distr losses (% of output)

Figure 7: Co2 emission from elect & heart pdn (% of tot fuel combustion)

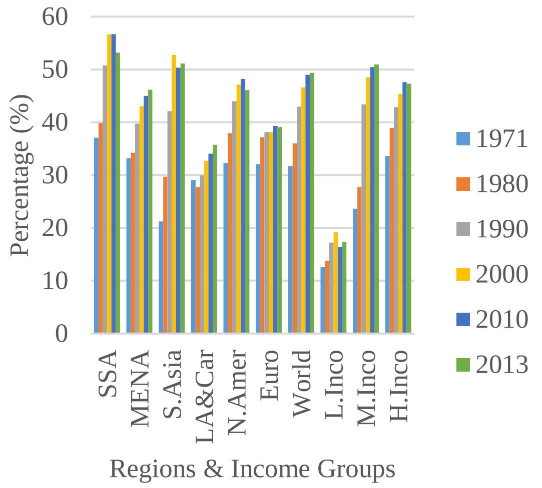


Figure 8: Co2 emission from gas consumption (% of total)

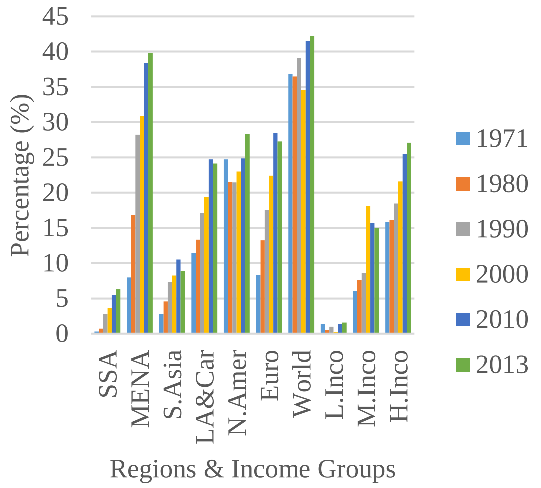


Figure 9: Co2 emission from liquid fuel consumption (% of total)

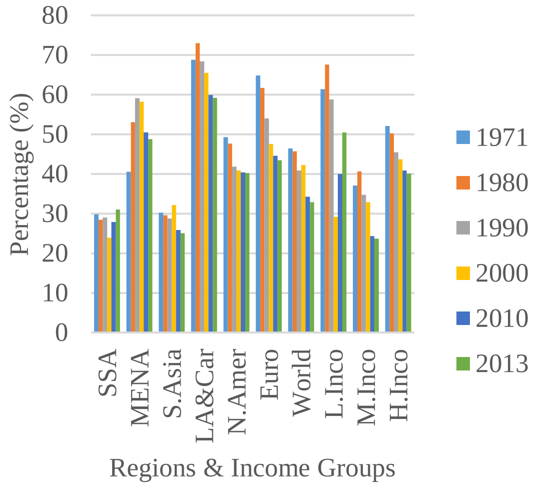


Figure 10: Co2 emission from solid fuel (% of total)