The Effect of Electricity Shortages on Electricity Consumption in Africa: Using Night-Time Light Data from Satellite Images

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Table of Contents

1. Introduction

Electricity access is a major problem in multiple regions of the world. In some African countries, access to electricity is still extremely low. The gap between the African continent and the rest of the world in terms of electricity production and consumption is intensifying (Mohammed, 2015). Along with the problem of access to electricity, quality of infrastructure is also a concern in Africa. The lack of infrastructure development causes the majority of African countries to cope with electricity shortages (KPMG, 2015). This often has an impact on economic and social development. Unreliability of electricity supply increases the cost of doing business and decreases the confidence of investors (Mohammed, 2015).

Multiple studies have worked on estimating the demand of electricity and the causal relationship between electricity consumption and economic growth. Very few studies have worked on showing the effects of electricity shortages on developing countries and more particularly, the ones already suffering from unreliable electricity supply. It was previously shown in multiple empirical studies that increasing consumption of electricity is a factor contributing to the wealth of a country. Because of this, the factors influencing electricity consumption are important to consider for the economic prosperity of countries in development. This paper attempts to estimate the effects of electricity shortages on electricity consumption of 22 African countries for the period 1992-2012. The study uses satellite data from the United States Air Force Defense Meteorological Satellite Program-Operational Linescan System (DMSP-OLS), to construct a measure of electricity shortages, similar to the methodology in Alam (2013).

The first step of the work presented in this paper was to perform a review of the research performed on the subject of electricity and economic growth, electricity demand and electricity shortages. Following the literature review, the first and most significant step of the work presented in this paper was extracting the DMSP-OLS data to construct a measure of electricity shortages. Following this, data was collected for the other variables that are used in the analysis. Two types of regression analyses were performed to understand the effect of electricity shortages on electricity consumption per capita; a standard pooled regression and a country fixed effects regression. As an extension, the regressions are performed restricting for countries that are rich in oil and natural resources and results are compared with countries that are not.

The main results show that income has the greatest impact on consumption of electricity in Africa. The results show that in Africa, income-elasticity of consumption is high and sometimes higher than 1. The variable of interest, the measure of electricity shortages frequencies had, as expected, negative estimated coefficients. This indicates that with an increase in electricity shortages frequencies, there is a decrease in consumption. Finally, the results of the study give incentives to dig deeper into the issue of electricity shortages for the development of policies in countries where electricity access or stability is problematic. The study also provides guidance on the extraction and use of remote-sensing data (data detected from a distance using a satellite or an aircraft for example), using night-time light from satellite images.

This paper is structured as follows. Section 2 is a literature review on the state of electricity in the African continent. Multiple studies that worked on the causal relationship between electricity consumption and economic growth as well as studies that worked on estimating electricity demand are presented. The end of this section highlights the studies that worked on electricity shortages as well as different studies that used remote sensing with night-time light data from satellites images in their research. Section 3, the data section, highlights the methodology used to measure electricity shortages using night-time light data from satellite images. It also presents a summary of the statistics and problems encountered with the data collection, extraction and analysis. Section 4 presents a description of the econometric model and Section 5 presents the main outcomes and results of the empirical analyses performed in this study. Finally, Section 6 provides a conclusion summarizing the main findings. All data tables are presented at the end of the paper.

2. Literature Review

This section is a literature review on the state of electricity in Africa to better understand the causes of the African electricity crisis. In addition, multiple empirical studies focusing on the causal relationship of electricity consumption and economic growth, the estimation of electricity demand and the effects of electricity shortages will be presented. A discussion on the use of remote sensing using night-time light data from satellite images as well as the measure of electricity shortages used in this study will also be presented in this section. Finally, the indicator of electricity shortages used in this study will be introduced and a conclusion summarizing the main findings will be presented.

Electricity in Africa

Multiple African countries are suffering from an electricity crisis. In 2013, approximately 17% of the global population did not have access to electricity and of those, 95% were in sub-Saharan Africa (OECD/EIA: 2016). Multiple countries are also facing repeated electricity shortages. The instability of power supplies has been a big obstacle for businesses and households. According to the World Bank Enterprise Survey, the average number of electrical outages in a typical month was of 8.3 in sub-Saharan Africa. In the Middle East and North Africa, the average number of electrical outages was 17.6. According to the manufacturing firms interviewed in the World Enterprise Survey, annual sales losses out of total sales were estimated to be on average 8.6% in Sub-Saharan Africa and 6.9% in the Middle East and North Africa. (World Bank: 2016).

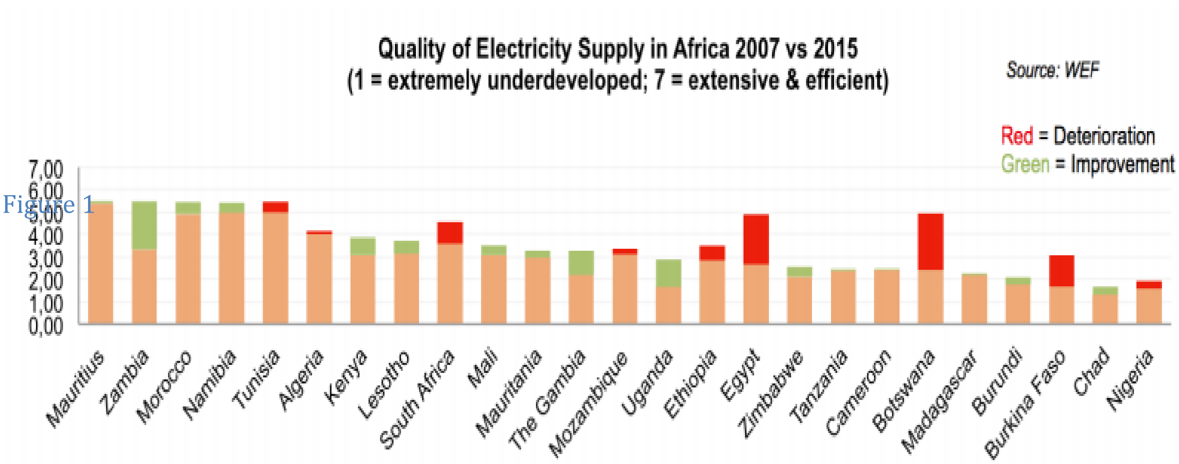
Cameroon, Côte d'Ivoire, Gabon, Ghana, Namibia, Senegal and South Africa are said to be the only sub-Saharan African countries with an access rate to electricity of at least 50%, a percentage dropping to 20% for other Sub-Saharan African countries (Castellano et al., 2015). Multiple factors can be associated with this electricity crisis such as poor infrastructure, instabilities and high prices to name a few. In Senegal, prices rise on a monthly basis forcing the government to spend large amount of money on electricity subsidies and making it difficult to invest in power infrastructure (CSIS, 2016).

The expansion in electricity-intensive mining in countries such as South Africa and Botswana are significantly increasing electricity demand (CSIS, 2016). Multiple countries like Egypt and South Africa have worked on expanding their electricity generation. Despite this, they are still facing electricity shortages. Countries like Zimbabwe and Botswana have not been able to increase their power generating systems (KPMG, 2015). The quality of supply is one of the main issues in Africa as seen in Figure 1. Egypt, as mentioned previously, has significantly increased its power generation capacity but total electricity losses have also increased. The political instability also affected the quality of supply in multiple African countries (KPMG, 2015). According to Bazilian et al. (2015), uncertainty during instabilities and wars delay and if not, cancel infrastructure development. Finally, African countries are in urgent need of electricity infrastructure development to increase access to electricity and to decrease electricity shortages causing uncertainty and unattractive business environment.

Electricity Consumption and Economic Growth

Multiple studies have shown the causal relationships of electricity consumption and economic growth in African countries. Jumbe (2004) used a Granger-causality test and an error correction test to show that in Malawi, for the period 1970-1999, there was a bi-directional causality between electricity consumption and gross domestic product (GDP) and a one-way causality running from national GDP to electricity consumption. Solarin (2011) used data for

Figure 1



Nigeria covering the period 1980-2008. An Autoregressive Distributed Lag (ARDL) model bound test and a Granger-causality test were done and a causality running from electricity consumption to economic growth was found.

Source: KPMG, (2015)

A similar study, Solarin et al. (2013), showed that in Angola, for the period 1971-2009, there was a long-run relationship between electricity consumption, economic growth and urbanization. It was also found that in the short-run, urbanization and electricity consumption Granger-cause each other. Bélaïd et al. (2013) found a long-run and a short-run bi-directional causality between energy consumption and GDP in Algeria. Kouakou (2011) found for Cote-D'Ivoire, between 1971 and 2008, a bi-directional causality between electricity consumption per capita and GDP per capita as well as a bi-directional causality between electricity consumption and industry value-added. The results for Burkina Faso found in Ouédraogo (2010) suggest a bi-directional causality between electricity consumption and GDP in the long-run. Wolde-Rufael (2006) used data for 17 African countries to test the long-run causal relationship between electricity consumption and GDP for the period 1971-2001. The study found a long-run causal relationship for nine countries and a short-run causality for twelve countries. Six countries out of the twelve were found to have a unidirectional causality running from real GDP per capita to electricity consumption per capita. The opposite was found for three other countries. The last three countries were found to have bi-directional causalities between electricity consumption and GDP. Finally, many studies show the importance of electricity consumption for a country`s wealth. The question of whether the causal relationship runs from electricity consumption to GDP or in the other way is ambiguous in Africa but to estimate electricity demand or consumption, GDP per capita is used as an explanatory variable in most cases as will be seen in the next section.

Electricity Demand

Multiple studies in the literature have focused on estimating electricity demand. GDP and electricity prices were most commonly used as the explanatory variables. For example, Jaunky (2007) used electricity consumption per capita and real GDP per capita as explanatory variables using data for 16 African countries between 1971 and 2002. Using a fully modified ordinary least square method (FMOLS) and a dynamic ordinary least square (DOLS) method, it is found that the long-run income elasticities were 0.70 and 0.76 respectively. It was also found that the short-run elasticity was 0.39. Ziramba (2008) used real GDP per capita and electricity prices in South Africa for the period 1978-2005 as explanatory variables for residential electricity consumption. The study used a bounds testing approach and found that prices were insignificant in estimating the residential demand of electricity as opposed to income, which was the main determinant. Chaudhry (2010) used a panel of 63 countries for the period 1998-2008. The explanatory variables used were real GDP and prices of electricity. Using a simple fixed effects model, the study found that with a 1% increase in per capita income, there is a 0.69% increase in electricity demand. Yépez-Garcí el al. (2011) also used a simplified specification with GDP and electricity prices as explanatory variables to forecast electricity demand in Latin America up to 2030.

Along with proxy variables related to GDP and prices of electricity, other variables were often added according to how relevant they were for the study. Most of the studies that used linear regressions to estimate electricity demand used GDP, electricity prices and demographic variable as explanatory variables. Bianco et al. (2013) used a linear regression to forecast electricity demand in Italy for the period 1970-2007. Using GDP and population as explanatory variables, it was found that the estimations were close to national forecasts. Mohammed et al. (2005) also used population and GDP along with electricity prices to forecast electricity demand in New Zealand. The results were also aligning with national forecasts. Egelioglu et al. (2001) used the ordinary least square (OLS) method to estimate electricity demand in Cyprus between 1988 and 1997. The explanatory variables were prices of electricity, the number of customers and the number of tourists. It was concluded that the explanatory variables had strong predictive ability. Holtedahl et al. (2004) used an error-correction framework on a model of residential electricity demand. More specifically, the study used population, GDP, prices of electricity, international prices of oil, urbanization and weather as explanatory variables to estimate residential electricity demand in Taiwan. A variable on the prices of oil was used as it was considered a good substitute for electricity in the country analysed. Urbanization was used as a proxy for electricity-using equipment. Pao (2004) used national income, population, GDP and the consumer price index (CPI) to forecast consumption of electricity in Taiwan. A linear regression model showed that national income and population had more effects on electricity consumption in Taiwan than the GDP and the CPI. Shahid et al. (2014) used OLS with GDP and population as explanatory variables for electricity consumption in Brazil. The estimated coefficients for both explanatory variables were positive and significant.

To summarize, it was found from the literature review that the most commonly used explanatory variables for electricity demand are GDP and electricity prices. Different controls are added to these two explanatory variables throughout the studies depending on relevance. Demography-related variables like population and urbanization rates are often added. Prices of substitutes are also, in some cases, considered. In multiple cases, studies also focus on weather-related data.

Electricity Shortages

Only few studies have tackled the question of the effects of electricity shortages on economic variables. This is because data related to electricity shortages frequency and duration is often unavailable. This section will present papers that explored this question. More specifically, a discussion on the different proxies used for electricity shortages in the case data was unavailable will be produced.

Qasim et al. (2014) performed an empirical study on electricity shortages in Pakistan using data for the period 1971-2010. A novel indicator was created to proxy electricity shortages. The electricity shortages proxy was computed using a ratio of the sum of oil and gas consumed over electricity consumed. It was mentioned that in Pakistan, this ratio should be constantly growing over time and that the substitution effect caused by the use of generators using oil and gas during electricity shortages should be reflected by bigger variations of the indicator. The main finding is that the price adjustment strategy adopted by the government of Pakistan is not an effective policy to deal with power shortages in the short run.

Alam (2013) studied the consequences of electricity shortages on firm's behaviours in India. The study shows how adapting to electricity outages varies across industries. It uses data on rice mills and steel mills, two industries that adapt differently to electricity shortages in India and finds that an increase in electricity shortages decreases the output and profits of steel mills but not rice mills. The study constructs a novel measure of power outage frequencies using DMSP-OLS meteorological satellite data. The same measure will be used in this study and be described later on.

Similarly, Allcott et al. (2016) used manufacturing data in India to estimate the effects of electricity shortages. The conclusion is that based on the average number of electricity shortages, plant's revenues and producer surplus is decreased from 5% to 10%. According to the study, the impact of shortages could be reduced if interruptible retail electricity contracts were implemented.

Andersen et al. (2013) attempted an estimation of the effects of electricity shortages on real GDP per capita in sub-Saharan Africa for the period 1995-2007 using night-time light data from satellite images. A measure of lightening density is created and used as an instrumental variable for electricity shortages. The measure is compared with statistics on electricity shortages from the World Bank's Enterprise Surveys 2011. Due to the fact that the instrumental variable could be correlated with geographical factors, binary variables are added to account for countries that are oil exporters, coastal and resource rich. The conclusion is that shortages in electricity decreased economic growth in Africa.

Multiple studies have also tried to estimate the cost of power outages, e.g. Sanghvi (1982), Beenstock (1991), Beenstock et al. (1997), and De Nooij et al. (2009). Cheng et al. (2013) estimates by how much electricity shortages affected China's GDP growth by using data on electricity generation growth for the period 1953-2010. The study finds that electricity generation growth Granger-causes GDP growth, but not the opposite. Also, it is found that an increase of 1% in the growth of electricity generation would increase GDP by 0.6%.

Finally, remote sensing using night-time light data from satellite images is the method chosen for this papers` work as it is judged more innovative and relatively new in economic research. The novel measure of electricity shortage frequencies using DMSP-OLS meteorological satellite data as in Alam (2013) will be used. Next section will provide more detail on studies that used the same type of data.

The Use of Remote Sensing Using Data of Night-Time Light from Satellite Images

Remote sensing using night-time light data from satellite images is relatively new in economic research. The use of night-time light data from satellite imagery to create economic indicators and proxy economic activities in the world was tested to be an efficient and innovative solution to encounter the problem of the unavailability of data. Night-time light data from satellite imagery is said to be unique and often useful in detecting human activities on earth for different purposes, whether it is human settlements, pollution, disaster management, gas-emissions, shipping fleets etc. (Doll, 2008). Multiple studies have used it as an alternative for economic indicators like GDP, GINI and other welfare indices. Night-time light data was also used for studies on vegetation, disaster studies and urbanization studies to name a few (Thenkabail, 2016). Some have also used night-time light data to proxy electrification rates, access to electricity and more rarely, electricity shortages as in this paper.

Elvidge et al. (1997) estimates the lighted areas using an indicator based on night-time light data for 21 countries and concludes that it is highly correlated with GDP and electricity consumption. A relationship is also found between the areas with light and population. Kulkarni et al. (2011) uses night-time light data to make a comparative analysis of economic activities in China, the United States and India between 2001 and 2007. The study compares 3108 counties in the U.S., 570 districts in India and 200 prefectures in China for three different years. The conclusion was that night-time light data can be used as a proxy for GDP for a percentage of the territorial divisions. Natalya et al. (2014) studied night-time light intensity and economic activities in Europe. The study did a multivariate analysis and concluded that night-time light data can explain up to 88.8% of the intensity of economic activities in the manufacturing sector, in construction, as well as in the agricultural sector confirming the effectiveness in using night-time light data as an economic indicator.

Nadejda et al. (2014) examined whether night-time light data can be used as a proxy to forecast electricity demand. The study produces an estimate of world demand of electricity if all countries were to live like OECD countries. Anderson et al. (2015) creates a framework that can be used to estimate national and sub-national agricultural and non-agricultural economic activities of administrative areas using night-time light data. Mina el al. (2013) is also a study that attempted to prove the validity of the use of night-time light imagery to detect rural electrification. The study used night-time light data against ground-based survey data on electricity usages in 232 electrified villages and additional administrative data on 899 unelectrified villages of Mali and Senegal. The study highlights the potential of using night-time light imagery for the planning and monitoring initiatives related to electrification in countries in development.

Producing the literature review was useful to understand the state of electricity in Africa. It was found that access to electricity is very low in multiple countries and that electricity shortages are a real issue in Africa. It was also useful to see that in most studies, the relationship between electricity consumption and economic prosperity exists, more specifically in the case of African countries. Also, reviewing studies on electricity demand was beneficial to identify the main control variables used to estimate electricity consumption. It was found that in general, GDP as well as prices of electricity are the main controls used. Population-related variables, weather-related variables and price of substitutes are examples of other controls that are added depending on the relevance for the study. Finally, the literature review gives an insight on what researchers do with data from night-time light satellite images. It was found that many things are done, such as estimating economic indicators like GDP or GINI or identifying human settlements, pollution, disaster management, gas-emissions to name a few.

3. Data

The main interest of this paper is to use remote sensing data to examine the way electricity consumption changes with electricity shortages in Africa. Data on 22 African countries is collected for the period 1992-2012 as seen in Table 1. Satellite data capturing night-time light from the United States Air Force Defense Meteorological Satellite Program using the Operational Linescan System (DMSP-OLS) is extracted and used to construct an indicator of electricity shortages frequency as constructed by Alam (2013) to be used as a control variable. The other control variables used along with the measure of electricity shortages frequencies are GDP per capita, a proxy for electricity prices, GDP value-added from the manufacturing sector and urban population. A standard pooled regression and a country fixed effects regression are computed. Also, a binary variable is used to restrict the sample for countries with oil and natural resources and countries with no oil or natural resources and results are compared between the two groups.

Several data sources were used for this work. The dependant variable, electricity consumption in kilowatt-hour per capita was collected from the U.S Energy Information Administration database, an organization specialized in data products and reports related to energy. The Gross Domestic Product (GDP) is in constant $U.S per capita and was collected from the World Bank database. The World Bank is an international organization with a mission to end extreme poverty in the world. Data on urban population and manufacturing value-added as a percentage of GDP was also extracted from the World Bank database.

No data on the price of electricity could be found. To resolve this problem, a proxy of electricity prices was constructed. The international price of oil, gas and the South African price of coal were used along with the percentage use of each type of fuel in the total production of electricity in each country. Data on the proportion of each fuel used to produce electricity for each country as well as the international prices of oil, gas and coal was also collected from the World Bank database. A weighted relative price per kilowatt-hour was computed.

To compute the electricity price measure, we take the percentage of oil, gas and coal used to produce electricity in each country that we recalculate so that the sum is 100%. We multiply these percentages by a cost per kilowatt-hour. These costs per kilowatt-hour are computed using American efficiency numbers of electricity production that are 572kWh/BBL, 2179 kWh /tonne and 2,056 kWh/ m^3 for oil, coal and gas respectively. The fuel prices are expressed in current $U.S and adjusted for inflation using the U.S consumer price index (CPI). Finally, prices are added up to form a unique price measure for electricity per kilowatt-hour. If no data is available on the proportions of use of each fuel in the production of electricity, it is assumed that the country uses 100% of oil.

Methodology behind Measuring Electricity Shortages

One of the main interests of the study was to explore and evaluate the option of using remote sensing to create a proxy for electricity shortages. The proxy was created using night-time light data from satellite images. The raw data (satellite images) was collected from the National Center for Environmental Information (NCEI)[1]. Two composites were collected, the Average Visible Stable Light (SL) and the Normalized Visible Light (NVL). The first is cloud-free light detection of areas that are lit most of the time (Pestalozzi, 2012). The second is the average visible stable light detection multiplied by the percent frequency of light detection, which represents the persistence of lighting. For example, if the light is only detected half the time by the satellites, it is multiplied by 50% (NCEI, 2016). Figure 2 and 3 represent two low definition examples of the raw data. Figure 2 represents South Africa and Figure 3 represents Morocco. The left-hand side of Figure 2 and Figure 3 shows an example of the Normalized Visible Light (NVL) and the right-hand side represents the Stable Light (SL).

Since 1970, the satellite has been orbiting the earth multiple times every night capturing night-time light on the globe between 8:30 p.m. and 10:30 p.m. (Alam, 2013). These observations have been aggregated yearly between 1992 and 2012 and the Stable Light (SL) and Normalized Visible Light (NVL) composites were created. A pixel intensity ranging from 0-63 is attributed to each 30 arc seconds representing approximately 0.86 square kilometer on the earth if measured at the equator (Pestalozzi, 2012). The DMSP is primarily a tool created for the U.S military. It provides strategic weather prediction to help in the planning of operations at sea, on

[1] Downloaded from http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html

land and in the air (LA AFB, 2016). The Operational Linescan System (OLS) is the name of the sensors that observes clouds via visible and infrared spectrum. (Akiyama, 2012)

Figure 2: South Africa's Normalized Visible Light (NVL) and Stable Light (SL) composites

Source: Image created with ArcGIS using DMSP-OLS data

Figure 3: Morocco's Normalized Visible Light (NVL) and Stable Light (SL) composites

Source: Image created with ArcGIS using DMSP-OLS data

As mentioned in Pestalozzi (2012), dealing with geographical images that are up to 10 Gigabytes is not an easy task. ArcGIS is known to be one of the most efficient geographical information systems and this is the software that was used to analyze the geographical dataset. Lowe (2014) provides one of the rare comprehensive guides for economists on the extraction of night-time light data using ArcGIS. A long learning process was required to extract the required data from the raw satellite images for the two composites for each country and each year considered in the analysis. The early steps of handling the data included converting the image formats to formats that are easier and faster to process. In addition, the satellite images are of the whole world, so they had to be clipped for each country considered in the analysis for both composites for each year. Special filters were also applied on the images to filter-out the spots in the images that are lit by gas flares. ArcGIS was also used to drive the calculations needed to construct the electricity shortages measure.

The measure of electricity shortages was calculated as follow:

$$Short_{c,t} = Median\ (SL_{c,t,p} / NVL_{c,t,p}) \qquad (1)$$

where $Short_{c,t}$ is a proxy for electricity shortages frequencies for country c at year t, $SL_{c,t,p}$ is the Stable Light (SL) composite for country c at year t for each pixel point p (representing different regions) and $NVL_{c,t,p}$ is the Normalized Visible Light (NVL) composite for country c at year t for each pixel point p. The median of all ratios at each pixel point is calculated to form one measure of electricity shortages in each country. Higher $Short_{c,t}$ indicates higher frequency of shortages. This is because a higher variability in electricity shortages results in higher variability of lighting and thus, a larger ratio between both composites. After the division was done for each pixel point in ArcGIS, the data was exported into 462 EXCEL files (21 years, 1992-2012, for 22 countries from Table 1). A Python script was developed to automate calculating the median for each year in each of the EXCEL files.

Summary Statistics

According to the dataset used in this paper and summarized in table 2, the lowest consumption of electricity per capita is in Chad in 2000 with a level of less than 10 kWh per capita. According to the World Bank, only 6.4% of the population of Chad had access to electricity in 2012. The mean consumption for the countries analysed is of 584 kWh per capita. The highest level of consumption recorded is in South Africa in 2007 with a level of 4530 kWh.

South Africa is also the country with the highest income after Libya and both have respective GDP per capita of 6051 $U.S and 7078 $U.S in 2012. The mean value for GDP per capita is 1489 $U.S and it is similar to the Egyptian GDP per capita in 2012.

In terms of manufacturing value added as a percentage of GDP, the mean is around 12%, similar to the level in Algeria in 1995. When the urban population variable is examined, it is noted that Nigeria is the most populated country in Africa; it is also the country with the highest level of urban population at 76.1 million. The mean for African urban population is a little more than 11 million similar to the urban population of Cote-d'Ivoire in 2012. According to the data, the highest frequencies of electricity shortages were in 2011 and 2012. The highest frequency of electricity shortages observed in the sample is in Niger in 2011.

Econometric Problems

Multiple econometric problems were encountered mostly due to data unavailability. The most important problem was related to the price measure variable computed. The international prices of oil and gas and the South African price of coal are used along with the proportion of each fuel used to produce electricity in each country. It is assumed that only these fuels are used to produce electricity. Also, if data on the proportions used to produce electricity is unavailable, only the price of oil is used. All fuels are transformed so that a single price per kilowatt-hour is computed. Other studies used, as a proxy for prices of electricity, international price of oil or the Consumer Price Index (CPI) (e.g. Chandran el al., 2010, Lean et al., 2010). This study did not use these proxies because energy produced from oil, gas, coal or other sources varies from one country to the other. According to the World Bank data, in 2012, South Africa produced 94% of its electricity from coal as opposed to Algeria and Cote d'Ivoire who did not use coal to produce electricity at all.

The main problems with the measure used are differences in efficiency of production as well as the use of international prices that might not reflect the real level of prices. Countries where subsidies are high also impose a problem due to the impossibility to capture some of the variations in prices faced due to different policies related to subsidies from one country to the other.

Another problem encountered was related to the dependant variable used, as it is an aggregate value for electricity consumption. This means that electricity consumption represents commercial consumption, residential consumption and industrial consumption all together. In an ideal situation, the use of disaggregated consumption data would have been used.

Using night-time light has also multiple disadvantages mostly due to measurement errors. For example, it is necessary to assume that economic activities at night are correlated with economic activities during the day similar to what was done in multiple studies that used remote sensing with night-time light (e.g. Alam, 2013). A more technical problem related to each satellite image is the background noise and ephemeral events such as forest fires, fishing boats, and gas flares that are not completely removed (Pestalozzi, 2012). Also, the averaging of both the Stable Light (SL) and the Normalized Visible Light (NVL) causes measurement errors, as the variations during a year are not fully captured. Despite these technical measurement errors, studies using DMSP-OLS data are exponentially growing in economics literature.

4. Econometric Model

The formula used to study the effect of electricity shortages on consumption is:

$$Cons_{c,t} = B0 + B1\ GDP_{c,t} + B2\ Price_{c,t} + B3\ Short_{c,t} + B4\ Manufacturing_{c,t} + Urban_{c,t} + B6\ Y\ Country_{c,t} + B7\ Y\ Resources_{c,t} + \varepsilon_{c,t}$$

(2)

where $Cons_{c,t}$ is the natural logarithm of electricity consumption in kilowatt-hours per capita in country c at year t. $GDP_{c,t}$ is the natural logarithm of the gross domestic product (GDP) per capita for country c at year t. $Price_{c,t}$ is the natural logarithm of the price measure for country c at year t. $Short_{c,t}$ is the measure of electricity shortages frequencies in natural logarithm for country c at year t. The higher it is from one, the more there is electricity shortages. $Manufacturing_{c,t}$ is the natural logarithm of manufacturing value added as a percentage of GDP for country c at year t. $Urban_{c,t}$ is the urban population of country c at year t. Finally, $Y\ Country_{c,t}$ is a vector Y of binary variables for each country c at year t and $Resources_{c,t}$ is a vector Y of binary variables to indicate if a country is rich in oil and natural resources. The panel is unbalanced as seen in Table 1. Two types of regressions are performed in this analysis, a standard pooled regression and a country fixed effects regression. Specification I is a regression of $Cons_{c,t}$ on $GDP_{c,t}$ and $Price_{c,t}$.. $Short_{c,t}$ is added to Specification II and $Manufacturing_{c,t}$ and $Urban_{c,t}$ are added to Specification III. When the country fixed effects regressions are computed, $Y\ Country_{c,t}$ is added to the specifications. The results are in 4. $Resources_{c,t}$ is also added to differentiate countries rich in oil and natural resources from those that are not. The results are in Table 5.

5. Results

Two types of regressions were computed to test the effects of electricity shortages frequencies along other important controls on electricity consumption in African countries; a standard pooled regression and a country fixed effects regression. The main results are shown in Table 4. Table 5 also shows the results when the sample was restricted to separate for countries rich in oil and natural resources and countries that are not.

In Table 4, GDP per capita is used in all specifications. As expected, the variable has an estimated coefficient that is positive for all types of regressions. GDP per capita also has estimated coefficients that are higher than 1 in specifications I and II and a little less than 1 in specification III. According to economic theory, this means that income-elasticity of consumption for electricity is highly elastic in Africa making electricity a more luxurious good. More specifically, the results for specification I, II and III of the pooled regressions are 1.235, 1.230 and 0.951 respectively. Results are all significant at a 1% level. In the fixed effects regressions, the estimated coefficients are 0.913, 0.906 and 0.990 respectively. Results are also all significant at the 1% level. This shows that with a 1% increase in GDP per capita, there is an increase in consumption per capita ranging from 90.6% and 123.5%.

The results for the price measure estimated coefficients are unexpectedly positive. In the pooled regressions the results for specification I, II and III are 0.096, 0.103 and 0.264 respectively. The results are not significant for specification I and II and become significant at the 1% level in specification III. In the fixed effects regression, the estimated coefficients are 0.178, 0.178 and -0.023 respectively. The results are significant at the 1% level for specification I and II and not significant for specification III. This means that with a 1% increase in the price measure computed, there is an increase in consumption of electricity ranging from 9.5% to 17.8%. Unexpectedly, the estimated coefficients for both types of regressions are positive. This can be due to multiple effects. First, this can be due to a substitution effect of one type of fuel to another. Although the price measure is computed taking into account the proportion of each fuels used in the production of electricity proper to each countries, oil, gas and coal can be substitutes as each country use them differently. The results are similar to Sa’ad (2012), a study on elasticity of demand for oil products in African OPEC countries, with results showing mixed and unexpected signs. The conclusion was that in general, changes in income affect much more the demand in oil product than changes in real price. This is also the case for the results obtained in Table 4 and Table 5. Another explanation is indirect effects due to wealth that is not fully captured in the GDP per capita variable.

The variable of interest, electricity shortages frequencies, is added to specification II and III. In the pooled regression, the estimated coefficients are -0.426 and -0.727 respectively. The results are significant at the 10% level for specification II but become significant at the 1% level when all the controls are added. The estimated coefficients obtained for the country fixed effects regressions are 0.075 and -0.149 for specification II and III respectively. The results are not significant for specification II but become significant at the 10% level when all the controls are added in specification III. The results show that with a 1% increase in electricity shortages frequencies, there is a decrease in consumption per capita ranging from 14.9% to 72.7%. Results are less significant for country fixed effects and this was expected because some countries experience shortages that are constant in time although very large.

In specification III, two controls are added to the model; manufacturing value added as a percentage of GDP and urban population. The estimated coefficient of manufacturing value added is 0.655 in the pooled regression and 0.196 in the country fixed effects regression. Both results are significant at the 1% level. As expected, the signs are positive and with a 1% increase in manufacturing value added to GDP, there is an increase of electricity consumption per capita ranging from 19.6% to 65.5%. The estimated coefficient of urban population is 0.414 for the pooled regression and 0.637 for the country fixed effects regression. Both results are significant at the 1% level. More specifically, with a 1% increase in urban population, there is an increase of electricity consumption per capita ranging from 41.4% to 63.7%. While the effect of an increase in the manufacturing sector value added is stronger in the pooled regression, the effect of an increase in urban population is much stronger when controlling for countries.

Table 5 illustrates the results for both types of regressions when the sample is restricted for oil and resource rich countries and for countries that are not. Table 3 shows the country categorization. The estimated coefficients for GDP per capita in the pooled regression is 1.244 for oil or resource rich countries and 0.971 for countries that are not. Results are significant at the 1% level. The estimated coefficients for GDP per capita in the country fixed effects are

0.838 for oil and resource rich countries and 1.089 for countries that are not. Results are significant at the 1% level. Although the results are similar to the previous results in Table 4, whether income-elasticity of consumption is greater for countries that are rich in oil and natural resources or not is ambiguous. Country rich in oil or natural resource have a higher elasticity-demand of consumption than countries that are not in the pooled regressions. The availability of more resources in countries rich in oil and natural resources can create a stronger effect of substitution.

The results for the estimated coefficients of the price measure are ambiguous, as the signs of the estimated coefficients are positive for the pooled regressions and both positive and negative for the country fixed effects regressions. The estimated coefficients for the pooled regression are 0.170 for country rich in oil and natural resources and 0.155 for countries that are not. The results are significant at the 10% level and significant at the 5% level respectively. The estimated coefficients for the country fixed effects are 0.124 significant at the 1% level for oil and resource rich countries and -0.127 significant at the 10% level for countries that are not. In this case, the price affects positively consumption in countries that are rich in oil and natural resources and negatively affects consumption in countries that are not. This can be interpreted as a richness effect not fully captured by the GDP for countries rich in oil and natural resources. This makes sense since the resource rich country group include the ones that have oil, which should be used as a fuel for electricity production and cheaper as it is extracted locally.

The estimated coefficients for the measure of electricity shortages frequencies in the pooled regression are -1.500 for oil and resource rich countries and -0.807 for countries that are not. Both results are significant at the 1% level. The signs are negative as expected and interestingly, countries that are rich in oil and natural resources seem to experience the highest impact on consumption of electricity with changes in electricity shortages frequencies. The estimated coefficients for countries fixed effects are -0.007 not significant for oil and resource rich countries and -0.194 significant at the 10% level for countries that are not. According to the country fixed effects regressions, electricity shortage frequencies affect only the countries with no oil or natural resources when comparing within the countries.

The results obtained for the manufacturing value added control show that oil and resource rich countries see much greater changes in consumption of electricity when there is an increase in the manufacturing value added as a percentage of GDP in the pooled regression. The estimated coefficients for the pooled regression are 0.514 for the oil and resource rich countries and 0.354 for the countries that are not. The results are significant at the 1% level. The estimated coefficients for the country fixed effects are 0.137, significant at the 1% level for the oil and resource rich countries and 0.286, significant at a 10% level.

An increase in urban population has a positive impact on consumption of electricity in general. The effect is greater for countries that are rich in oil and natural resources in the pooled regression as opposed to being greater for countries that are not rich in oil and natural resources in the country fixed effects regressions. The estimated coefficients are 0.599 for countries that are rich in oil and natural resources and 0.374 for the countries that are not. Both results are significant at the 1% level. For the country fixed effects regressions, the estimated coefficients are 0.007, not significant for countries rich in oil and natural resources and 0.998, significant at a 1% level for countries that are not.

Finally, the results obtained show that the income-elasticity of consumption is highly elastic and sometimes higher than 1 for certain specifications in Table 4 and Table 5. Whether the elasticity is higher for countries that are rich in oil and natural resource or not is ambiguous. Unexpectedly, the measure of price of electricity has positive estimated coefficients in the pooled regressions and positive and negative estimated coefficients in the country fixed effects regressions. The change in signs can be due to the substitution effect as the three types of fuels used to compute the price measure are used differently from a country to the other. The positive sign can also be due to an indirect effect of richness not fully captured by the GDP variable.

The variable of interest, electricity shortages has, as expected, negative estimated coefficients showing that with an increase in the frequency of electricity shortages there is a decrease in electricity consumption per capita. Countries with oil and natural resources seem to see a greater variation according to the pooled regression results. The country fixed effects results for countries rich in oil and natural resources are not significant as opposed to the results for the countries with no oil and natural resources. Consumption of electricity per capita increases with an increase in the manufacturing value added. Urban population is also moving with consumption. Whether the variations are stronger for countries rich in oil and natural resource or not is ambiguous if results from the pooled regression or country fixed effects regression are compared.

6. Conclusion

The main objective of this paper is to analyse how electricity shortages affected the consumption of electricity in the African continent using a new measure of electricity shortages that leverages remote sensing data. The sample used for the study consists of data on 22 African countries and the time period analyzed ranges from 1992 to 2012. A measure of electricity shortages frequencies is constructed using data from satellite images from the United States Air Force Defense Meteorological Satellite Program (DMSP-OLS) as in Alam (2013). The measure is used as a control variable along with GDP per capita, a measure for electricity prices, manufacturing value added and the level of urbanization to estimate consumption of electricity per capita. A pooled regression and a country fixed effects regression on three specifications are computed. Also, the sample is restricted to separate the countries rich in oil and natural resources from those that are not and a comparison is done.

The results show that income has the greatest impact on consumption of electricity in Africa. The estimated coefficients where positive and high in all the specifications indicating that in Africa, the income-elasticity of consumption is high. The results for the measure of electricity prices are ambiguous as the signs of the estimated coefficients were unexpectedly positive in the pooled regression and positive and negative in the country fixed effects regression. They also lost significance when they were negative. This can be due to the substitution effect as multiple fuels are used to compute the measure of prices. These fuels are used very differently from one country to the other. This can also be due to an indirect effect of richness that is not fully captured by the GDP variable. The variable of interest, the measure of electricity shortages frequencies had, as expected, negative estimated coefficients. This indicates that with an increase in electricity shortages frequencies, there is a decrease in consumption. Results are less significant for country fixed effects and this was expected because some country experience shortages of electricity that are high but constant in time. Finally, the increase in consumption of electricity comes with increases in manufacturing value added and in urbanization.

Finally, the results show that a variation in electricity shortages can have negative effects on consumption of electricity. This study gives incentives to dig deeper into the issue of electricity shortages. Data on the subject is scarce but an innovative solution is the use of remote sensing with satellite data on nigh-time light. The present study provides guidance on the extraction and use of DMSP-OLS data for economic purposes. The availability of more observation should result in the application of more robust econometric techniques to estimate the effects of electricity shortages in a context where multiple countries suffer from an energy crisis in the world. Hopefully, these results will support the development of future infrastructure planning policies that can help shape better lives in countries where problems of access and stability of electricity persist.

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Tables

TABLE 1. NUMBER OF OBSERVATION BY COUNTRY (1992-2012)

Countries	Consumption per capita	GDP per capita	Price measure	Shortages	Manufacturing value added	Urban population
1. Algeria	21	21	21	21	9	21
2. Angola	21	1	21	21	10	21
3. Cameroon	21	21	21	21	21	21
4. Chad	21	21	21	21	21	21
5. Congo	21	21	21	21	21	21
6. Cote d'Ivoire	21	21	21	21	21	21
7. Egypt	21	21	21	21	21	21
8. Ethiopia	21	21	21	21	21	21
9. Kenya	21	21	21	21	21	21
10. Libya	21	14	21	21	7	21
11. Mali	21	21	21	21	…	21
12. Mauritania	21	21	21	21	21	21
13. Morocco	21	21	21	21	21	21
14. Mozambique	21	21	21	21	21	21
15. Niger	21	21	21	21	21	21
16. Nigeria	21	21	21	21	21	21
17. Rep. Dem. Congo	21	21	21	21	21	21
18. Senegal	21	21	21	21	21	21
19. South Africa	21	21	21	21	21	21
20. Sudan	21	21	21	21	21	21
21. Tunisia	21	21	21	21	21	21
22. Zimbabwe	21	21	21	21	21	21
Number of Countries	22	21	22	22	21	22
Number of Observations	462	435	462	462	404	462

Note: The table illustrates the data collected for each country. Consumption is electricity consumption in kilowatt-hours per capita. GDP is the gross domestic product per capita in constant $US. The price measure is in $U.S per kilowatt-hour and manufacturing value added is a percentage of GDP. Three comas indicate that data is unavailable. The data was collected for the period 1992 to 2012, all the years available for satellite data.
Sources: U.S EIA database and World Bank Database.

TABLE 2. SUMMARY STATISTICS (1992-2012)

Variables	Mean	Standard Deviation	Min	Max
Consumption	583.961	1028.479	9.586	4530.063
GDP per capita	1488.823	1695.053	113.706	9153.106
Price measure	0.080	0.036	0.037	0.148
Shortages	2.038	0.361	1.236	3.500
Manufacturing Value added	11.539	5.852	0.237	29.537
Urban population	11,224,197	12,072,666	917,889	76,101,864

Note: The table is the summary statistics for the data collected for each country. Consumption is electricity consumption in kilowatt-hours per capita. GDP is the gross domestic product per capita in constant $US. The price measure is in $U.S per kilowatt-hour and manufacturing value added is a percentage of GDP.

Sources: U.S EIA database and World Bank Database.

TABLE 3: COUNTRY CATEGORIZATION FOR OIL AND RESOURCE RICH COUNTRIES

Country	Oil	Natural Resources
1. Algeria	1	1
2. Angola	1	1
3. Cameroon	1	1
4. Chad	1	1
5. Congo, Republic	1	1
6. Cote d'Ivoire	0	0
7. Egypt	1	1
8. Ethiopia	0	0
9. Kenya	0	0
10. Libya	1	1
11. Mali	0	0
12. Mauritania	0	0
13. Morocco	0	0
14. Mozambique	0	0
15. Niger	0	0
16. Nigeria	1	1
17. Rep. Dem Congo	0	1
18. Senegal	0	0
19. South Africa	0	0
20. Sudan	1	1
21. Tunisia	0	0
22. Zimbabwe	0	0

Note: Data for Algeria, Egypt, Morocco and Tunisia was unavailable but were added according to World Bank Oil & Natural resource rents (% of GDP)
Source: Table from Arbache et al. (2009) following the methodology of Collier et al. (2006).

TABLE 4: REGRESSION RESULTS USING WEIGHTED PRICE OF OIL, GAS AND COAL

Explanatory variables	Pooled regressions			Country fixed effects regressions		
	I	II	III	I	II	III
GDP per capita	1.235*** (0.035)	1.230*** (0.035)	0.951*** (0.038)	0.913*** (0.133)	0.906*** (0.135)	0.990*** (0.103)
Price measure	0.096 (0.084)	0.103 (0.084)	0.264*** (0.061)	0.178*** (0.035)	0.178*** (0.035)	-0.023 (0.051)
Electricity shortages	…	-0.426* (0.229)	-0.727*** (0.170)	…	0.075 (0.085)	-0.149* (0.090)
Manufacturing value added	…	…	0.655*** (0.053)	…	…	0.196*** (0.032)
Urban population	…	…	0.414*** (0.034)	…	…	0.637*** (0.117)
Constant	-2.896*** (0.374)	-2.546*** (0.452)	-8.022*** (0.688)	-0.232 (1.125)	-0.225 (1.118)	-12.432*** (2.274)
R^2	0.705	0.707	0.848	0.977	0.977	0.978
Number of observations	435	435	394	435	435	394

Note: All variables are in natural logarithm. All standard errors are in brackets. Significance are *** for 1%, ** for 5% and * for 10%. All results are robust.

TABLE 5: REGRESSION RESULTS USING WEIGHTED PRICE OF OIL, GAS AND COAL

Explanatory variables	Pooled regression		Country fixed effects	
	Oil or resource rich countries	Not an oil or resource rich country	Oil or resource rich countries	Not an oil or resource rich country
GDP per capita	1.244*** (0.073)	0.971*** (0.061)	0.838*** (0.085)	1.089*** (0.162)
Price measure	0.170* (0.095)	0.155** (0.075)	0.124*** (0.040)	-0.127* (0.072)
Electricity shortages	-1.500*** (0.270)	-0.807*** (0.188)	-0.007 (0.086)	-0.261** (0.126)
Manufacturing value added	0.514*** (0.057)	0.354*** (0.123)	0.137*** (0.021)	0.286* (0.162)
Urban population	0.599*** (0.052)	0.374*** (0.034)	0.120 (0.091)	0.998*** (0.178)
Constant	-12.588*** (1.153)	-6.880*** (0.610)	-2.179 (1.617)	-19.014*** (3.617)
R^2	0.836	0.906	0.992	0.971
Number of observations	163	231	163	231

Note: All variables are in natural logarithm. All standard errors are in brackets. Significance are *** for 1%, ** for 5% and * for 10%. All results are robust.