Assessment of the Driving Factors Affecting Electricity Consumption in Africa Using Index Decomposition Analysis and Satellite Derived Data

Almaz Akhmetov[1,*] and Augusto Vundo[2]

1 Orizon Consulting, McLean VA, USA
2 University of Tsukuba, Graduate School of Life and Environmental Sciences, Tsukuba, Japan
*E-mail: akhmalm@orizonllc.com

Abstract. Inadequate electricity access limits human development and affects quality of life in Africa. Hence, the improvement of electricity access has become a cornerstone of the African energy policy. This study proposes the use of satellite derived data of nighttime lighting, population count and Index Decomposition Analysis (IDA) to identify the driving factors for changing in electricity consumption in Africa between 2000 and 2013. The results of decomposition analysis indicated that population growth throughout the continent resulted in increased electricity consumption, while other factors had different effects. The results of this study could contribute to the design of better energy policy to achieve sustainable development of the continent.

Keywords: Africa, decomposition analysis, nighttime lighting, population count, electricity consumption.

1. Introduction

Universal access to modern energy is crucial to achieve sustainable development in Africa [1]. Central deficiency of African energy system, primarily in Sub-Saharan Africa, is the limited access to electricity. For example, average annual per capita residential electricity consumption of the household with electricity access in Sub-Saharan Africa (excluding South Africa) is around half the average amount of China, 20% of Europe and about 7% of the USA [2]. In general, energy poverty undermines education, healthcare and economic development of the vast majority of African nations. Hence, addressing this issue has become a regional energy policy challenge.

Energy development in the continent needs to keep pace with economic aspirations of the continent [2]. Kebede et al. (2010) identified the presence of positive relationship between economic growth and energy use and 1% GDP increase requires 0.55% increase in energy use in Sub-Saharan Africa [3]. Massive internal and external investments are required to improve energy access in Sub-Saharan Africa [4-5]. Moreover, there is no universal policy to ensure expansion of energy sectors due to significant regional diversity in energy systems, energy consumption economic structures and population structures [4-7].

It is proven that improved access to electricity has positive impact on African nations` health and education systems and private sector`s productivity [8]. However, power sectors of African states are significantly underdeveloped comparing to other developing countries [9]. Another constraint to development of the continent is the low reliability of electricity supply. It is estimated that the alleviation of electricity poverty in Sub-Saharan Africa requires almost 40 times increase of the electrification rate [10].

There are multiple international initiatives aiming to eradicate energy poverty in Africa. The African Development Bank focuses on technologies and subsectors that are important to address current and future energy demand of the content, including renewable energy, project related to fossil fuels, power transmission and distribution, region cooperation and supply- and demand-side energy efficiency measures [11]. To address the regional energy crisis, the Economic Community of West African States (ECOWAS) plans to attract private investments in energy efficiency and increase the use of renewable energy to address energy security and access challenges in the region [12-13]. The USAID-led "Power Africa" initiative aims to install additional 30 GW of power generation capacity, primarily renewable energy, to provide access to 60 million homes and businesses across the continent [14]. Akon Lighting Africa project intents to develop solar power solutions to provide electricity access to African villages [15]. As a part of its global "Shaping the Future of Energy" initiative, the World Economic Forum facilitates activities aiming to understand opportunities and obstacles to achieve universal electricity access in Africa through public private collaboration [16]. The Africa renewable energy initiative under African Heads of State and Government on Climate Change is set to utilize the renewable energy potential of the continent [17].

The continent possesses significant, but so far untapped energy resources [18-19]. In particular, utilization of abundant renewable energy resources considered being a solution to the existing energy crisis [1]. However, effective exploitation of the potential as well as development of adequate energy policy requires thorough understanding of driving factors behind electricity consumption in Africa.

2. Literature Review

Index Decomposition Analysis (IDA) has been widely utilized to assess changes in aggregate national and regional energy consumption. Furthermore, several studies used decomposition analysis of sectoral energy consumption in Africa.

Karekezi (2002) indicated that changing population structure and economic growth are the main factors behind the growing demand for modern energy services [7]. It was defined that the urbanization and growing wealth are the key drivers of demand. The study demonstrated inadequate energy services for the poor in Africa.

Ben Hammamia et al. (2014) utilized the Fisher Ideal Index decomposition methodology to decompose energy intensity in Tunisia into two factors: structural change of the economy and energy efficiency [20]. It was identifies that improved energy efficiency was the main driving factor in reduction of energy intensity in the period 1990-2008. Additionally, increased role of service sector in the Tunisian economy also contributed to reduction of the energy intensity.

Iglesi-Lotz and Blignaut (2011) utilized the three factor (output, structural changes and efficiency improvements) sectoral decomposition analysis to define the driving forces of electricity consumption in the

South African economy for the period 1993-2006 [21]. The results indicated that the sectoral activities were the primary factor behind the increase in electricity consumption, followed by structural changes. Efficiency improvements were not sufficient to offset the combined effects of output and structural effects on electricity consumption.

Olanrewaju et al. (2013) developed a combined Index Decomposition Analysis-Artificial Neural Network-Data Envelopment Analysis (IDA-ANN-DEA) model to assess the industrial energy consumption in South Africa for the period 1971-2008 [22]. Energy consumptions of the 11 sectors were decomposed into three explanatory factors: activity, structure and energy intensity. The results of IDA indicated that the activity had the biggest effect on energy consumption, while the structure and intensity effects were negligible.

Decomposition analysis of residential electricity consumption in the United States of America indicated that the number, the size of the homes and increased electricity intensity per foot caused significant rise in electricity use [23]. Decomposition analysis of regional energy and electricity consumption and consequent ranking of the regions in China and India respectively revealed different driving factors and significant regional differences in consumption and saving potential, implying the need for distinctive regional energy saving policy needs [24-25]. Decomposition analysis of household electricity consumption in Indonesia indicated significant contribution of electrified households to GDP, while the effects of intensity and efficiency were smaller [26].

The night-time light (NTL) satellite data was used in research for different purposes, from urban land extraction and poverty analysis [27, 28-31]. Furthermore, the NTL data was widely used to assess economic and energy poverty in Africa. For example, Elvidge et al. (2009a) produced a global poverty map using satellite data of population count and NTL [27]. A poverty index was calculated by dividing population count by NTL. Authors assumed that areas with higher population counts and lower NTL in developing countries would have higher poverty level and vice versa. NTL was considered as a proxy for wealth. It was estimated that there were 20 African countries among the countries with population larger than 10 million and poverty level higher than 50%. African countries with greater than 80% poverty level were Ethiopia, Burkina-Faso, Madagascar, Uganda, Tanzania, Malawi and Niger, while the country with the lowest poverty rate (34%) was South Africa.

Doll and Pachauri (2010) utilized global datasets of NTL, a gridded population dataset and a global urban area dataset to estimate population without access to electricity by comparing satellite data to the International Energy Agency (IEA) statistics on electricity access between 1990 and 2000 [32]. The study showed the decline of population without access to electricity in North Africa, while in Sub-Saharan Africa population without electricity increased, indicating the slow progress in providing electricity assess in the latter region. It was partially due to the low population densities in rural areas.

Min et al. (2013) used NTL imagery to detect rural electrification of the villages in Senegal and Mali by comparing satellite data with survey data [33]. The study utilized a direction algorithm based on NTL and the geographic location of the villages to classify electrified villages. It demonstrated the direct correlation between NTL and access to electricity of the villages. Electrified villages appeared to be brighter and vice-versa.

This paper aims to identify factors of electricity consumption in Africa using three-factor (electricity intensity of the economies, economic activity and population) decomposition analysis and assessment of NTL satellite data for the period 2000-2013. On top of that, the study investigates the changes in energy profiles, electricity production and consumption patterns of African states during the same period. It also reviews demographics and socioeconomics of the countries. The ultimate goal of this study is to contribute to the existing research and better understanding of the African energy system.

The rest of this paper is organized as follows. A brief overview of energy profiles of African countries with focus on electricity sector is done in Chapter 3. Chapter 4 describes methodology and sources of data. The results are presented and discussed in Chapter 5. Chapter 6 provides conclusions of this research and future studies.

3. Energy Profiles of African Countries

Africa possesses more than sufficient energy resources to satisfy its demand [2]. However, the potential remains mainly untapped. Underdeveloped electricity infrastructure and population trends are the main obstacles to African energy and economic development [2, 6]. Furthermore, energy profile and the relationship between energy consumption and economic growth in the African countries are notably divergent [34].

Electricity consumption in Sub-Saharan Africa is the lowest in the world [35], while Northern African countries consume significantly more electricity. There are significant disparities in electricity consumption among the African countries as displayed in Fig. 1. South Africa is the highest consumer of electricity on the continent. In contrast, Guinea-Bissau consumed only 35 GWh of electricity in 2013, which constituted only 0.02% of South Africa`s total final electricity consumption. Top-10 countries consume 84% of total final electricity in Africa. Share of electricity in the total final consumption (TFC) is generally higher in more developed countries and Small Island Developing States (SIDS). Lower share of electricity consumption in the TFC are primarily observed in countries with significant energy resources and the less developed countries.
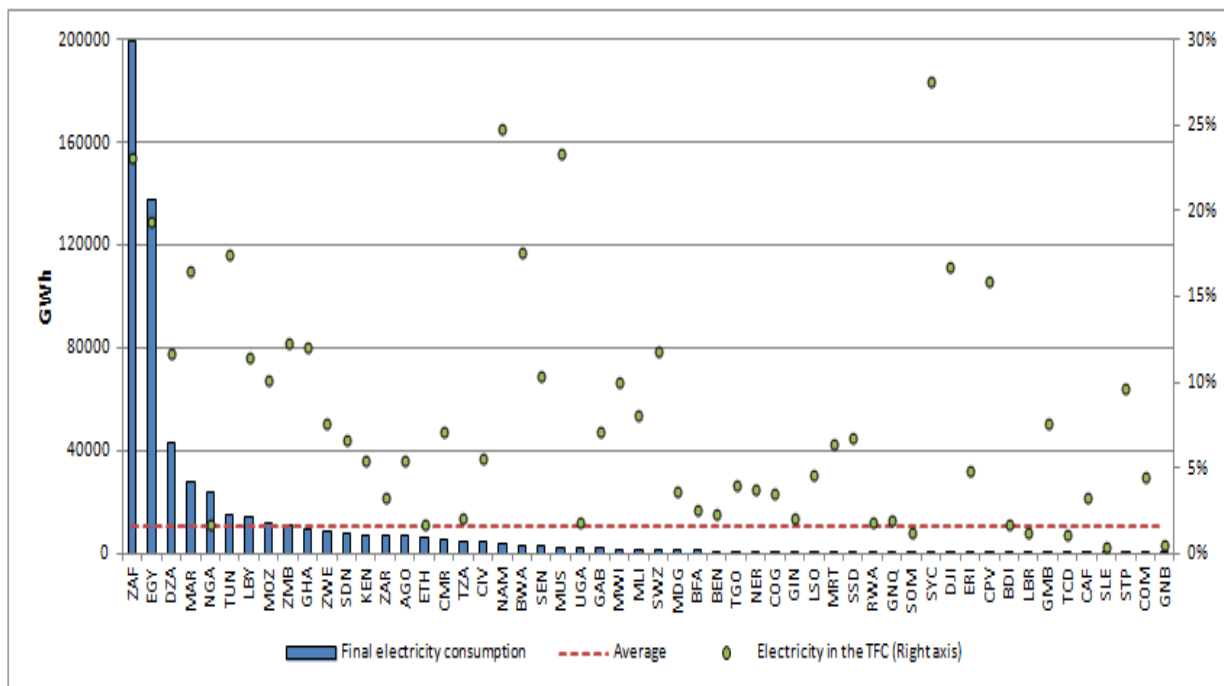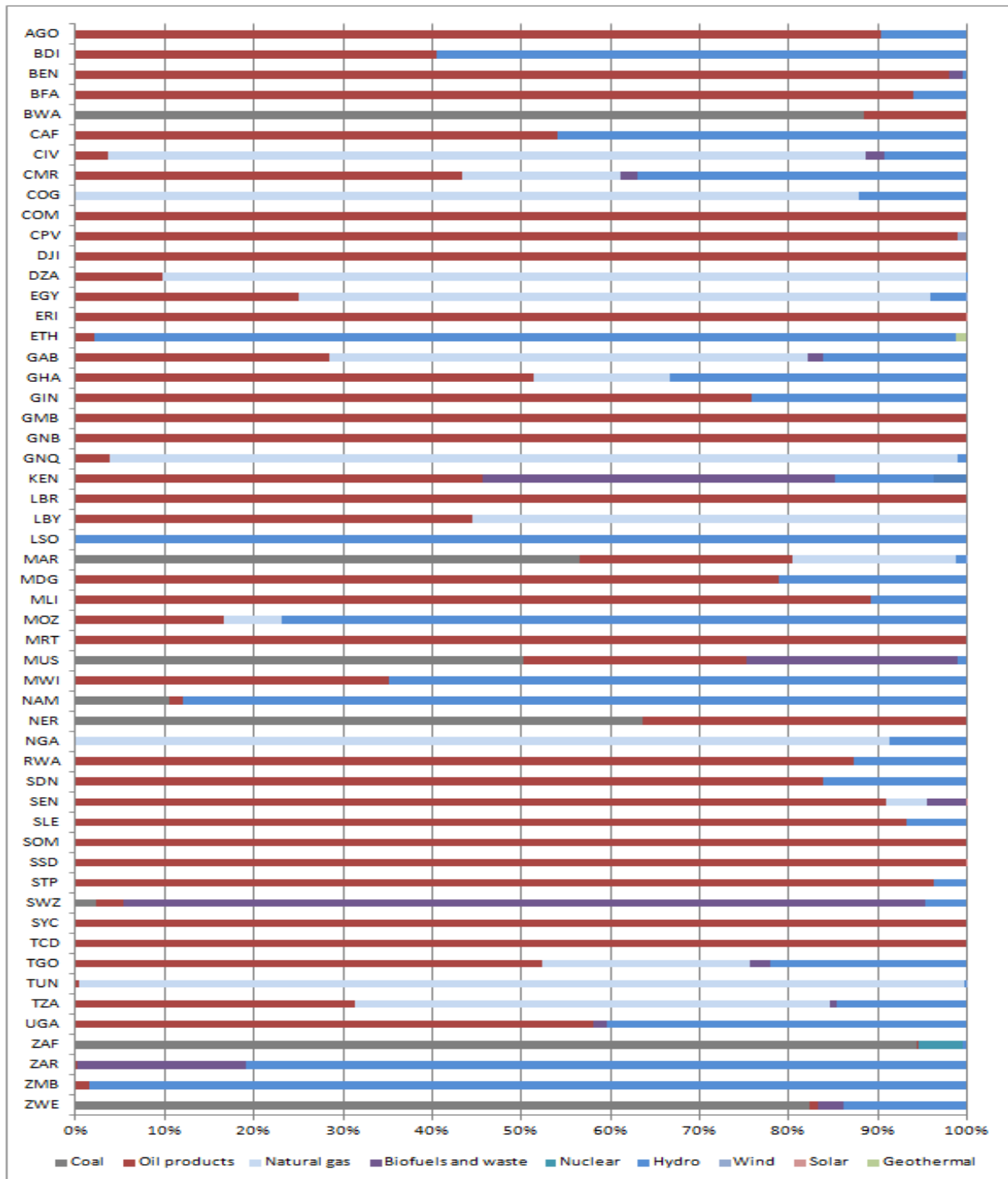

Source: Authors` calculations using UN data [36].

Fig. 1.   Final electricity consumption in Africa in 2013.

There are also substantial variations in installed capacities due to alterations in socio-economic factors, infrastructure development and resources availability. African countries with the largest installed capacities are South Africa and Egypt. Island nations of Comoros and Sao Tome and Principe are notable for their low installed capacities on the continent. Total installed capacities have declined in Eritrea, Seychelles and Zimbabwe by 25 MW, 3 MW and 2 MW respectively since 2000. Meanwhile, total installed capacity in Equatorial Guinea has increased by almost 3000% since 2000 due to utilization of abundant hydrocarbon resources and hydropower potential.

Electricity fuel mix in Africa varies significantly from one country to another due to availability of energy sources. South Africa is the largest electricity consumer of the continent and only country with operating commercial nuclear reactors. Oil products (52%) dominate the fuel mix for electricity production in Africa, followed by hydropower (20%) and natural gas (16%) as seen in Fig. 2. Coal is the dominant fuel in South Africa, Botswana, Niger, Morocco, Mauritius and Zimbabwe. Non-hydro renewable energy constitutes only 0.1% of the TFC of the continent. The largest producers of non-hydro renewable energy are Kenya (4%), Cabo Verde (1%) and Ethiopia (1%). The African Great lakes and the river Nile are important for hydropower production for the countries located around the reservoirs.

Source: Authors` calculations using UN data [36].

Fig. 2.   Fuel shares of total electricity generation in Africa in 2013.

Industry (43%) is the largest consumer of electricity, followed by residential (33%) and other sectors (24%) in the continent as seen in Fig. 3. In Mozambique industry accounts for 80% of final electricity consumption, while the residential consumption (83%) is the largest in Gambia. Electricity is used by households primarily for lighting and electrical appliances, while it is widely unaffordable for cooking in Africa [37]. It is likely that the share of residential sector in many African countries would be higher if better access to electricity was achieved.
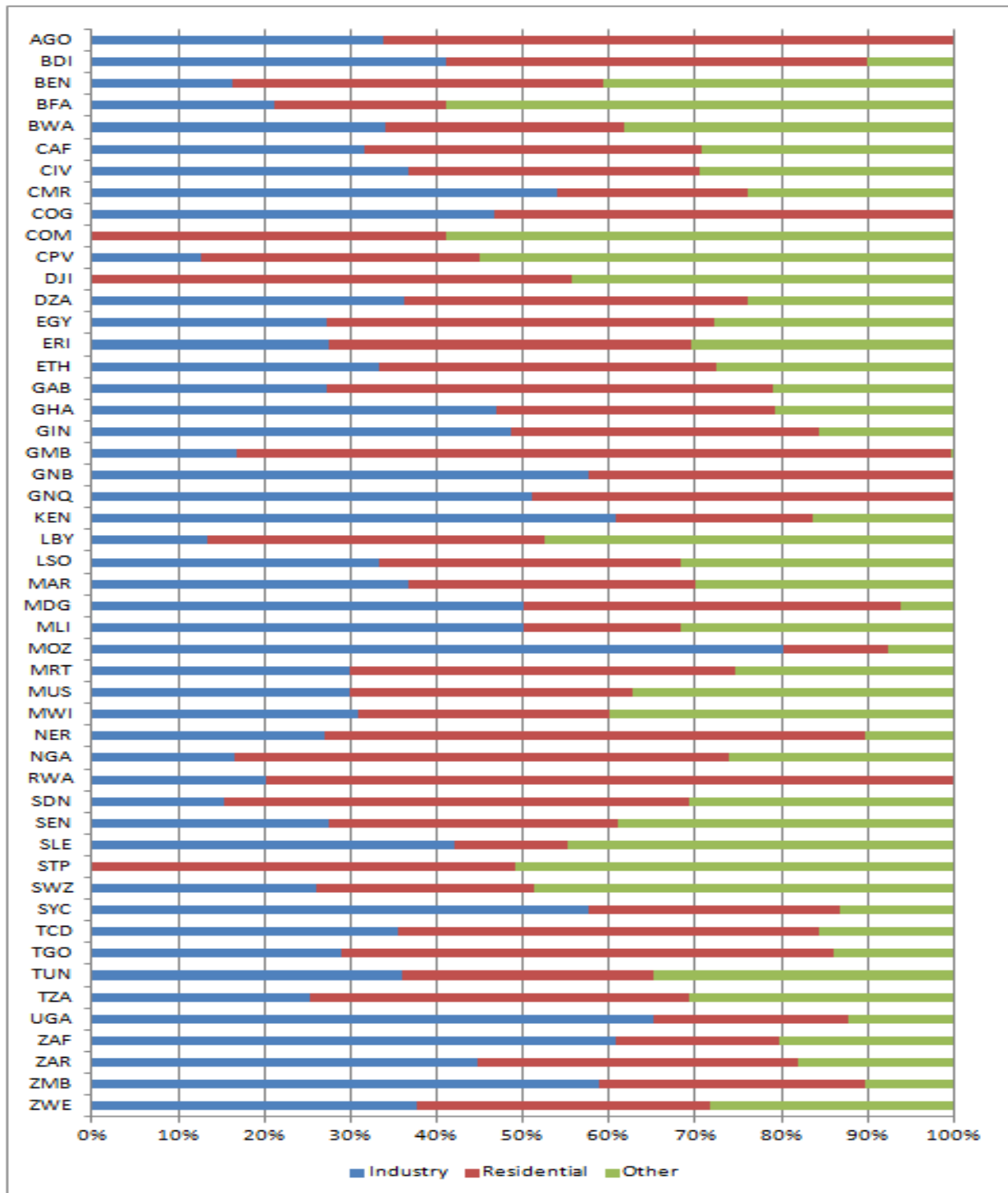
Source: Authors' calculations using UN data [36].

Fig. 3.   Final consumption of electricity by sector in Africa in 2013.

According to the World Bank data [38], 828 million people in Africa do not have access to electricity, of which 495 million live in rural area and 333 million live in urban area. All population of Northern African countries has access to electricity, while only about 5% of South Sudanese have access to electricity as presented in Fig. 4. Continent-wide about 70% of urban population and 27% of rural population have access to electricity. Poverty, gross domestic savings, corruption, share of rural population and population density are the main factors of the electricity access variations in Sub-Saharan Africa [6].
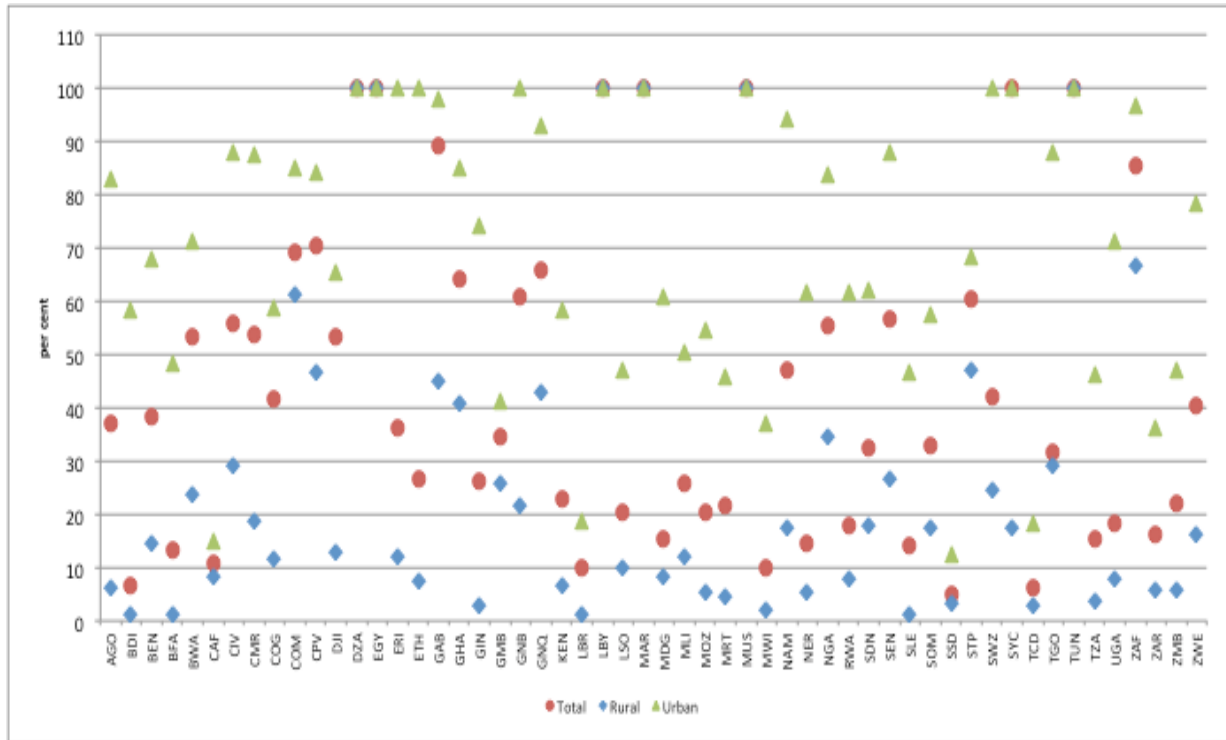
Source: Authors' calculations using World Bank data [38].

Fig. 4.   Access to electricity of urban and rural population in Africa in 2012.

Significant variations in electricity profiles of African countries imply the need for the country specific energy policies based on analysis factors of electricity consumption in Africa. Understanding the main reasons for underlying changes in electricity consumption can assist in addressing energy security of the African countries. To the best authors` knowledge, this is the first continent wide attempt to perform decomposition analysis electricity consumption and satellite derived data assessment.

4.   Data and Methodology

This study utilizes temporal decomposition analysis of economic and demographic factors affecting electricity consumption and spatial assessment of satellite derived NTL and population count. After that, the results of decomposition analysis are combined with satellite data. Socio-economic and electricity indicators of the countries under analysis are presented in Appendix I.

4.1. Decomposition Analysis of Electricity Consumption

Index Decomposition Analysis is the preferred methodology in energy studies to investigate factors influencing energy consumption [39]. The Logarithmic Mean Divisia Index (LMDI) is the preferred method among the existing IDA methodologies due to theoretical robustness, adaptability, and availability of perfect decomposition [40]. This study aims to conduct decomposition analysis of the factors affecting total electricity consumption between 2000 and 2013 in the African countries. Total electricity consumption is decomposed into three explanatory factors as follows:

$$\sum_i E_i = \sum_i P_i \frac{E_i}{Q_i} \frac{Q_i}{P_i} = \sum_i P_i I_i A_i \qquad (1)$$

where E_i is the total final electricity consumption (GWh) in country i. Q_i is the Gross Domestic Product (GDP) (Purchasing Power Parity [PPP] based constant 2011 international USD) in country i, I_i is the electricity intensity of GDP (GWh/PPP constant 2011 international USD) in country i, A_i denotes economic activity (PPP constant 2011 international USD per capita) in country i, and P_i is the total population in country i.

Total changes in electricity use between target year (2013) and base year (2000) is expressed as follows:

$$\Delta E_i = E_i^{2013} - E_i^{2000} = \Delta E_{pop} + \Delta E_{int} + \Delta E_{act} \qquad (2)$$

where ΔE_{pop} is the changes in electricity consumption caused by changes in population, ΔE_{int} denotes changes in electricity consumption due to changes in electricity intensity of GDP, and ΔE_{act} is the changes in electricity use caused by changes in economic activity.

The explanatory factors are expressed as follows:

$$\Delta E_{pop} = \sum_i w_i \ln\left(\frac{P_i^{2013}}{P_i^{2000}}\right) \qquad (3)$$

$$\Delta E_{int} = \sum_i w_i \ln\left(\frac{I_i^{2013}}{I_i^{2000}}\right) \qquad (4)$$

$$\Delta E_{act} = \sum_i w_i \ln\left(\frac{A_i^{2013}}{A_i^{2000}}\right) \qquad (5)$$

Due to limited data availability, Eritrea, Somalia, and Western Sahara are excluded from data decomposition analysis, but available for NTL and population count assessment. For the purpose of analysis, data for former Sudan (including South Sudan) is used for decomposition analysis. Total number of countries analyzed is 51. Total electricity consumption data is from UN Data [36], while GDP data in Purchasing Power parity based 2011 international USD and population data are acquired from World Bank data [38]. Table 1 presents the overview of the indicators considered in this study.

Table 1. Electricity consumption indicators.

Indicator	Unit	Mean		Max		Min	
		2000	2013	2000	2013	2000	2013
E	TWh	6.72	11.43	162.52	199.31	0.02	0.04
P	Mln.	15.7	21.8	122.9	172.8	0.1	0.1
A	PPP (2011) USD/capita	4111	5665	21997	34233	518	561
I	MWh/Mln. PPP (2011) USD	51	51	372	424	7	6

Although there is internationally accepted definition of official electricity consumption, in international practice statistics is usually referred as official statistics if it follows the United Nations Fundamental Principals of Official Statistics [41]. The UN electricity consumption data are collected from the national official statistical agencies following methodological recommendations from the United Nations on the sources, methods and procedures of the statistics [42]. Furthermore, the United Nations have also developed specific recommendations for countries with less sophisticated data compilation and analysis technique [43].

Three most common methods to convert GDP into a common currency are nominal, real and purchasing power parity. Nominal GDP uses market exchange rate and does not take into account differences in the cost of living in different countries. The indicator could be used for spatial analysis in a given year. Real GDP adjusts the value of economic output for price changes between different time periods. The indicator could be suitable for temporal decomposition analysis. However, a combination of temporal decomposition analysis and spatial analysis of NTL and population count requires a macroeconomic measure of the value of GDP adjusted to the cost of living in different countries of the continent. Hence, GDP PPP is more useful when comparing difference in living standards between the African nations.

Mean values of all indicators, apart from electricity intensity, have increased since 2000. Electricity consumption in more developed countries has grown larger than in the least developed countries in Africa. Faster population growth (more than 50%) was observed in DR Congo, Gambia, Mali, Niger and Uganda. Faster economic growth (more than 100%) was observed in Chad, Equatorial Guinea, Ethiopia, and Mali, while GDP per capita has declined in Central African Republic, Comoros, Cote d`Ivoire, Liberia, Libya, Madagascar, and Zimbabwe since 2000. Average continent-wide electricity intensity of GDP has not changed since 2000. Electricity intensity has grown faster (more than 100%) in Angola, Gambia, and Mozambique,

while the indicator has declined in Chad, DR Congo, Ghana, Guinea, Malawi, Mali, Namibia, Sierra Leone, South Africa, Swaziland, Uganda, Zambia, and Zimbabwe.

4.2. Assessment of NTL and Population Count

The NTL dataset is a very import source of information for electricity consumption analysis. This data can be easily accessed, thus giving an opportunity for researchers to explore and understand the elements involved in the energy sectors. This study focused on Africa as a whole with some special cases highlighted as they stood out during the analysis.

Satellite derived data of NTL and the gridded human population of the world on a continuous raster surface were used for analysis. Since the release of the first version in 1995, the essential inputs to Gridded Population of the World (GPW) have been population census and administrative boundaries. The purpose of GPW v4 is to provide a spatially-disaggregated population layer that is compatible with datasets from social, economic, Earth science disciplines, and remote sensing data. It provides globally consistent and spatially explicit data for use in research, policy-making, and communications [44]. These datasets are constructed from national or sub-national input for administrative units. GPW v4 is gridded with an output resolution of 30 arc-seconds, or ~1 km at the equator. Separate grids are available for UN-adjusted population counts, population density, data quality indicators, and land and water areas [44]. In total, eight datasets within the GPW v4 are available. Three datasets from this collection were used, namely the UN-Adjusted Population Count v4, Land and Warer Area v4, and National Identifier Grid v4. The land and water area were used as a mask for the UN-Adjusted Population Count, v4 for years 2000, 2010 and 2015. Unfortunately in the GPWv4 data there is no information for year 2013, consequently the average of the years 2010 and 2015 was used for year 2013. Then the continent was split into countries using National Identifier Grid, v4. To avoid any mismatch in terms of area or country extension between the datasets, the GPW v4 and the NTL used the same National Identifier Grid v4.

The NTL data was acquired from the National Oceanic and Atmospheric Administration`s National Geophysical Data Center [45]. The Global Gas Flares data was also used as a mask for the African countries with oil and gas activities [46]. According to Elvidge et al. (2009b), in the production of the gas flares polygon vectors each of the Defense Meteorological Satellite Program (DMSP) features suspected to be gas flares and inspected in higher resolution remote sensing data available in Google Earth [47].

Both the NTL and the population data are version 4 and have an output resolution of 30 arc-seconds or ~1 km, and were reprojected to Geographic Lat/Lon WGS_1984 geographic coordinate system. The NTL are cloud-free composites of the highest quality. In cases where two satellites collected data, the composites were produced [45]. The NTL data F142000, F152000 and F182013 were used for this analysis. For the data where two composites were present, the case of year 2000, an average was taken in order to avoid any missing information that could be present in one satellite and missing in the other. If only one satellite data was available, no changes were made. Each country data was subset by using the national identifier grid shapefile from the Socioeconomic Data and Applications Center (SEDAC) for both the NTL and population count [48].

After extracted by country, the NTL data was further refined through the gas flares shapefile in countries with gas flares to remove them from the NTL data composite. A total of 17 countries were masked for gas flares. If there was any problem related to the shapefiles, the kmz files were used to support the identification and demarcation of the respective gas flares on the ground by using the high-resolution Google Earth imagery. For example, in Nigeria the mask area includes a big number of cities such as Koko, Orhuwhorun, Islokolo, Yenagoa and Port-Harcourt, just to mention a few. Therefore, the shapefiles for flare gas were adjusted guided by the original from the DMSP product. Once refined the raster data was extracted given the condition NTL>0. Only pixels with a digital number (DN) greater than 0 were used, knowing that the DN ranges from 0 to 63, and this process was done using ArcMap 10.1 and ENVI version 5.1. The same condition was given to the UN-Adjusted Population Count. From the extracted pixels mean values were calculated for each country on the yearly basis and further used in the analysis

Many researchers have pointed out some drawbacks of the NTL data, e.g. the so-called "overglow", which tends to over-represent the extent of lit area [49]. In most of the studies a threshold is set depending on the purpose of the research. Many areas in Africa have no NTL, but have population present causing a gap between the existing population and the non-lit area. It is assumed that the overglow phenomenon can actually have a positive effect. In a sense, that it is an indicator of the increase in the actual NTL.

5. Results and Discussion

The results of the study are organized into the sections, reporting the results of decomposition analysis, NTL and population count assessment and combined results of decomposition and satellite derived data analyses. The states are grouped into three groups based on mean NTL: high (NTL>1000 km²); medium (1000 km²>NTL>100 km²) and low (NTL<100 km²).

5.1. Results of Decomposition Analysis

The results of decomposition analysis are presented in Appendix II. Total electricity consumption in all 51 countries has increased by almost 70% since 2000. However, the growth was unequal. High NTL countries has accounted for 74% of total increase in electricity consumption, followed by medium NTL countries (22%) and low medium NTL countries (4%). The biggest electricity consumption increase occurred in Mozambique (by 1046%), while consumption in Zimbabwe and Sierra Leone declined by 21% and 15% respectively.

Average electricity consumption by high NTL countries has increased by 104% since 2000. The biggest increase occurred in Nigeria and the lowest was in South Africa. Electricity intensity of GDP was the main relative factor that has affected electricity consumption in Algeria, Libya and Tunisia, while changes in economic activity have had the biggest effect in Egypt, Morocco, Nigeria and South Africa. ΔE_{int} was the highest in Algeria and the factor caused the relative decline in South Africa by 21%. It is possible that the decline in the latter might indicate improvements in energy efficiency. ΔE_{act} was the highest in Nigeria and the factor caused the relative decline in Libya by 14%. The decline in the latter was likely caused by Libyan civil war. ΔE_{pop} was the positive relative factor on electricity consumption in all high NTL countries with the highest effect in Nigeria and the lowest in Libya.

Average electricity consumption by medium NTL countries has increased by 205% since 2000. The biggest increase was observed in Mozambique and the electricity consumption declined in Zimbabwe. Electricity intensity of GDP was the main relative factor in Angola, Congo, Mozambique and Sudan (former). Economic activity was the main relative factor in Botswana, Ethiopia, Ghana, Namibia, Tanzania and Zambia. Population was the main relative factor in Cameroon, Cote d'Ivoire, DR Congo, Kenya, Senegal and Zimbabwe. ΔE_{int} was the highest in Mozambique and caused the biggest relative decline in Ghana. It is possible that the energy efficiency contributed to relative decline in electricity consumption in Ghana and Namibia due to high access to electricity, while in DR Congo, Zambia and Zimbabwe the relative decline was caused by insufficient electricity supply. ΔE_{act} was the highest in Mozambique and caused the biggest relative decline in Zimbabwe. The latter is likely was caused by considerable economic hardship. ΔE_{pop} was the positive relative factor on electricity consumption in all medium NTL countries with the highest effect in Mozambique and the lowest in Zimbabwe.

Average electricity consumption by low NTL countries has increased by 124% since 2000. The biggest increase occurred in Equatorial Guinea and the consumption of electricity declined in Sierra Leone. Electricity intensity of GDP was the main relative factor in Central African Republic, Comoros, Gabon, Gambia and Sao Tome and Principe. Economic activity was the main relative factor in Cabo Verde, Chad, Djibouti, Equatorial Guinea, Lesotho, Mali, Mauritius, Rwanda, Seychelles, Sierra Leone and Uganda. Population was the main relative factor in Benin, Burkina Faso, Burundi, Guinea, Guinea-Bissau, Liberia, Madagascar, Malawi, Mauritania, Niger, Swaziland and Togo. ΔE_{int} was the highest in Equatorial Guinea and caused the biggest relative decline in Sierra Leone. It could be argued that the relative decline caused by the indicator in low NTL states was due to insufficient electricity supply. ΔE_{act} was the highest in Equatorial Guinea and caused the biggest relative decline in Central African Republic. ΔE_{pop} was a positive relative factor on electricity consumption in all low NTL countries with the highest effect in Equatorial Guinea and the lowest in Mauritius.

Uncertainties of energy decomposition analysis results are associated with quality and selection of data source [24]. For example, using real GDP instead of the output adjusted to PPP may lead to different decomposition results [50]. Furthermore, using electricity consumption from other sources (i.e., International Energy Agency or national statistical agencies) might also lead to different outcomes.

5.2. Results of NTL and Population Count Assessment

The NTL data from 2000 and 2013 for African countries has shown a mixture in terms of increase and decrease in lit area as seen in Fig. 5. Our analysis showed that all African countries had an increase in NTL, however some countries with a high and others with a minimum increase. Countries like Congo, Equatorial Guinea, Kenya, Liberia, Zimbabwe and Gambia presented a minimum (1 km²) increase of NTL among the African countries. On the other hand, Tunisia, Ghana, Tanzania, Egypt, Angola, Cape Verde and Mozambique have shown the highest increase in NTL from 2000 to 2013 and it varies from 381 km² in Angola and 4089 km² in Tunisia.
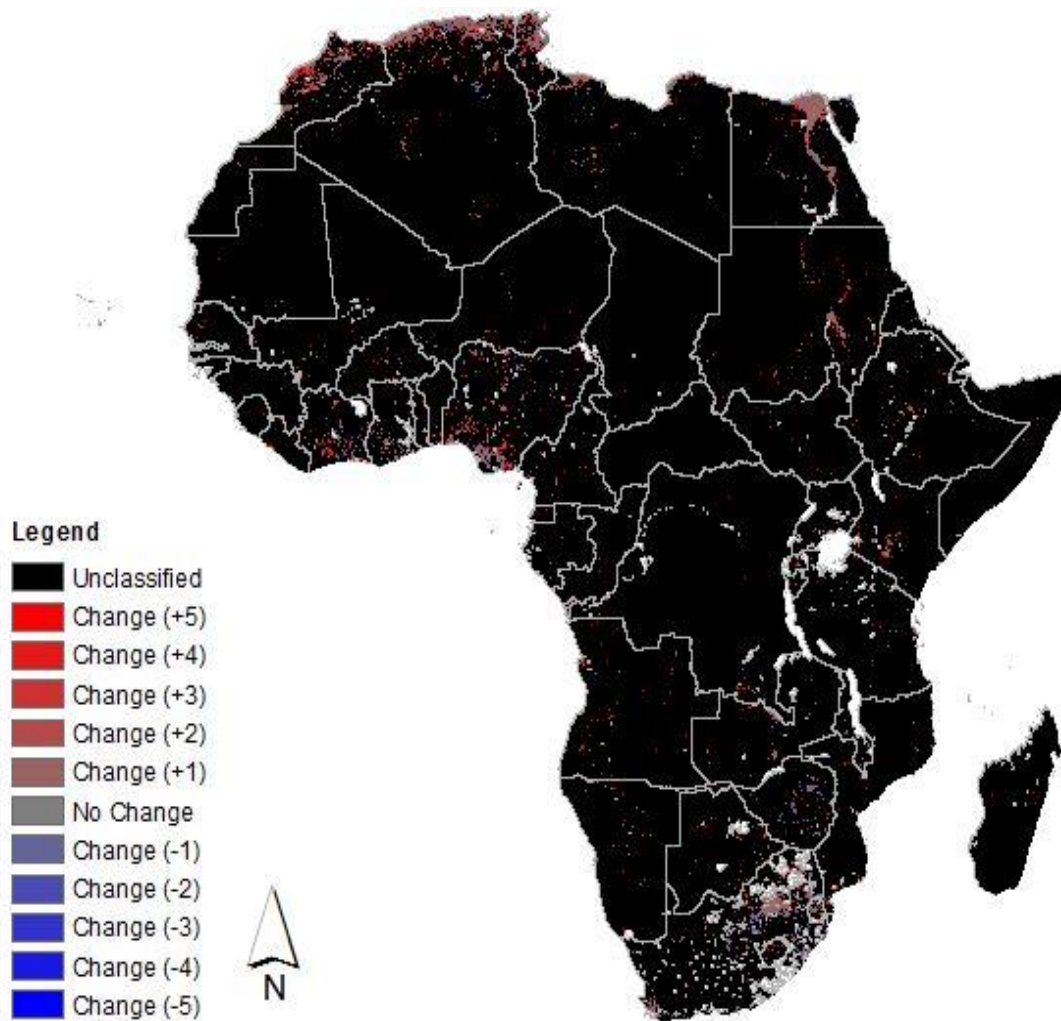

Fig. 5.   Changes in NTL (km²) between 2000 and 2013.

From these results, it is obvious the presence of countries with high growth in electricity intensity more than 100%, Angola, Gambia, and Mozambique, at the same time countries with more than 50% in population growth. Although some countries have increased their NTL, it may not be related to their total electricity consumption, especially in Africa where few infrastructures are capable of functioning in the evening. Mozambique has shown the biggest increase in electricity consumption and it has also increased NTL, but from its total consumption only 20% goes to the residential. This increase can be justified by the increase in population and GDP. Two countries from the northern part of Africa have also shown an increase in NTL.

In general, the population count has increased for all the countries in Africa (Fig. 6). Countries with the highest increase are Nigeria, Ethiopia, Egypt, Uganda, Democratic Republic of Congo Tanzania and Kenya. These are just the outstanding ones among all the increases in population count in the continent. It is important to point out that although some countries are more developed than others, the tendency of

population and NTL, if not disturbed by any natural disasters or armed conflict, is set to increase. However, the increase in population is not directly correlated with NTL increase, as we have seen in some countries in Africa, where the electricity consumption are diverted to other sectors other than residential and NTL are mostly representative of cities, towns and other places with persistent lights that can be detected at night by the satellite.
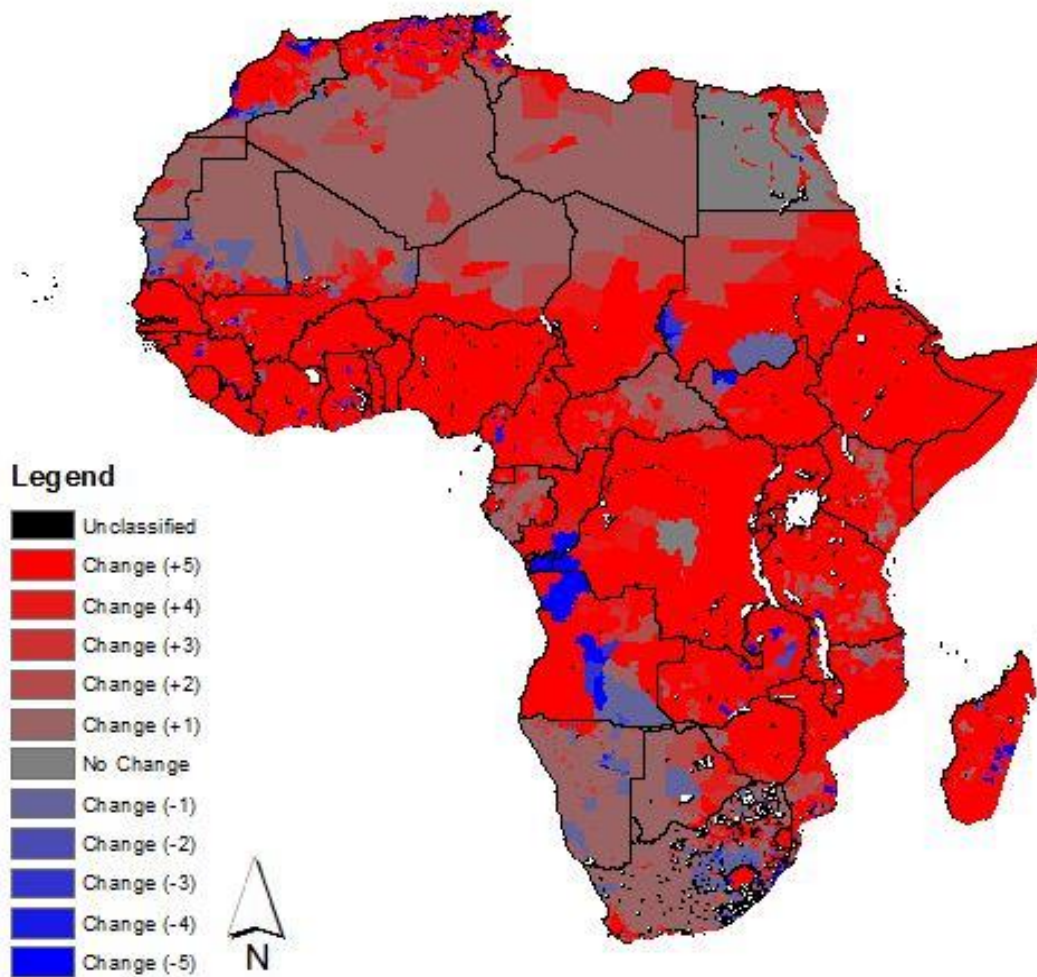

Fig. 6. Changes in population count per km² between 2000 and 2013.

In general, in most of the sub-Saharan countries, the population count has had a positive change. However, there can be some sources of uncertainty for both population count and NTL data sets. The uncertainties could be a result of the different approaches in collecting the data, and the satellite sensitivity loss during the years.

5.3. Combined Results of Decomposition Analysis and Satellite Derived Data Assessment

Average continent-wide NTL has increased by 43% since 2000. However, the growth was unequal between the groups. The NTL has increased in high, medium and low NTL countries by 11%, 32% and 18% respectively since 2000. Population count in high, medium and low NTL countries by 27%, 39% and 32% respectively since 2000.

The countries where NTL has declined since 2000 include Cameroon, Cote d'Ivoire, Ghana, Zimbabwe, Cabo Verde, Comoros, Guinea-Bissau, Lesotho, Madagascar, Malawi, Seychelles and Swaziland. Meanwhile, the highest increase in NTL was observed in Congo. The economic activity decline was observed in Libya, Cote d'Ivoire, Zimbabwe, Central African Republic, Comoros, Liberia, Madagascar and Togo, while GDP in Equatorial Guinea has increased by 194% since 2000. Electricity intensity of GDP has declined since 2000

in South Africa, DR Congo, Ghana, Namibia, Zambia, Zimbabwe, Guinea, Malawi, Mali, Sierra Leone, Swaziland, Chad and Uganda, while the highest growth was observed in Mozambique.

Figure 7 presents the graph of NTL and population count in high NTL countries in 2013. It is shown that Nigeria may face the urgent need to improve its electricity supply due to fast total population (41%) and population count per km² (39%) growth. Egypt may have similar problems if the current population growth and urbanization rate persist. In total, population count growth since 2000 in high NTL countries was the slower (27%) comparing with other groups. The combination of the highest NTL in Africa, modest population count, diverse electricity mix and the highest installed capacity of power plants in the continent makes South Africa relatively safe in terms of energy security. The only factor of concern in South Africa is access to electricity (85% of total population and 67% of rural population).
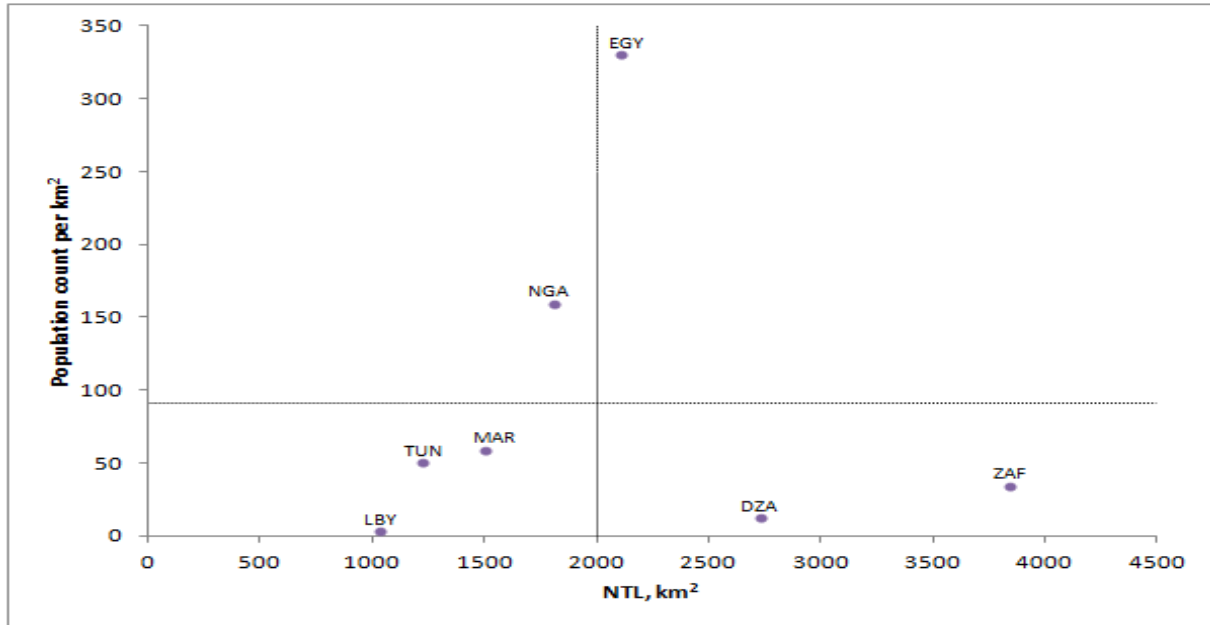
Fig. 7.   NTL and population count in high NTL African countries in 2013.

Libya and South Africa have experienced below average electricity consumption and NTL growth for period under investigation as shown in Fig. 8. It is possible that in the case of Egypt and Nigeria electricity consumption growth did not result in subsequent NTL increase due to higher population growth and urbanization. NTL has remained almost unchanged in Libya since 2000.
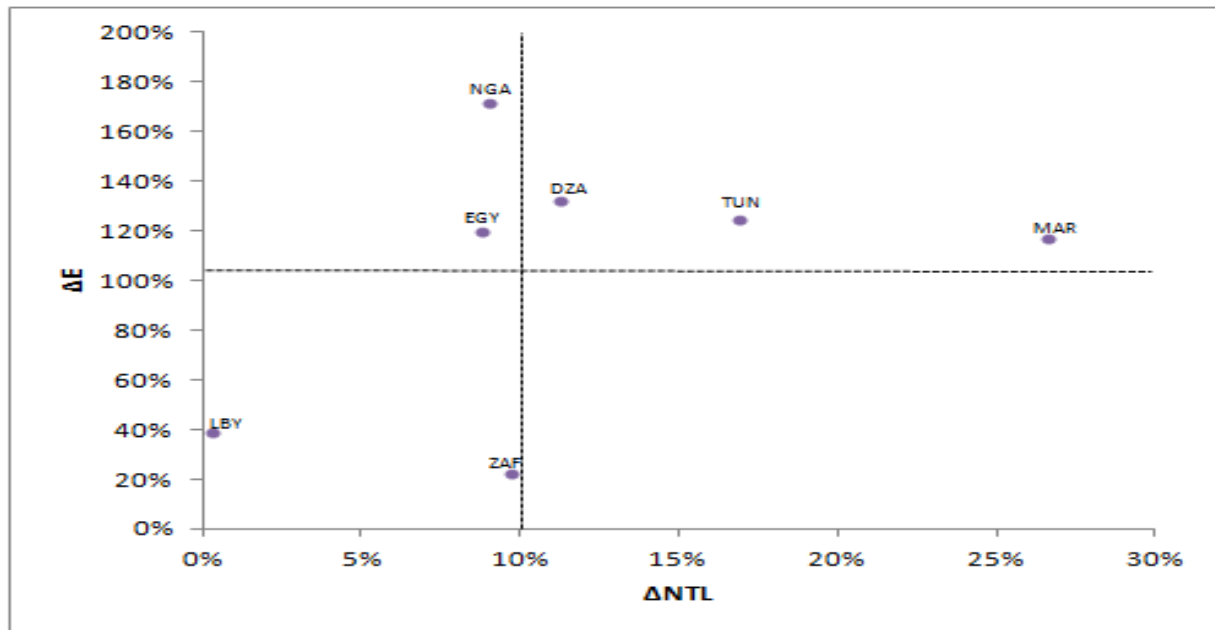
Fig. 8.   Changes in NTL and electricity consumption in high NTL African countries, 2000-2013.

The issue of electricity supply could become crucial for medium NTL Cameroon, Ethiopia, Senegal and Tanzania due to higher population count as seen in Fig. 9. Average population count in medium NTL countries has increased by 39% since 2000, faster than in other groups. However, the lower growth was observed in Botswana, Cote d'Ivoire, Namibia and Zimbabwe by 24%, 30%, 23% and 18% respectively. Population count in Namibia is the lowest in Africa, followed by Botswana and Libya.
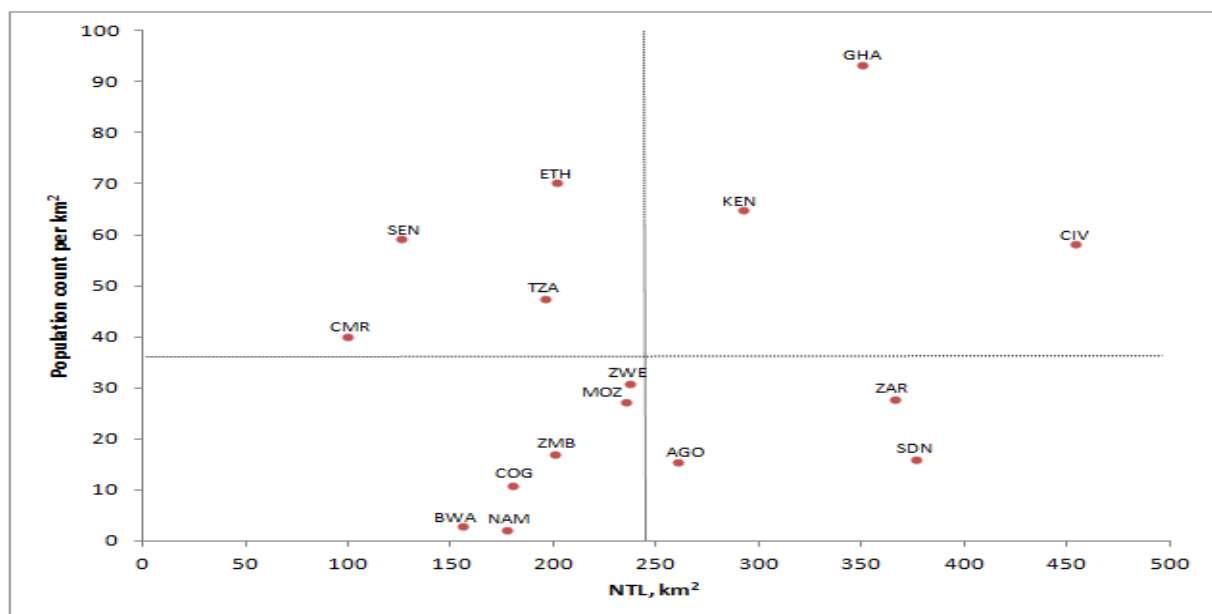
Fig. 9.   NTL and population count in medium NTL African countries in 2013.

Angola, Ethiopia, Congo, Mozambique and Sudan (former) have achieved significant increase in electricity consumption since 2000 as displayed in Fig. 10. It was primarily due to stronger economic growth and increased expansion of power plant capacities. NTL in Congo and DR Congo have increased by 431% and 316% respectively since 2000. Although Cote d'Ivoire has the largest lit area among the medium NTL countries, the indicator has declined since 2000 due to slower economic growth. It is likely that the ongoing economic and political crisis in Zimbabwe affected both electricity consumption and NTL area.
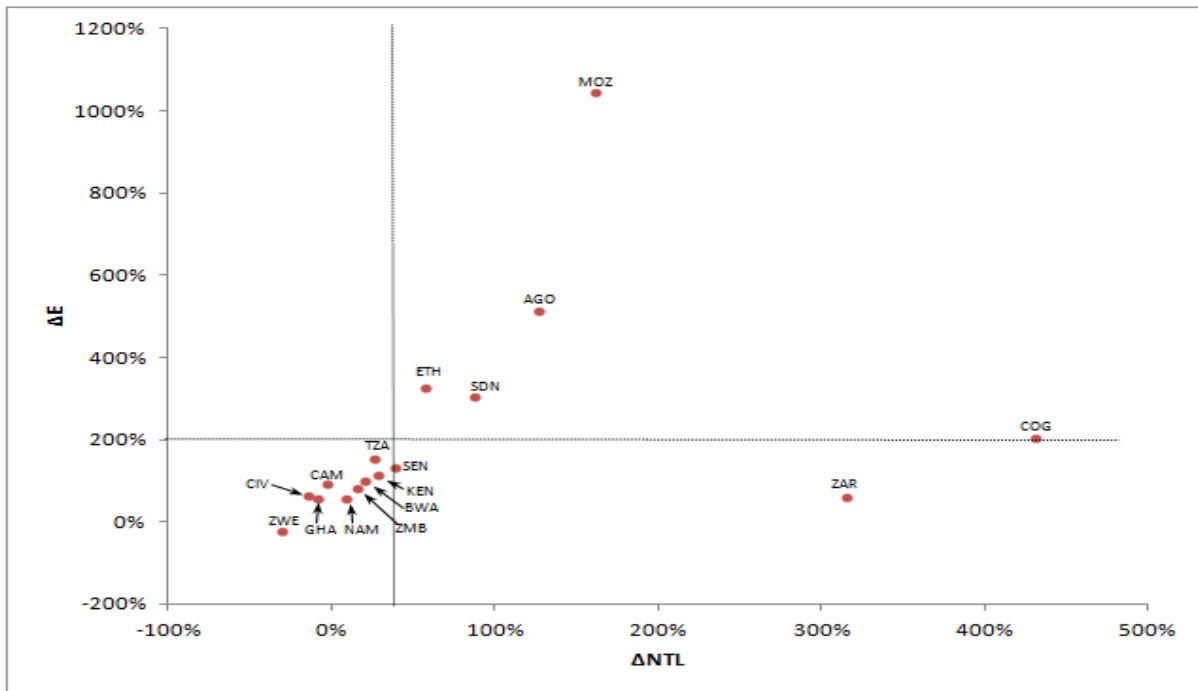
Fig. 10. Changes in NTL and electricity consumption in medium NTL African countries, 2000-2013.

There is a notable contrast in both NTL and population count among the low NTL countries as seen in Fig. 11. Comoros, Burundi, Mauritius and Rwanda have significantly higher population count. However, unlike other countries of the group, 100% of population in Mauritius has access to electricity, while only about 7% of population in Burundi has access to electricity. Guinea-Bissau is the country with the lowest NTL in Africa, while the population count in Mauritius is the highest in the continent. The highest total population growth in Africa since 2000 was observed in Niger, while the lowest was in Mali.

Fig. 11. NTL and population count in low NTL African countries in 2013.

Equatorial Guinea has achieved significant increase in both NTL and electricity consumption since 2000 as shown in Fig. 12. This is due to almost 200% growth in GDP per capita since 2000. Meanwhile, NTL in Comoros and Guinea-Bissau have dropped notably since 2000 by 77% and 50% respectively.
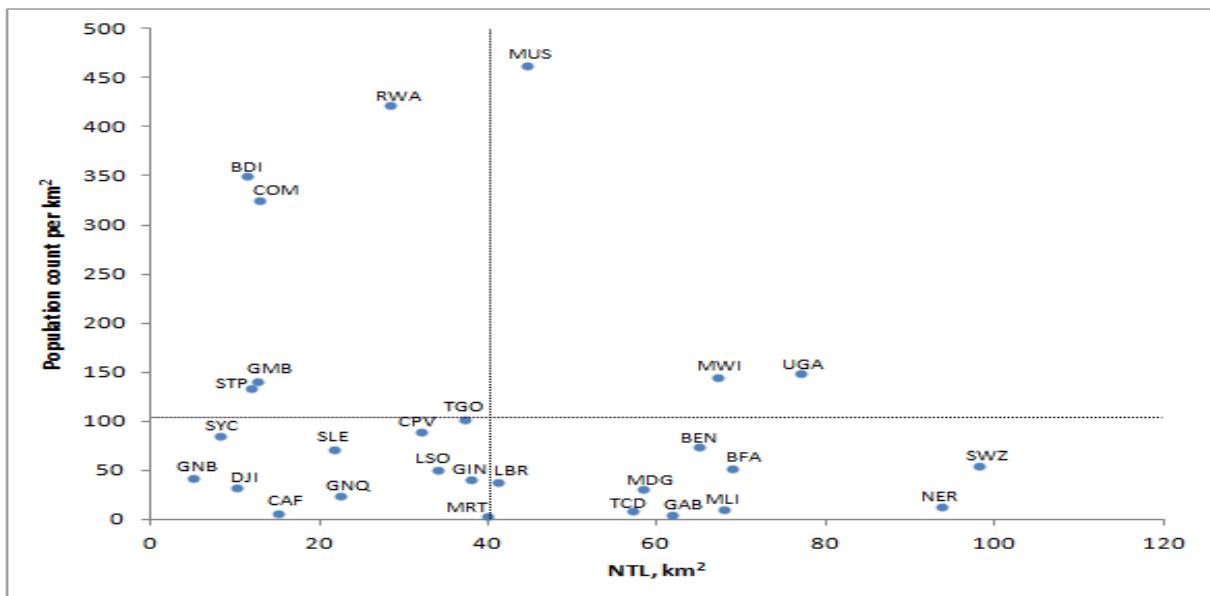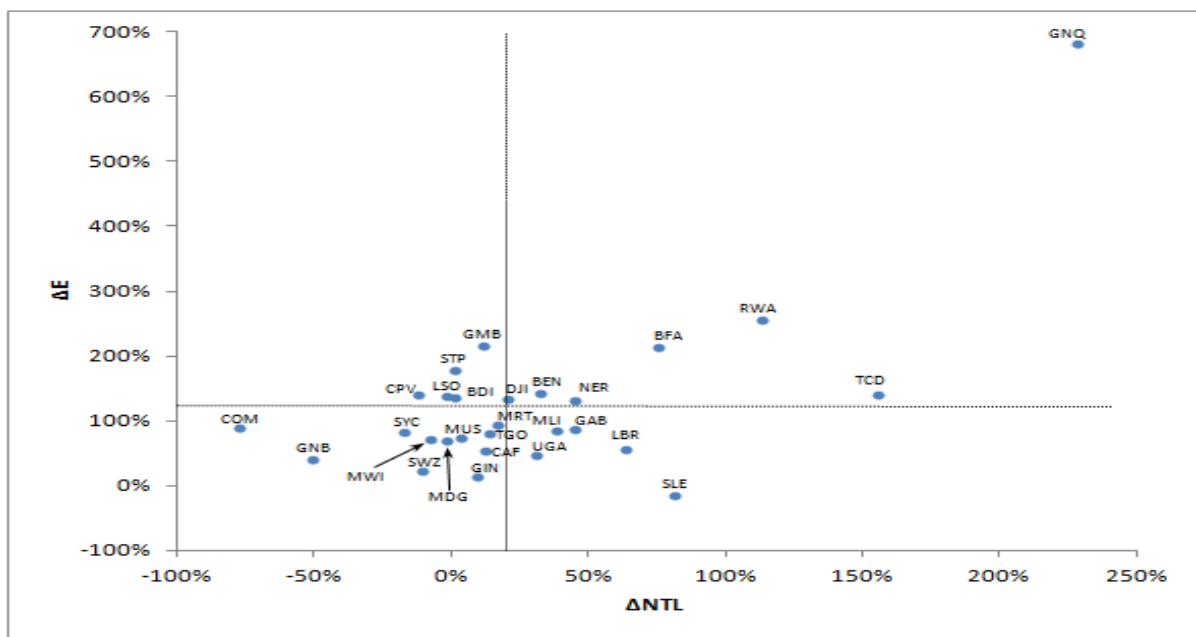
Fig. 12. Changes in NTL and electricity consumption in low NTL African countries, 2000-2013.

6. Conclusion

This study is the first attempt to perform continent-level decomposition analysis of electricity consumption, analysis of NTL and population count in order to identify driving factors behind electricity consumption in Africa between 2000 and 2013. The countries were divided into three groups based on the lit area: high, medium and low NTL. Prior to analysis, the energy profiles of the countries were assessed.

It was identified that the energy profiles of African countries vary significantly due to differences in resource availability, infrastructure and stages of economic. This resulted in the significant differences in the rate of electrification between more-developed and less-developed countries of the continent. Furthermore, there is a particularly large gap in the access to electricity between urban and rural population within the countries, primarily medium and low NTL states. The solution of energy poverty issues is going to positively impact economic development of the continent.

The results of decomposition analysis revealed that the economic activity and electricity intensity were the main factors behind increase in electricity consumption in high NTL countries. In medium NTL countries, the increase in electricity consumption was primarily attributed to population and electricity intensity growth. The same applies to low NTL countries. Population growth had a positive impact on electricity consumption in all countries of the continent, while the decline in electricity intensity caused a decrease in electricity use in some medium and low NTL countries.

It is likely that promotion of energy efficiency in high NTL countries in Africa will have positive effect on economic growth. Medium and low NTL countries would need to increase power production capacities in order to induce economic growth and address demand caused by growing population. However, there is an urgent need for better institutions, financing mechanisms, laws and regulation to promote a sustainable energy future in Africa [51].

Analysis of satellite derived NTL and population count data indicated the changes in both indicators between 2000 and 2013. In general, it could be said that urbanization rate has been on rise, causing increase of indicators in urban areas and decline in rural parts. It is likely indicating that electricity infrastructure and economic rural development trails behind in most of the countries of the continent. Combined assessment of decomposition results and satellite derived data contributed to better understanding of the differences between the countries of different groups.

The results of this study could be used not only to design better energy policies, but also could contribute to improve urban planning, resource management and economic policy development in Africa. Further studies will include the use of a multi-regional spatial decomposition model for electricity consumption [24],

and country-level benchmarking for improved NTL assessment based on the country or regional thresholding procedure as well as a shorter time span as a straight ten years period can hide fluctuations in satellite derived data along the years. Furthermore, there is a need for map overlay analysis of NTL map with solar and wind potential maps as it is likely that development of renewable energy, particularly community-based off-grid systems, could be a solution for Africa's energy poverty. On top of that, map overlay analysis of NTL and population data with gas flares could contribute to assessment of market and potential of utilization of flared gas for the generation of electricity on the continent.

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Appendix I. Socioeconomic and Electricity Indicators in Africa, 2013

Country	GDP	Electricity intensity	Installed capacity	Total population	Urban	FY 2012 access to electricity, %		
	PPP(2011) $/capita	MWh/PPP (2011)M$	MW	Million	% of total	Total	Urban	Rural
High NTL (NTL>1000 km²)								
Algeria	13314	85	15097	38.2	70	100	100	100
Egypt	10050	156	32702	87.6	43	100	100	100
Libya	19557	115	9455	6.3	78	100	100	100
Morocco	7192	116	7013	33.5	59	100	100	100
Nigeria	5448	25	9822	172.8	46	56	84	34
South Africa	12446	301	44170	53.2	64	85	97	67
Tunisia	10613	127	4539	10.9	66	100	100	100
Medium NTL (1000 km²>NTL>100 km²)								
Angola	6858	44	1530	23.4	42	37	83	6
Botswana	15022	101	753	2.2	57	53	71	24
Cameroon	2745	86	1571	22.2	53	54	88	19
Congo	5749	32	390	4.4	65	42	59	12
Cote d'Ivoire	2934	75	1525	21.6	53	56	88	29
DR Congo	673	148	2606	72.6	41	16	36	6
Ethiopia	1330	48	2311	94.6	19	27	100	8
Ghana	3834	94	3041	26.2	53	64	85	41
Kenya	2748	61	1723	43.7	25	23	58	7
Mozambique	1033	424	2646	26.5	32	20	55	5
Namibia	9140	176	487	2.3	45	47	94	17
Senegal	2191	99	854	14.2	43	57	88	27
Sudan	3409	49	3199	50.0	30	26	55	14
Tanzania	2268	42	1115	50.2	30	15	46	4
Zambia	3556	200	2038	15.2	40	22	47	6
Zimbabwe	1684	330	2112	14.9	33	40	78	16
Low NTL (NTL<100 km²)								
Benin	1867	50	208	10.3	43	38	68	15
Burkina Faso	1530	40	298	17.1	28	13	49	1
Burundi	725	34	39	10.5	11	7	59	1
Cabo Verde	6130	94	142	0.5	64	71	84	47
Central African Rep.	561	61	44	4.7	40	11	15	8
Chad	2005	8	47	13.1	22	6	18	3
Comoros	1369	42	24	0.8	28	69	85	61
Djibouti	2983	119	130	0.9	77	53	65	13
Equatorial Guinea	34233	13	334	0.8	40	66	93	43
Gabon	18172	61	514	1.7	87	89	98	45
Gambia	1593	70	91	1.9	58	35	41	26
Guinea	1192	51	518	11.9	36	26	74	3
Guinea-Bissau	1336	15	27	1.8	48	61	100	21
Lesotho	2459	139	80	2.1	26	21	47	10
Liberia	817	73	91	4.3	49	10	19	1
Madagascar	1367	39	508	22.9	34	15	61	8
Malawi	1088	101	502	16.2	16	10	37	2
Mali	2090	37	811	16.6	38	26	50	12
Mauritania	3633	50	263	3.9	59	22	46	4
Mauritius	17148	110	778	1.3	40	100	100	100
Niger	877	52	176	18.4	18	14	62	5

Appendix I. Socioeconomic and Electricity Indicators in Africa, 2013 (Contd.)

Country	GDP	Electricity intensity	Installed capacity	Total population	Urban	FY 2012 access to electricity, %		
	PPP(2011) $/capita	MWh/PPP (2011)M$	MW	Million	% of total	Total	Urban	Rural
Rwanda	1516	23	109	11.1	27	18	62	8
Sao Tome & Principe	2963	94	19	0.2	64	60	68	47
Seychelles	24805	138	85	0.1	53	61	100	17
Sierra Leone	1876	6	77	6.2	39	14	47	1
Swaziland	7836	125	164	1.3	21	42	100	24
Togo	1296	104	227	6.9	39	31	68	9
Uganda	1665	34	838	36.6	15	18	71	8

Source: Authors' calculations using World Bank and UN Data [19, 21].

Appendix II. The results of decomposition analysis, 2000-2013

Country	Code	ΔE	ΔE_{int}	ΔE_{act}	ΔE_{pop}	ΔE	ΔE_{int}	ΔE_{act}	ΔE_{pop}
		GWh				%			
High NTL (NTL>1000 km²)									
Algeria	DZA	24566	10917	7739	5909	132	59	42	32
Egypt	EGY	74995	24179	27151	23664	120	39	43	38
Libya	LBY	3934	3420	-1410	1924	39	34	-14	19
Morocco	MAR	15008	3189	9017	2802	117	25	70	22
Nigeria	NGA	14844	87	9693	5064	172	1	112	59
South Africa	ZAF	36792	-38186	40774	34204	23	-23	25	21
Tunisia	TUN	8177	3654	3204	1320	125	56	49	20
Medium NTL (1000 km²>NTL>100 km²)									
Angola	AGO	5930	2576	1905	1449	513	223	165	125
Botswana	BWA	1640	207	891	541	98	12	53	32
Cameroon	CMR	2550	757	511	1282	94	28	19	47
Congo	COG	537	266	103	168	203	100	39	63
Cote d'Ivoire	CIV	1847	887	-55	1015	63	30	-2	35
DR Congo	ZAR	2719	-1178	1513	2385	60	-26	33	53
Ethiopia	ETH	4659	1067	2458	1134	326	75	172	79
Ghana	GHA	3409	-3102	3995	2516	56	-51	66	41
Kenya	KEN	3888	913	1233	1742	114	27	36	51
Mozambique	MOZ	10592	6285	2695	1611	1046	620	266	159
Namibia	NAM	1386	-475	1219	642	58	-20	51	27
Senegal	SEN	1742	706	272	765	130	53	20	57
Sudan	SDN	6252	2731	1896	1624	304	133	92	79
Tanzania	TZA	2923	278	1416	1230	153	15	74	64
Zambia	ZMB	4817	-2532	4356	2993	80	-42	72	50
Zimbabwe	ZWE	-2209	-78	-3771	1640	-21	-1	-36	16
Low NTL (NTL<100 km²)									
Benin	BEN	569	234	81	254	143	59	20	64
Burkina Faso	BFA	707	233	235	239	214	70	71	72
Burundi	BDI	149	70	3	76	136	64	3	69
Cabo Verde	CPV	170	49	93	28	140	40	76	23
Central African Republic	CAF	57	78	-52	31	55	75	-50	29
Chad	TCD	120	-39	97	62	140	-45	112	73
Comoros	COM	21	12	-1	10	90	50	-5	44
Djibouti	DJI	175	67	71	37	134	51	54	28
Equatorial Guinea	GNQ	314	88	164	62	683	190	357	135

Appendix II. The results of decomposition analysis, 2000-2013 (Contd.)

Country	Code	ΔE	ΔE_{int}	ΔE_{act}	ΔE_{pop}	ΔE	ΔE_{int}	ΔE_{act}	ΔE_{pop}
			GWh					%	
Gabon	GAB	855	424	30	401	87	43	3	41
Gambia	GMB	143	89	2	52	216	134	3	79
Guinea	GIN	86	-158	35	209	13	-25	6	33
Guinea-Bissau	GNB	10	0	1	9	41	2	5	35
Lesotho	LSO	414	164	195	55	139	55	66	18
Liberia	LIB	91	14	-5	82	55	8	-3	50
Madagascar	MDG	503	200	-54	356	70	28	-7	50
Malawi	MWI	738	-62	292	508	71	-6	28	49
Mali	MLI	588	-486	684	389	85	-70	99	56
Mauritania	MRT	344	16	144	184	95	5	40	51
Mauritius	MUS	1010	146	757	108	74	11	55	8
Niger	NER	475	117	80	278	131	32	22	77
Rwanda	RWA	279	67	141	71	256	62	129	65
Sao Tome & Principle	STP	33	12	11	9	179	67	62	50
Seychelles	SYC	139	48	68	24	83	28	41	14
Sierra Leone	SLE	-12	-88	45	31	-15	-109	56	39
Swaziland	SWZ	226	-102	149	180	23	-10	15	18
Togo	TGO	416	170	-3	249	80	33	-1	48
Uganda	UGA	657	-855	770	742	47	-61	55	53