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Power Supply and the Role Hydropower Plays in Sub-Saharan Africa's Modern Energy System and Socioeconomic Wellbeing

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ABSTRACT

This study overviews the status of the power supply; implications of the inadequate power supply; and the significance of hydropower in the socioeconomic wellbeing of Sub-Saharan Africa (SSA). This study noted that despite the large presence of energy potentials across the entire region, the power supply is grossly inadequate. Currently, the world's highest population without access to electricity live in SSA and the number, which was 585 million in 2009 is expected to increase to 645 million in 2030. The supply of clean, affordable and adequate power in the region is compounded by the global energy trends, described as energy trilemma by the world energy council. These attributes are anchored in three pillars - energy equity, energy security and environmental sustainability. This article sees hydropower technology, which has been revolutionised over the years into different categories, as a vital modern energy source for clean power generation. The hydropower technologies discussed are large hydropower, small hydropower (SHP) and pumped storage hydropower. Hydropower provides clean, relatively cheap electricity, reliable and sustainable power supply. The study identifies SHP as a system that satisfies the modern energy attributes of low CO_2 emissions and environmentally friendly scheme, suitable for standalone and rural electrification.

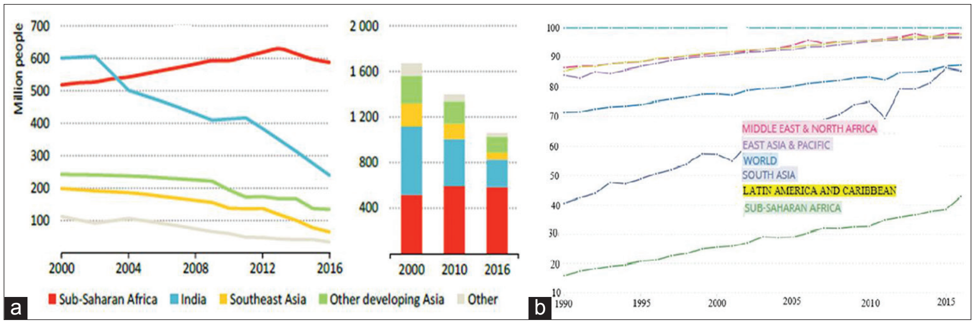
Keywords: Hydropower, Small Hydropower, Renewable Energy, Power, Electricity, Sub-Saharan Africa
JEL Classifications: Q2, Q4, Q5, Q420

1. INTRODUCTION

In 2000, the World Bank reported that 70% of the 1.6 billion people that gained access to electricity between 1990 and 2000 were in urban areas. Its 2010 report has it that 1.2 billion people lack access to electricity, with 173 million of them in urban areas because of the increase in urban population. In 2018, Renewable Energy Policy Network for the 21st century (REN21) reported that about 14% of the world's population, which is estimated to be 1.06 billion people, have no access to electricity (REN21, 2018). Developing Asia and sub-Saharan African (SSA) regions have over 95% of the population without electricity and with approximately 84% of the people without electricity access being rural areas dwellers (International Energy Agency [IEA], 2017). Although the population without access to electricity shows a downward trend in these reports, many people with access to electricity suffer from the poor quality supply.

Many developing countries are witnessing rapid economic growth alongside urbanisation with an on going energy access scheme implemented, to meet these developmental trends. In the last 20 years, Asia countries, especially Bangladesh, China, India and Indonesia, recorded huge achievements in providing hundreds of millions of people with modern energy in the form of electricity. However, the story is different in SSA, a region that accommodates the world's highest number of people without access to electricity, as shown in Figure 1a. One question begging for an answer is what the region has been doing in electrification, considering Europe's 100% electrification since 1990, as shown in Figure 1.

Figure 1: Regional population in % (a) without access to electricity (International Energy Agency, 2017); (b) with access to electricity access to electricity (World Bank, 2018a).



IEA observed that since 2000 the urban-rural electrification ratio in SSA is 2–1 (IEA, 2017).

This article provides information and analysis of the power situation in SSA and how its present status affects the economy and health of the people. This study focuses on hydropower systems as one of the sources of RE that satisfies the modern energy attributes that are largely untapped in SSA. Despite the gross inadequate power supply in SSA, only 8% of the available exploitable hydropower potential that has been tapped (Codi, 2015). The study will correlate power availability, poverty, CO_2 emissions and the role of hydropower in meeting the global energy need trends in SSA.

2. METHODOLOGY

The study is based on quantitative information and data obtained from text books, verified websites, government documents, published research articles, thesis, news media, local and international organisations' reports and outlooks on energy transition and sustainability. The international organisations include World Bank, International Renewable Energy Agency (IRENA), United Nations (UN), IEA, REN21 and world energy council (WEC). The focus is on the socioeconomic consequences of high-carbon energy use, power inadequacy in SSA and the role power technology schemes play to bridge the inadequacy. Hydropower will be examined in terms of availability and its usable prospect in the provision of electricity and the socioeconomic gains that come with it.

3. SSA POWER SUPPLY AND ITS IMPLICATION IN ECONOMY

3.1. Access to Electricity in SSA

One third of the world's population which covers 50 poorest nations lack access to electricity while 2.1 billion are short of safely managed water services (Gronewold, 2009; International Hydropower Association [IHA], 2018b; Lindeman, 2015). Sadly, about 33 of the countries are in SSA (Gregson, 2017). There have been concerted efforts at both domestic and international levels to increase the accessibility to electricity tremendously. These efforts have not yielded the expected results as SSA and South Asia regions still have relatively high percentages of the population without power supply. It was reported that the population without access to electricity in the rural areas of SSA would increase from 585 million in 2009 to 645 million in 2030 (IEA, 2011). The insufficient electricity supply observed in the developing countries is worse in rural areas (Mohammed et al., 2014; Trotter, 2016), as shown in Figure 2.

Globally, the amount of electricity consumed by a country is correlated with the strength of her economy. The more electricity consumed, the richer the country and by applying this to SSA, suggests a poor and deindustrialised economy. This implies that SSA has little share in the world's manufacturing and heavy industries, which consumes most of the electricity. This in turn keeps SSA's electricity demand the lowest and consequently, the poorest region in the world. According to Burton, the 10 poorest countries are in SSA and also, 22 countries out of the 25 poorest countries in the world are in SSA (Burton, 2017a). The level of electricity access in % of the population in SSA according to World Bank, is shown in Figure 3 (World Bank, 2018a).

3.2. Increase in Biomass Business in SSA

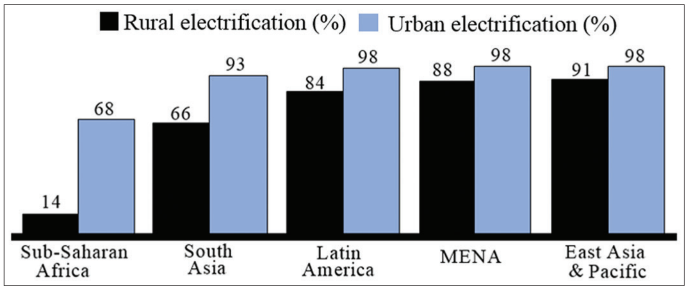
Energy poverty and the consequences of unemployment in SSA, make businesses on natural resources, such as firewood supply and lumbering massive, as shown in Figure 4. The value of firewood business in the region is worth about 11 billion USD (Schenk, 2016). The massive exploitation of firewood in SSA - results in the rise of socioeconomic, environmental and health challenges in the region. These businesses have exposed the region to an unimaginable challenge, such as - extensive deforestation, land degradation and distorting the general ecosystem; diseases and deaths resulting from indoor air pollution; and immense labour for children and women in sourcing firewood (Figure 4d), and this affects their physical health, productivity and development.

3.3. The use of High Carbon Energy

The consequences that come with the inadequate and low-quality power supply are unemployment, health issues, insecurity, poor research, low investments, and slow industrialisation. More than 2.8 billion people (41% of households) depend on coal and biomass for heating and cooking globally (Amegah and Jaakkola, 2016). Typically, in developing countries, liquid and solid fuels, such as firewood and kerosene, are burnt in an inefficient traditional open fire and cook stoves with poor ventilation. Sources of household indoor air pollution, are shown in Figure 5. This has health consequences on the students who use kerosene lamps for studying, women who are responsible for cooking, and their young children who stay around them (Agrawal and Yamamoto, 2015; Amegah and Jaakkola, 2016; Das et al., 2017). They are exposed to high levels of air pollutants, such as carbon monoxide (CO) and particulate matter (PM) emitted to the air (Amegah and Jaakkola, 2016).

A study reported that women living in households where solid fuels are used are two times higher of having preeclampsia/eclampsia symptoms than those living in households where cleaner fuels are used (Agrawal and Yamamoto, 2015). An estimated 3.5 million premature deaths due to household air pollution worldwide were reported in 2010. The world's death caused by outdoor pollution was 370,000 deaths and 9.9 million disability-adjusted life years globally in 2010 (Chafe et al., 2014). In about 25 countries, mostly in SSA, over 90% of households depend on charcoal, wood, and solid waste for cooking. This releases noxious fumes that are connected to about 2.8 million premature deaths annually (IEA, 2017). Figure 6 shows 2012 largest populations in SSA that are cooking with traditional biomass.

Figure 2: Population with access to electricity in percentage (Mohammed et al., 2014)



3.4. The Region's Electrification Projections

IEA stated that an investment of over $30 billion will be required to achieve universal electricity in SSA by 2030. A substantial part of this fund will go to rural areas electrification where about 85% of the population lack access to electricity (IEA, 2017). There seems to be no light at the end of the tunnel for electricity access in the near future in SSA considering IEA 2017 energy access outlook projection (IEA, 2017). The projection shows that about 600 million people in the region will have no access to electricity in 2030, as shown in Figure 7.

The electrification rate in SSA is expected to progress in percentage but the total number of households without access will increase due to the rapid population growth of the region. By 2030, the population without electricity will have increased from the present 588 million to 602 million and this will account for 36% of total population (IEA, 2017; Urpelainen, 2017). The type of rural electrification is expected to change and about 50%

Figure 3: Access to electricity in Sub-Saharan Africa (% of the population) (World Bank, 2018a)

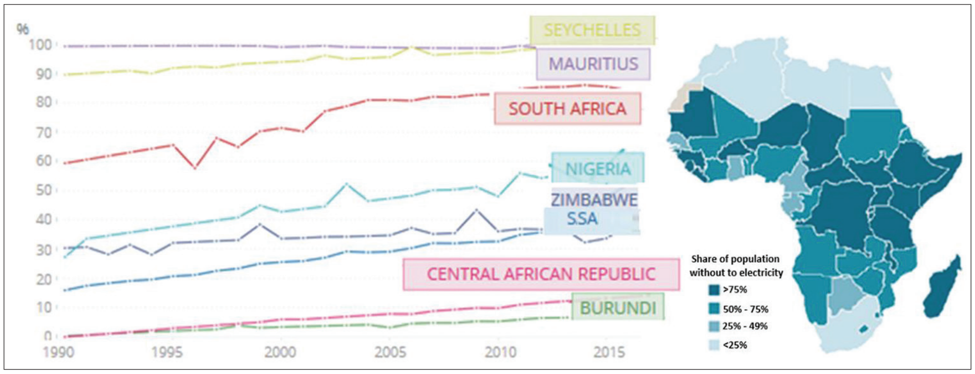
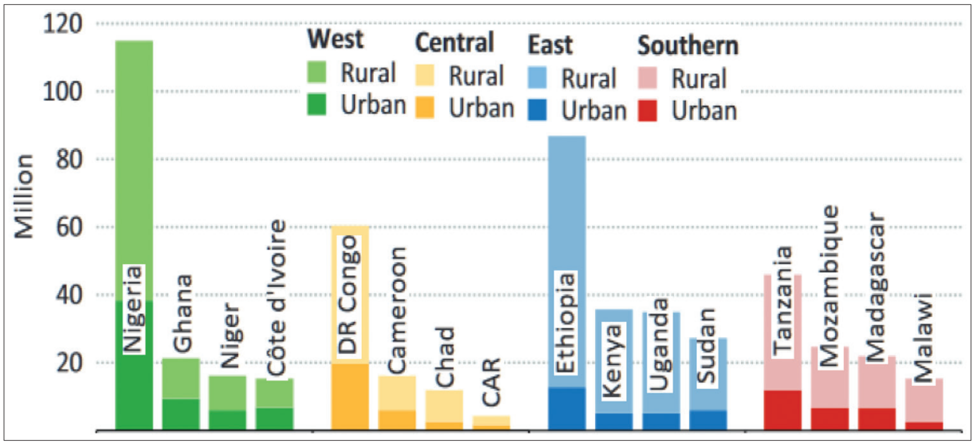


Figure 4: Businesses on natural resources in Sub-Saharan Africa

Figure 5: Sources of household indoor air pollution

Figure 6: Largest populations in Sub-Saharan Africa that are cooking with traditional biomass (Morrissey, 2017)



of the new connections will be to the grid while the remaining half will be mini-grids and micro-grids. This is expected to improve power generated distribution and ease the connection of sparsely populated areas that are intricate to connect to the grid (Urpelainen, 2017). In another report (Castellano et al., 2015), by 2040 the power consumption in the region is expected to increase by four times the power consumed by the region in 2010. This projection is based on certain dynamics, such as an increase in gross domestic product (GDP), the rise in urbanisation, and a doubling of population. It's obvious that by 2030, the status of power supply in the region is not going to change much and the negative impact will still be felt. This calls for an appraisal of the ongoing interventions and sustainability development initiatives towards the provision of clean, adequate and affordable energy.

3.5. Economic Implication of Inadequate Power Supply

The main supports of SSA economy are agriculture, mining and oil. However, the region cannot provide sufficient power; and unemployment and poverty are ravaging the region. The trade in the region though stable is not favourable because imports far exceed export and this creates an economic imbalance. The region's economy is faced with trade, debt, aid, and numerous other challenges. Abundant usable energy, such as electricity is the heart of a thriving economy and has a direct correlation to development indexes like poverty level, GDP, gross national income (GNI) and debt status. The aftermath effects of inadequate access to electricity are abject poverty, underdevelopment, slow urbanisation and industrialisation. The power supply circumstance in SSA is mainly responsible for the poor development indexes shown in Figures 8 and 9. The power supply curve and the indexes show the same trend. Extreme poverty has fallen, the daily living of about 70% of the developing world of $2 in 1981 has dropped to over 36% in 2011 (Kiersz, 2015). Although the world's poverty has witnessed drastic reduction averagely since 1981, as shown in Figure 8, SSA has a lot to do to bring poverty level to an acceptable level. The region's GNI per capita, and gross domestic per capita (GDP) are relatively low as observed in Figure 9a and b.

Literally, inadequate power supply promotes poverty, increases debt and limits GDP and GNI. The dynamics of government debt in SSA are weak and attract a rapid increase in private sector debt. The region's domestic banks private credit in 2016 was 29% of GDP (Kambou, 2018). According to FocusEconomics, 5 of the 10 world's poorest countries are in SSA (Figure 10) and 14 of the 50 world's poorest countries are in the region (FocusEconomics, 2018). The rapid increase of debt in the private sector across the region indicates the likelihood of contingent liabilities for the public sector. The World Bank reported that 27 of 31 low income countries are in the region. SSA witnessed a decline in investment growth from about 8% in 2014 to 0.6% in 2015 (World Bank, 2017).

One could conclude that the region's economy is in shambles and needs an urgent response on a number of fronts. The status of socioeconomic development in the region reflects the level of electricity deficit and this correlation is presented in Table 1. It is observed that poorest countries have the lowest electricity access while the richest countries have 100% access. Developed countries have high electrification rates and high GDP per capita while developing countries is otherwise, as presented in Table 1. Hence, it is logical to say that a rise in energy access indicates

Figure 7: Electrification projections in developing regions in 2030 (International Energy Agency, 2017)

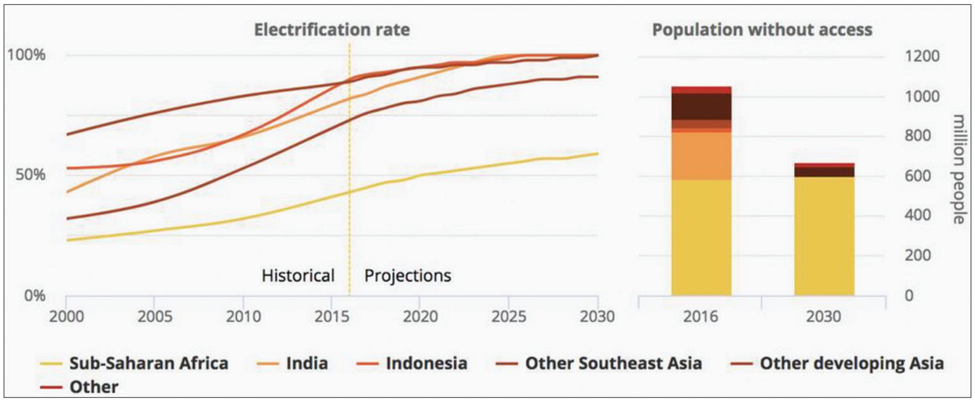


Figure 8: Poverty headcount ratio at $1.90 a day (2011 purchasing power parity) (% of the population) (World Bank, 2018d)

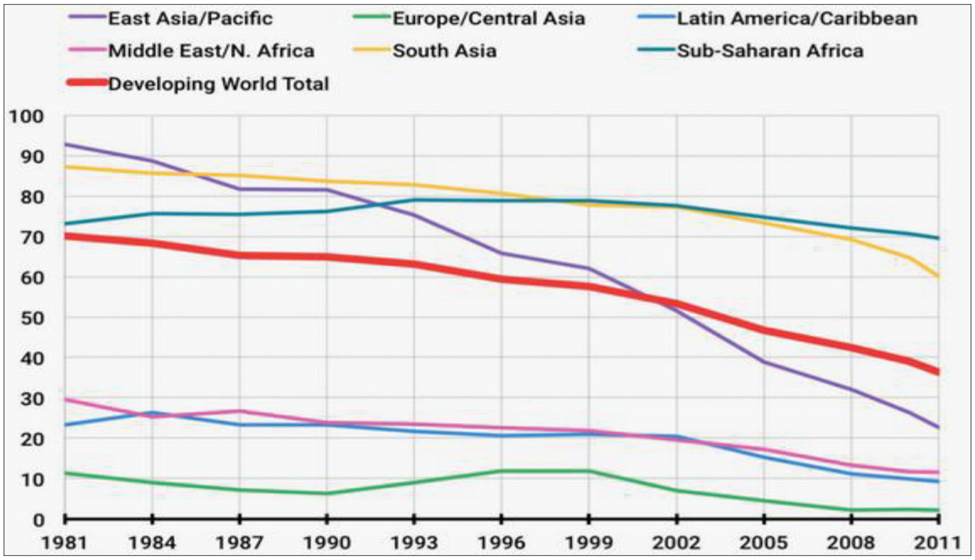
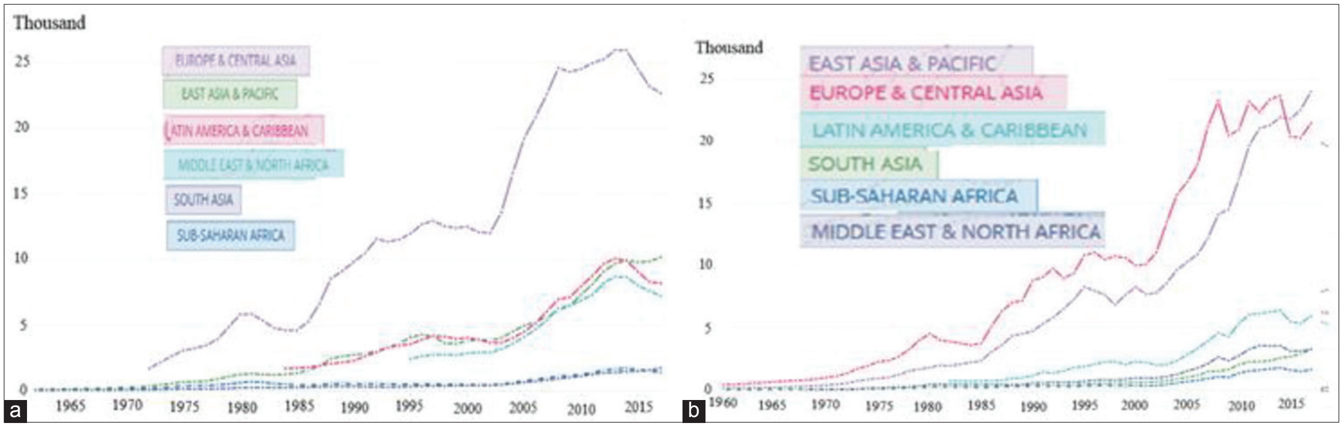


Figure 9: (a) Gross national income per capita, Atlas method (current US$); (b) gross domestic per capita (GDP) (current US$) (World Bank, 2018e)



improvements in people's wellbeing, economic opportunities, education, healthcare, and life expectancy. This invariably enhances national productivity, which is a panacea for economic development.

3.6. High Energy per Unit Output Production

Currently, SSA has the world's highest energy intensity (Figure 11a), that is, the ratio between the energy supplied in the region and GDP measured at purchasing power parity (PPP) (World Bank, 2018c). It is an indicator that shows the energy used per unit output production. This reflects the region's energy use pattern that does not transform into economic growth. The pattern is characterised by the energy that is expensive, imported, and environmentally unsustainable, and the sources of energy include coal, oil, natural gas, and wood products (biomass). Figure 11a shows that energy used to produce one unit of output in SSA is the highest in the world. Also, Figure 11b shows that Somalia has the highest energy intensity in the region.

3.7. Uphill Task for the Region

The total electricity generation capacity of Africa, without South Africa, is 28 Gigawatts and this is equivalent to Argentina's generation. The population with access to electricity in SSA is only 24%, which means the region is starving for energy, yet the region's population growth is rapid. Apart from the population, the quest to satisfy modern energy attributes further compounds the provision of power in the region. To meet modern energy attributes, the supplied power must be cleaned, adequate, affordable and sustainable. The WEC coined these requirements as energy trilemma with these three components - energy security, energy equity, and environmental sustainability (Gent and Tomei, 2017; Harvey, 2014; Heffron et al., 2015). Again, urbanisation is expected to spread to all regions of the world by 2050 with urbanisation in Asia and Africa being swifter than other regions. This rise will come with sustainable development challenges, as more energy will be required to support the growth. In the contemporary world, urbanisation should be based on a sustainable energy system that is affordable, secure and promotes CO_2 emission reduction in accordance with SDGs (Nganga, 2016; UN, 2015). This implies the reduction or eradication of the use of fossil fuel, which is the main source of CO_2. The conventional pathways of boosting power supply, which is the utilisation of fossil fuels are increasingly becoming obsolete and unsustainable on a daily basis.

Figure 10: The world's poorest countries (FocusEconomics, 2018)

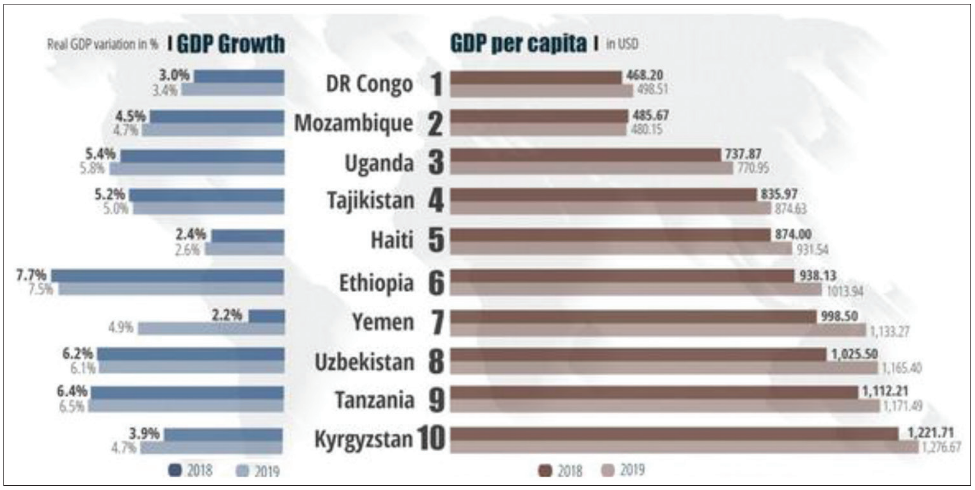
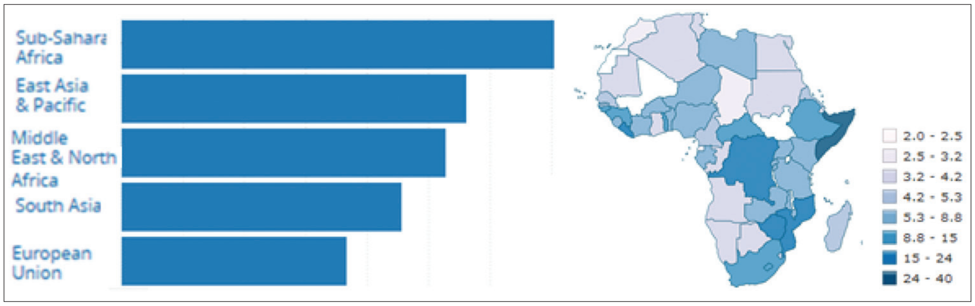


Table 1: Poorest and richest countries and their electricity access (% population)

Rank	Poorest countries in the world (FocusEconomics, 2018)	GDP $/capita/year	Countries with the least electricity in the world (Wee, 2017)	Population with access to electricity (%)	Richest countries in the world (Burton, 2017b)	GDP Per Capita	Population with access to electricity (%) (World Bank, 2018a)
1	Central African Republic	652	South Sudan	5.1	Qatar	124,927	100.0
2	Congo DC	773	Chad	6.4	Luxembourg	109,192	100.0
3	Burundi	814	Burundi	6.5	Singapore	90,531	100.0
4	Liberia	855	Liberia	9.8	Brunei Darussalam	76,743	100.0
5	Niger	1,107	Malawi	9.8	Ireland	72,632	100.0
6	Malawi	1,134	Central African Republic	10.8	Norway	70,590	100.0
7	Mozambique	1,215	Burkina Faso	13.1	Kuwait	69,669	100.0
8	Guinea	1,265	Sierra Leone	14.2	United Arab Emirates	68,245	100.0
9	Eritrea	1,410	Niger	14.4	Switzerland	61,360	100.0
10	Madagascar	1,505	Tanzania	15.3	San Marino	60,359	100.0

Figure 11: (a) Energy intensity level of primary energy (MJ/$2011 purchasing power parity [PPP] gross domestic product [GDP]), acros world's regions, 1990–2015 (World Bank, 2018c); Energy intensity level of primary energy (MJ/$2011 PPP GDP) across Africa



4. SSA ENERGY POTENTIAL AND THE ASSOCIATED CHALLENGES

SSA is endowed with both fossil and renewable energy resources. These energy sources that are dispersed across the region have the capacity of generating a total power of 11,000 gigawatts (GW) (Morrissey, 2017), which is sufficient to meet the future energy needs of the region. Table 2 presents the different energy resources and their estimated capacity generation and the distribution of the potentials as shown in Figure 12.

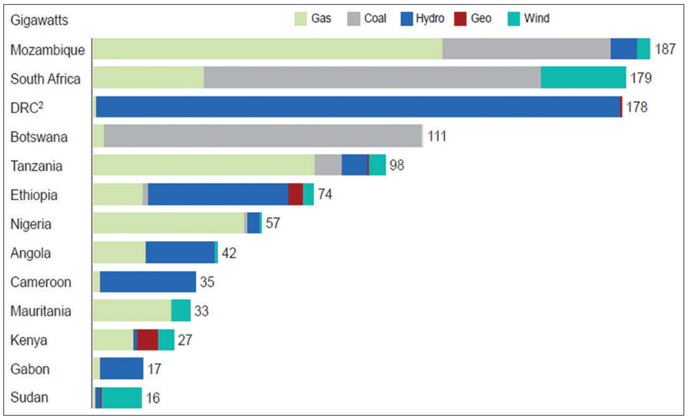
SSA is rich in energy resources and very poor in energy supply seems contradictory, but this is the exact situation. The region is rich in natural resources that are not sufficiently developed into usable energy and this has left the rapidly growing economy unstable. The present SSA power capacity is about 147 GW (Davis).

4.1. Fossil Fuels and the Deployment of Renewable Energy in SSA

Although, fossil fuels, such as oil, coal, and natural gas, are highly effective economic growth drivers, they come with human health and environmental consequences. Subsequently, climate change, global warming, and greenhouse gas (GHG) are linked to fossil fuels usage. However, these known consequences have not completely deterred a man from the use of fossil fuels. Large volumes of fossil-based energy are still being consumed daily because energy is a fundamental need for human existence and for industrialisation. In 2016, it was reported that the annual global growth rates of oil, gas and coal consumptions per day were 1.6%, 1.5%, −1.7%, respectively and with 0.1% CO_2 rise from energy generation (BP, 2017). In 2014, IEA reported that grid-based electricity generation capacity in SSA increased from about 68 GW in 2000 to 90 GW in 2012, with South Africa accounting for almost half of this total (IEA, 2014). The estimated fossil-based energy sources for electricity generation in the region is 76% while the RE, which is mainly hydropower account for about 22%, Figure 13a. The end-use sector electricity consumption in Africa sub-region in 2012 is shown in Figure 13b.

The grid-based power capacity of 90 GW in the region is grossly inadequate and this has coerced industries, residence and service providers to depend on back-up generators for the deficit, as shown in Figure 14. In 2012, about 16 TWh was estimated as the amount of electricity demand provided by back-up generators is the region (IEA, 2014). Nigeria accounts for about three-quarter of the power supply served by back-up generators in the region.

Figure 12: Sub-Saharan African energy potential (Castellano et al., 2015)



4.2. CO_2 Emissions in SSA

Although SSA contributes 14% of the of the world's population, the region only accounts for 7.1% of the world's GHG emissions. At present, some countries in Africa emit insignificant amounts of $CO_{2,}$ this is largely due to the current level of industrialisation in the region. However, since 1960 CO_2 emissions have been in the rise and this trend is expected continue due to increasing industrialisation, urbanisation and population growth. The trend of CO_2 emissions in the region since 1960 is shown in Figure 15.

Ironically, experience has shown that rise in CO_2 reduces abject poverty; it was observed that increase in CO_2 led to the reduction of extreme poverty in Asia and other regions of the world, as shown in Figure 16. The CO_2 emissions of SSA in 2011 are less than 1981 emission by 17% and this increased the extreme poverty by 98%. The reverse is the case in Asia, as the CO_2 emission increased by 189% and decreased extreme poverty by 85% in 2011 (Goldstein, 2015). Figure 8 shows CO_2 emissions in the different regions and their effects on poverty. There is a vast difference between the profile of sources of GHG in SSA and the Globe. Globally, transport, energy, and industry sectors and waste account for about 75% of total GHG emissions, while agriculture, forestry and land utilisation (AFOLU) account for 25%. In the case of SSA, AFOLU contributes more than 80% of the emissions, waste 1-4% of total anthropogenic (Johnson et al., 2017).

4.3. Should SSA Continue to Increase the Deployment of Fossil Energy to Reduce Poverty?

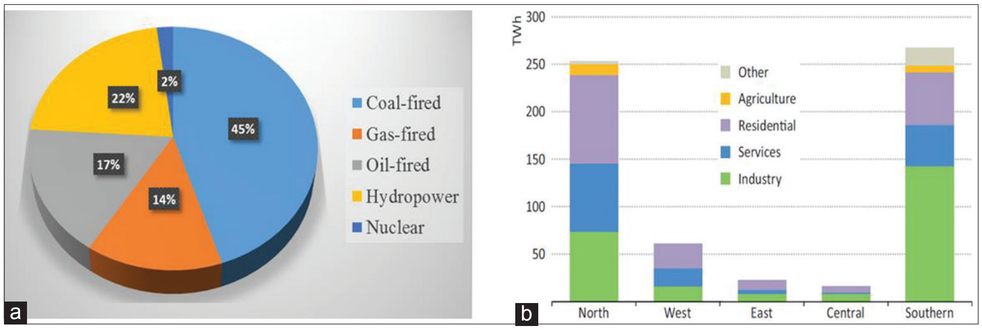
The region should avoid compromising the future in the quest to meet the present need. The need to increase electricity access by deploying RE to reduce the amount of fossil fuel used is unarguably

Table 2: Generation capacities of the energy resources available in SSA

Source	Solar (GW)	Wind (GW)	Geothermal (GW)	Hydroelectric (GW)	Natural Gas (GW)	Coal (GW)
Total	10,000	109	15	350	400	300

SSA: Sub-Saharan Africa

Figure 13: (a) Sources of electricity in Sub-Saharan Africa; (b) end-use sector electricity consumption in Africa sub-region, 2012 (International Energy Agency, 2014)



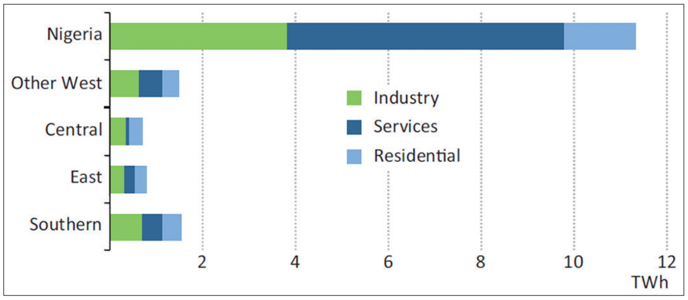
the right way to go. This will stimulate the region's socioeconomic development in accordance with UN-SDGs position on energy. To achieve this herculean task, alternative energy means must be available to provide adequate, reliable and affordable energy with low or without GHG emissions. Renewable energy is expected to play a vital role in this regard and in the future energy mix of SSA. It has projected that by 2040, about 25% of the region's energy generation is expected from RE - hydro, geothermal, solar and wind. The region's exploitable capacity of hydropower and other RE and the countries where the potentials are hugely located are presented in Table 3.

Alternative energy sources in SSA to replace or supplement fossil fuels are geothermal, tidal, solar, biofuels, hydro, nuclear and wind. Currently, the prices of renewable energies are relatively economical as they are currently competing with that of conventional fossil fuels technologies. Low-cost electricity generation is crucial to every economy; therefore, advancing alternative power sources in this regard should be a collective responsibility. Low energy cost will increase employment, income in all sectors, and the purchasing power of the consumer. This benefit coupled with environmental friendliness, off-grid and centralised grid electricity supply applications in locations with good potentials make renewable energy the best option for developing economies. Both developed and developing countries can capitalise on these benefits to provide reliable, affordable and adequate energy to reduce GHG emissions, improve energy security, reduce energy price volatility, and promote economic development. Subsequently, renewable energy, which has been playing a supplementary role to the conventional power, is increasingly being considered as the main source of power.

5. HYDROPOWER SYSTEM

Hydroelectric technology is a flexible and versatile technology that provides renewable electricity on the national grid and/or off grid schemes. At its minimum capacity it can supply a single home and at its maximum capacity it can supply the public and industry clean power. In summary, the key trends and growths in hydropower as at 2017 are: A total of 4,185 TWh electricity was generated from hydropower in 2017; about 1,267 GW is the global hydropower installed capacity; about 21.9 GW was the capacity added in 2017 (IHA, 2018a). Hydroelectric technology can be classified into four groups - impoundment, diversion, pumped storage, and offshore hydropower, as presented in Table 4.

Figure 14: Electricity demand supplied by back-up generators by sub-region, 2012 (International Energy Agency, 2014)



However, these technologies are sometimes overlapping, as they complement one another. At times storage projects are part of pumping to supplement the water that flows into the reservoir naturally. Again, the run-of-river plan may give some storage means. This study focuses more on the more developed technologies - impoundment, diversion, and pumped storage.

5.1. Classification of Hydroelectric Plants

Hydropower plants are classified in different ways; it could be based on capacity, type of turbine or head (ENCO; Gagliano et al., 2014; Gatte and Kadhim, 2012; Haidar et al., 2012; Majumder and Ghosh, 2013). These various types of categorisation are presented in Table 5.

5.2. Hydroelectric in SSA

In recent times, wind and solar energy usually grab headlines in global debates on renewable energy and the drive to find a cleaner, greener options to fossil fuels. However, the available data is contrary to this position but points to hydropower. Currently, hydropower generates over three-quarters of the global renewable

Figure 15: CO_2 emissions (kt) in Sub-Saharan Africa (World Bank, 2018b)

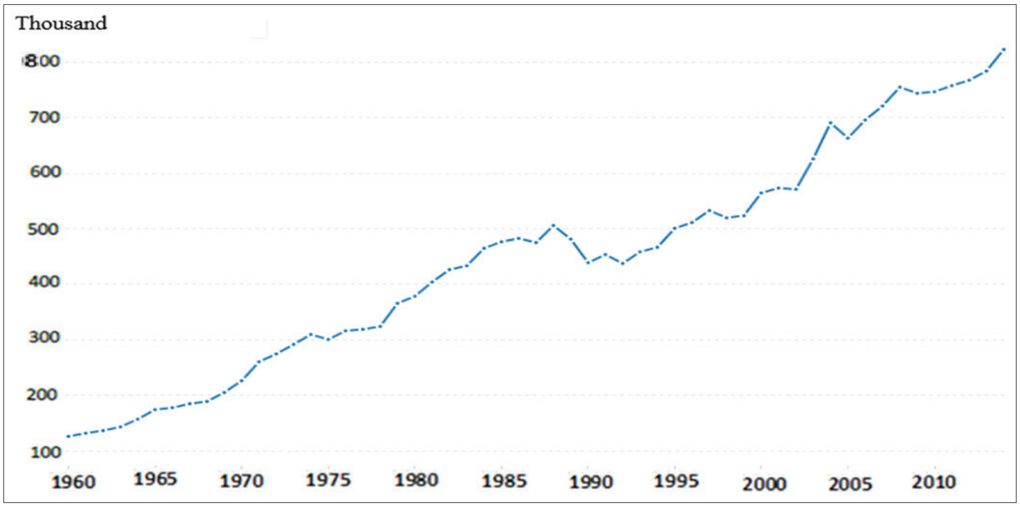


Figure 16: Effect of increase in CO_2 on extreme poverty (Goldstein, 2015)

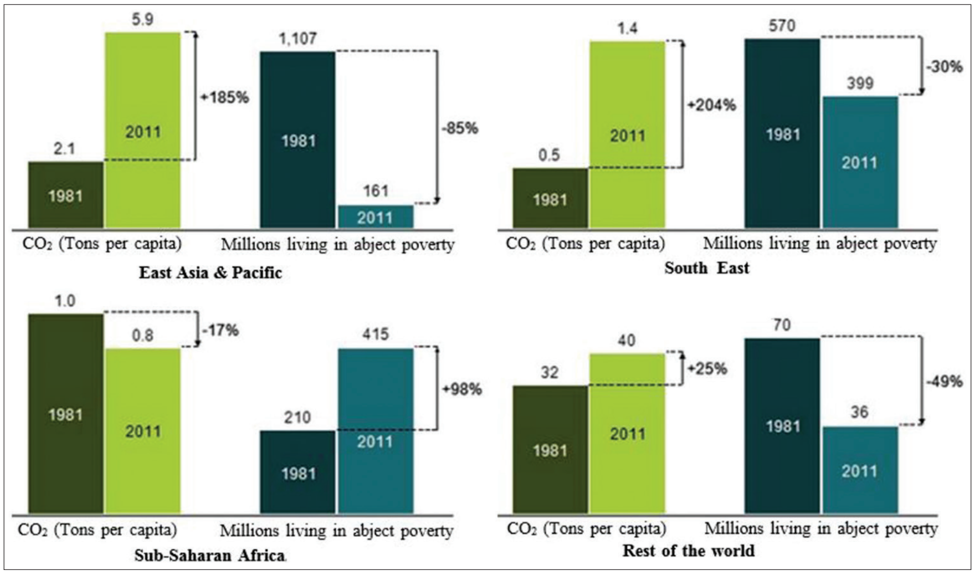


Table 3: Renewable energy generation capacity in SSA

Energy resource	Capacity	Countries in SSA
Solar	>10 TW	All
Hydropower	350 GW	Congo RC, Ethiopia, Nigeria, Zambia, Namibia, Ghana, and Sudan
Wind	109 GW	Ethiopia, South Africa, Kenya
Geothermal	15 GW	Ethiopia, Kenya

SSA: Sub-Saharan Africa

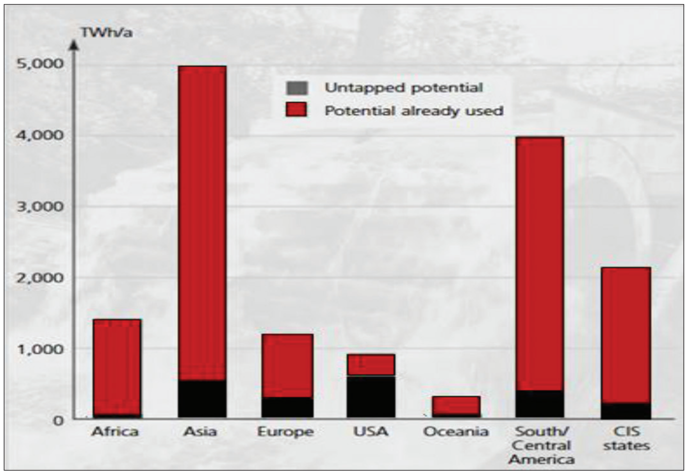
energy output each year and its CO_2 emissions over the entire lifecycle process are usually lower than other RE resources. Hydropower potential in SSA is about thrice the wind potential and it accounted for 84% of the non-fossil fuel energy use in Africa in 2013 (Bello). There are still opportunities for expansion as the untapped potential is huge. SSA has technically significant hydropower potential that is underdeveloped mainly due to lack of political structures and commercial viability. The share of hydroelectric to the estimated SSA power demand of 100 GW is 22%. The region's power demand is expected to rise to 385 GW by 2040 and hydropower is anticipated to supply 26% of that demand. To meet these projections, about 80 GW is required to be added to the current region's capacity within the next 24 years, which implies around 3 GW addition annually (Ayemba, 2017). The hydropower potential accounts for 10% of the world's total of 270 GW and only 10% of the hydropower potential in the region that has been exploited. The hydropower potentials in Africa are not evenly dispersed and 70% of the resources are concentrated in these countries - Congo RC, Egypt, Ethiopia, Nigeria, Mozambique, Morocco, Zambia, Sudan and Ghana (Harris, 2016).

Currently, the untapped hydropower potentials are about 10,000 TWh/y worldwide. These undeveloped hydropower potentials across the world regions remain significant, particularly in Africa, Asia, and Latin America. Significantly, however, about two-thirds of economically feasible hydropower potential globally is unutilised. Coincidentally, the highest number of people without electricity live in regions with the largest unutilised hydropower potential, such as SSA, Latin America, and South Asia (Seifried and Witzel, 2010). Figure 17 shows the tapped and untapped potential in the different regions. Asia is likely the leading market for future hydropower development because it has the largest unutilised potential of about 7,195 TWh/y (WEC, 2016). A strong foundation for continued hydropower development is formed by the demand for electricity coupled with other related reservoir services in these areas.

Hydropower had a boom in 2009 as many of the plants were operational but a decline was experienced in 2010. SSA contribution to world hydropower capacity has risen to 5% and the share region power generation has increased from 22% to 26%. Table 6 presents some of the major hydropower projects in SSA under development.

Hydropower represents a significant source of electricity production in eastern and southern Africa. Currently 90% of national electricity generation in Ethiopia, Malawi, Mozambique, Namibia and Zambia comes from hydropower. The share of hydropower in the energy mix is likely to grow further, driven by national and regional energy plans like the Programme for Infrastructure Development in Africa (PIDA). The PIDA estimates that generating capacity needs to increase by 6% per year to 2040 from a current total of 125 GW to keep pace with rising electricity demand (Conway, 2017). Several major new developments have been commissioned over the last decade, including the grand Ethiopian renaissance dam (GERD) on the Blue Nile. The GERD is expected to increase generating capacity by 6000 MW once completed. Also, if all the dams planned for 2030 are completed, they will increase electricity generation capacity across southern and eastern Africa more than 50%. By 2040, the various regions in Africa are expected to expand their hydropower generation capacities in the new scenario, as shown in Figure 18.

Figure 17: The tapped and untapped hydro potential in the different regions (Seifried and Witzel, 2010)



5.3. Small Hydropower (SHP) Off-grid Scheme

The numerous benefits that hydropower offers are now expedient for tackling the world's complex energy and water challenges, propelled by industrialisation, urbanisation and rapid population growth. One of such benefits is the exploitation of SHP system for the off-grid scheme. The plant that generates small-scale electricity, a capacity not more than 10 MW, from a water sources, such as a river, waterfall, and river run off is termed SHP plant. However, there is no internationally agreed definition of SHP in terms of capacity, it varies from country to country (BHA, 2012; Divas, 2006). The prospects of accessing grid-based electricity in isolated rural districts in developing countries are small. The grid electricity is usually for industries and other large customers residing in cities. Higher power supply to cities is reasonable due to their economic capacity to pay for the heavy utility expenditure from electricity. Consequently, several studies have advocated

Figure 18: Sub-Saharan hydropower capacity and the remaining potential in the new policies scenario (GW) (International Energy Agency, 2014)

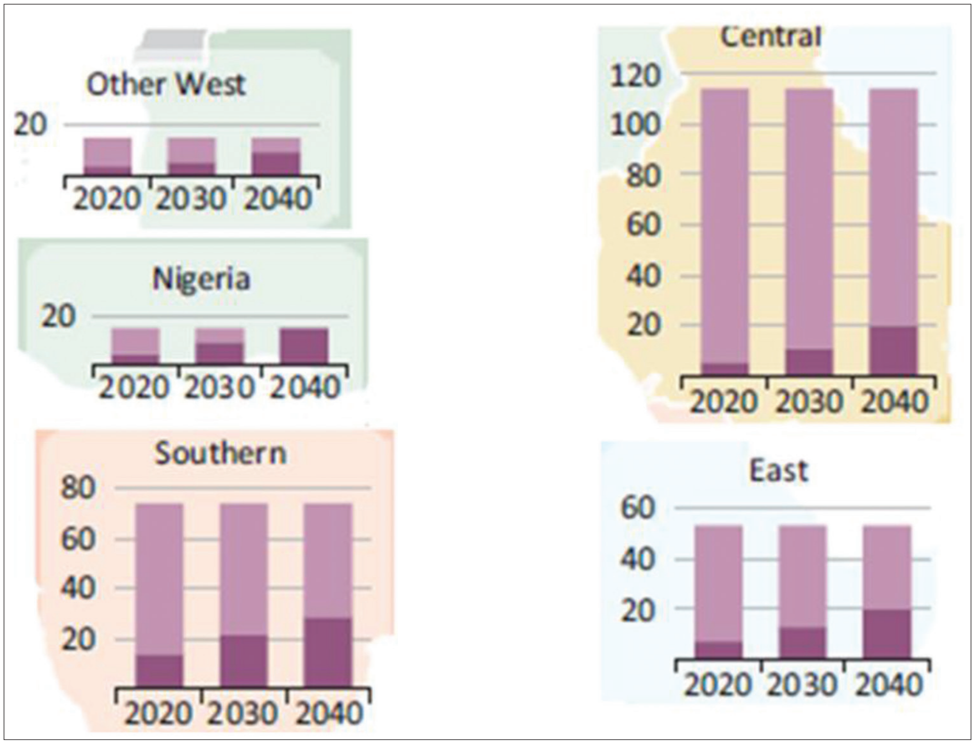


Table 4: Classification of Hydroelectric technologies

Hydropower type	Description
Impoundment (Li et al., 2017; Liu et al., 2018; Wu et al., 2016)	Impoundment hydropower is typically a large hydropower system that uses dam as a reservoir to store river water that is then released to flow through the penstock to the turbine and spin it.
Diversion (Fuentes-Bargues and Ferrer-Gisbert, 2015; Gaudard et al., 2018; Sindelar et al., 2017)	A diversion, also called run-of-river, directs a portion of a river through a canal to penstock or directly to a penstock. The type of facility requires little or no storage facility but at times a weir is needed. It provides a continuous supply of power with some flexibility of operation by regulating the water flow to address daily fluctuations in demand.
Pumped storage (Breeze, 2018a, 2018b; Lu and Wang, 2017; Pérez-Díaz et al., 2015; Popa et al., 2017; Zhang et al., 2018)	Pumped storage - this involves the harnessing of water through the cycling of previously used water by pumping between a lower and upper reservoir. Water is pumped uphill reservoir from a second reservoir at a lower elevation. It provides peak-load supply, harnessing the energy in the cycled water between the lower and upper reservoirs. The pumping is usually carried out during the low demand period
Offshore- hydropower (Barbarelli et al., 2018; Zhang et al., 2018)	This is an emerging hydropower technology that is currently less established. This growing group of technology uses the power of waves or tidal currents to generate electricity from seawater.

Table 5: A broad classification of hydroelectric plants

Basis of classification	Categories	
Inlet to the turbine	Impulse turbine: Energy in the form of kinetic, e.g., Pelton wheel, Turbo wheel. Reaction turbine: Energy in both Kinetic and pressure, e.g., tubular, bulb, propeller, Francis turbine.	
The capacity of water flow regulation	Run of river plants Storage plant Pumped storage plant	
Head (*H*)	Low head plants (H=2–30 m) Medium head plants (30>H > 100 m) High head plants above (H>100 m)	
Operation load supplied	Base load plants Peak load plants	
Storage and pondage	With dam/storage Without a dam/storage	
Plant generation capacity	Pico-plant (KW)	P<5
	Micro-plant (KW)	5<P < 100
	Mini-plant (KW)	100<P < 1,000
	Small-plants (KW)	1000<P < 10,000
	Medium-plants (KW)	10,000<P < 100,000
	Large-plants (KW)	100,000<P < 10,000
Location and topography	Low land Hilly area Mountainous region	
Water direction of flow through the runner	Tangential flow: Water flowing tangentially (perpendicular to both radial and axial directions) to the path of rotation. Radial outward flow as in Forneyron turbine Axial flow: Water flowing parallel to the axis of the turbine, as in Girard, Kaplan, and Jonval turbines Mixed flow: Radial entering Water at the outer periphery and exiting axially, as in modern Francis turbine.	
Turbine characteristics	Low specific speed, e.g., Pelton wheel. Medium specific speed, e.g., Francis wheel.	

High specific speed,

off-grid based renewable energy schemes for rural electrification (Williams et al., 2016; Williams et al., 2017; Mohammed et al., 2013). SHP system is a tested and trusted power scheme for rural electrification because its environment and simplicity is an advantage over large hydropower.

The scheme has received global acceptance for rural and standalone electrification. The utilisation of SHP system in SSA is favoured by an abundance of potential sites. For example, a study by Energy Commission of Nigeria (ECN) reported that Nigeria has 15,000 MW hydropower resources. and out of this capacity, technically viable SHP potentials form 3450 MW (Onyia, 2013). Several other studies have pointed out that these potentials are found in all parts of Nigeria and are suitable for rural electrification. The key benefits of this electrification scheme are system simplicity, the absence of GHG emmission, low maintenance and running costs (Abdullahi, 2005; Kela et al., 2012; Sambo, 2010). Other merits are the provision of cheap power for agro-allied industries and individuals for agro processing, contribution to local government revenue, the creation of job opportunities in the rural areas, and reduction of rural-urban migration.

SHP has been described as the best power system for rural areas and stand-alone electrification (Williams et al., 2016; Williams et al., 2017; Williams et al., 2017; Ebhota and Tabakov, 2018). In addition, SHP is a renewable energy generation system that produces electricity at low cost, between 0.02/kWh and 0.05/kWh USD (IRENA, 2014; UNIDO, 2013). A geospatial assessment study (Korkovelos, 2017) of small-scale hydropower potential defines mini and SHP as 0.1–1 MW and 1–10 MW respectively. Figure 14 shows mini and SHP potentials of selected points in 44 SSA countries. The study reported that:

i. About 5383 SHP sites have been identified across SSA, with the highest concentration in Central and South Africa and the estimated power capacity of these sites is 21,800 MW. One third of the identified potential sites are in DR Congo, South Africa, and Sudan and the estimated power pools of the sub regions in SSA is shown in Figure 19.
ii. Identified a total of 10,216 mini hydropower potential sites in SSA with an estimated generation capacity of 3,421 MW. These mini potential sites are concentrated in central Africa countries with Congo DR and Angola having the highest potential of about 975 MW. Mini and SHP potential points in SSA are shown in Figure 20.

Figure 19: Small hydropower potential per African power pool (Korkovelos, 2017)

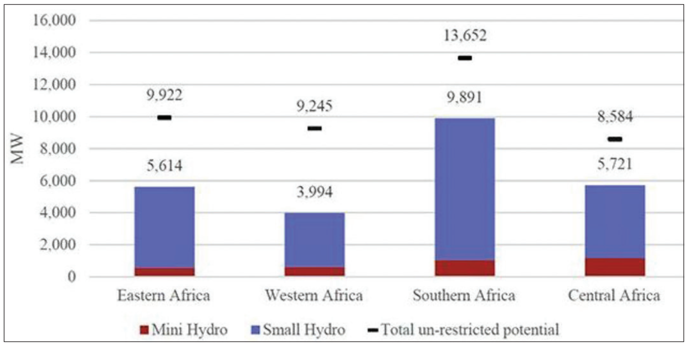
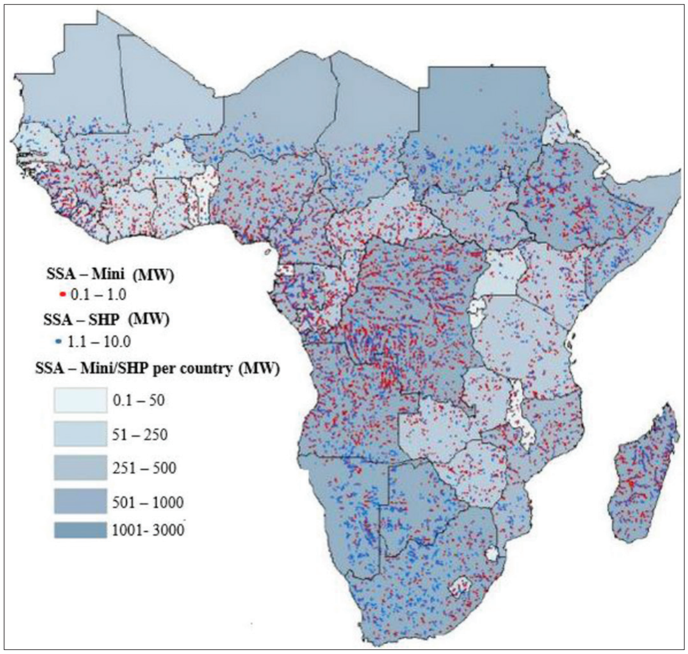


Figure 20: Mini and SHP potential in the selected points in Sub-Saharan Africa (Korkovelos, 2017)



5.4. Pumped Hydroelectric Storage

Pumped storage hydropower (PSH) is another hydroelectricity generation technology, though it is not new but is currently receiving much attention due to the global energy formation change. The technology has been described as a reliable power generating system for emergency peak demand. It is well exploited in areas where water availability is a challenge. The concept of PSH is the retaining of used water for reuse by utilising a pump back mechanism during low power demand periods instead of allowing the water being discharged into its flow path (Pérez-Díaz and Jiménez, 2016; Rehman et al., 2015). This implies, the reclamation of the surplus of the electrical energy generated by the PSHP in periods of low demand and stored as potential hydraulic energy. In a PSH system the turbine is in between two water reservoirs, which are separated vertically to form upper and lower reservoirs, as illustrated in Figure 21.

Best potential for pumped storage is usually found in the mountainous regions because they offer high heads of water that can be utilised. PSH technology is a facility for optimising the application of irregular generation over long periods and generally it may be deployed to perform the following operations (Táczi, 2016):

i. Peak shaving - PSH is used as a backup generating facility to meet the peak demands in short periods of time
ii. Quick start capability - the hydropower generation in a PSH starts in a few minutes. The PSH is about 30 minutes less than other turbines or hours less than the steam generation
iii. Black start capability - PSHPs have the capability to run at zero loads and additional power can be loaded rapidly when loads increase
iv. Load balancing - Load levelling involves saving power during periods of light loading
v. Voltage support - PSHPs have the ability to manage reactive power, which ensures that power will flow from generation to load
vi. Frequency regulation - hydropower helps to maintain the frequency through a continuous modulation of active power within the given limits
vii. Back-up reserve, spinning reserve - PSH facility has the ability to provide additional power supply within seconds to the transmission system to cushion surge in case of unexpected load changes in the grid.

5.5. PSH in SSA

At present, the level of PSH deployment in SSA, and the whole of Africa is insignificant. From PSH mapping conducted by the IHA, there are just two countries in the continent that have implemented PSH schemes. These countries are Morocco and South Africa (SA), as shown in Figure 22. Morocco's PSH system at Afourer near Beni-Mellal of 460-MW capacity, plays a complimentary role to the 26 hydropower stations, totalling 1,360 MW in capacity (OBG, 2016). Just this year (2018), a contract to build a 350 MW Abdelmoumen pumped-storage facility in Morocco, valued at a cost $339 million was awarded to Vinci consortium (Choukri et al., 2017; Ingram, 2018; OBG, 2016). This facility and two other PSHPs of 300 MW each are under development and are expected to be completed in 2020 and 2030. They are all part of Morocco's RE development and integration plan (Choukri et al., 2017).

Currently, four PSHPs are operational in SA, their total installed capacity is about 2910 MW, which amounts to about 6% of the total electricity generation capacity of SA (Barta, 2018). The details of these PSHPs operating across the country are presented in Table 7.

Figure 21: Schematic of PSH system's operating principle (Breeze, 2018a; Dvorak, 2018)

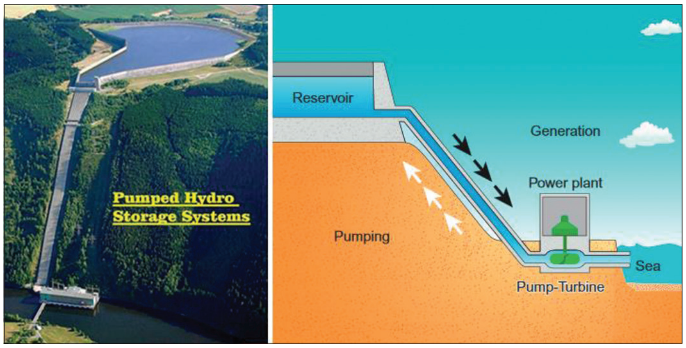
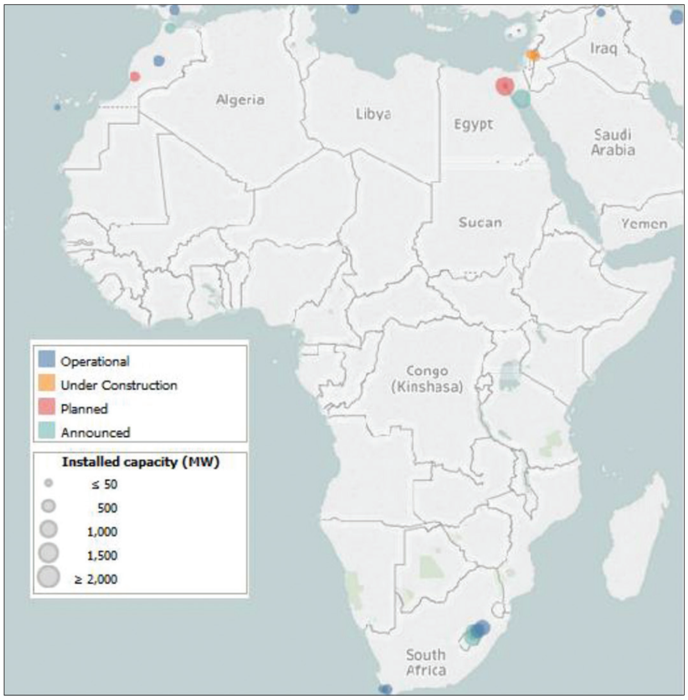


Figure 22: IHA's PSH Tracking Tool maps of Africa (IHA, 2017)



5.6. PSH Outlook

A study by Ecoprog in 2013 shows that the development and application of PSH will grow stronger between 2013 and 2023 (ECOPROG, 2013). By 2020, the PSH installed capacity is estimated to be 74 GW from about 100 new PSHPs and this amounts to 50% of a current number of plants and about 56-billion-euro investment. This emerging boom prediction is anchored on the world's resolution to increase the share of renewable energies in electricity generation. The new PSHPs will be designed as transitional storage of electricity from fossil power plants and for the fluctuating production especially of solar and wind power. This is due to the electricity generation fluctuations caused by the significant hourly, daily and seasonally variations of solar and wind power.

5.7. The Significance of Hydropower in Electricity Generation

Hydropower, solar, and wind are mostly used in renewable energies in SSA. Hydropower has the highest generation efficiency and is the leading global renewable energy source for electricity generation and it supplied 71% of all renewable electricity in 2015. The generation efficiency of the modern turbine is as high as 90% while the efficient of the best fossil fuel plants are only about 50%. It was reported in 1996 that Canada and the United States of America (USA) are the number one and two largest hydropower generating countries in the world (National Hydropower Association [NHA], 1996). In the USA, electricity produced from hydropower is enough to serve the needs of 28 million residential customers. This covers residential homes in Michigan, Minnesota, Tennessee, Indiana, Iowa, Nebraska, Kansas, Ohio, North and South Dakota, Missouri, Kentucky, and Wisconsin. Other countries with remarkable hydroelectric generation are Norway with more than 99% of its electricity from hydropower and New Zealand with 75% of its electricity from hydroelectric. However, in 2015, the IHA reported that China leads the rest of the world, followed by the USA in the hydroelectric generation, as shown in Figure 23 (IHA, 2015). Hydropower, which generates about 17% of the world's electricity, is expected to remain the world's largest source of renewable electricity production by 2022 (IEA, 2012).

5.8. The Role of Hydropower in CO2 Emissions Reduction

Hydroelectric is expected to play a critical role in checking CO_2 emission in the power sector and enhancing system flexibility.

Figure 23: Top hydropower generating countries as of 2015 (NHA, 1996; WEC, 2016).

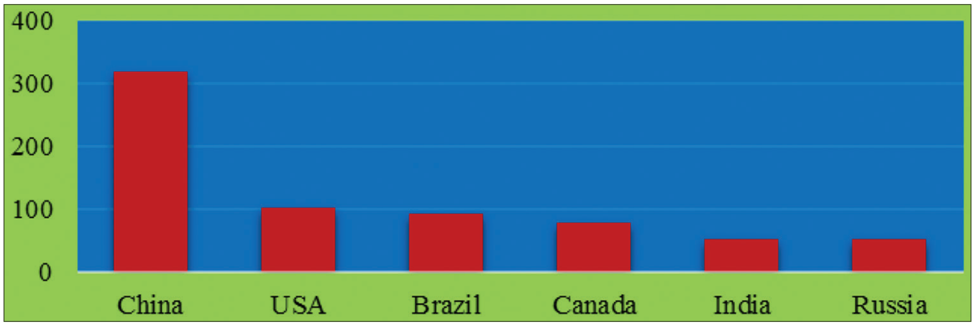


Table 6: Some major hydropower projects in SSA (Salini-Impregilo, 2017)

Country	Project	Capacity	Date of completion
Congo RC (Clowes, 2018; Green et al., 2015; Oyewo et al., 2018; WWF, 2003)	Inga 3 (low-head)	4755 MW	2020
	Inga 3 (high-head)	3037 MW	2025
	Inga 4	7182 MW,	2030
	Inga 5, MW,	6970 MW	2035
	Inga 6	6684 MW	2040
	Inga 7	6706 MW	2045
	Inga 8	6747 MW	2050
Nigeria	Mambilla (Brimmo et al., 2017; CGGC, 2017; Mongalvy et al., 2018; Monks, 2017)	3,050 MW	2023
	Zunguru (ESI, 2017; Sinohydro, 2013)	700 MW	2020
Ethiopia (Aigaforum, 2017; Bello)	Gilgel Gibe III (Poindexter, 2015)	1,870 MW	2018
	Genale Dawa III	254 MW	2018
	Genale Dawa VI	257 MW	2021
	Koysha dam (Salini-Impregilo, 2016)	2,160 MW	
	Grand Renaissance (Salini-Impregilo, 2017)	6,450 MW	2040
Tanzania (HydroWorld.com, 2017)	Rusumo Falls	80 MW	2018
Rwanda (ADBG, 2018)	The Ruzizi III	145 MW	2022
Gabon (ADBG, 2012; Bonface)	Ngounié Falls	84 MW	
Senegal (PIDA, 2017)	Sambangalou	128 MW	2018
Uganda (UEGC)	Isimba	183 MW	2018

PIDA: Programme for Infrastructure Development in Africa, SSA: Sub-Saharan Africa

Table 7: Operating PSHPs in SA

PSHPs in SA	Capacity	Property of
Steenbras (1979)	180 MW	City of Cape Town
Drakensberg (1981)	1,000 MW	Eskom SOC
Palmiet (1987)	400 MW	Eskom SOC
Ingula (2016)	1,330 MW	Eskom SOC

SHP: Small hydropower

The study greenhouse gas footprint of 500 large hydropower reservoirs, exploiting a new tool, GHG Reservoir (G-res), to assess net emissions, shows that the median emissions intensity of hydropower is only just 18.5 gCO_2-eq/kWh (IHA, 2018a). The use of hydropower instead of coal in the generation of electricity in 2017, prevented the emissions of – about 4 billion tonnes of GHG globally; 62 million tonnes of sulphur dioxide; 148 million tonnes of air polluting particles; 8 million tonnes of nitrogen oxide; and avoided the estimated 10% increase from global industry and fossil fuels emissions (IHA, 2018a).

6. CONCLUSION

Sub-Sahara Africa is bedevilled by chronic gross inadequate electricity supply that has plagued the region for decades. The region has the highest population without access to electricity and this comes with grievous consequences of retarded economic growth, high rate of unemployment, health issues and poverty in the region. The economic indexes, such as GDP, and DNI of the region reflect this and they show downward trends. Ironically, the region is blessed with both conventional and renewable energy resources that are inadequately tapped. Amongst the renewable energies, hydropower, has been identified to play a significant role in overcoming power inadequacies that come with population growth, industrialisation and urbanisation if adequately harnessed. The deployment of hydropower systems lessens the global dependence on fossil fuels, facilitates variable renewables through a hybrid renewable energy system (HRES) and storage. Apart from power generation, hydropower provides several economic benefits that repel poverty and manages water effectively.

7. ACKNOWLEDGMENT

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REFERENCES

Abdullahi, M. (2005), Small Hydro Power: An Important Renewable Energy Sources for Rural Electrification in Nigeria SHP Development and Programme Worldwide, SHP NEWS, Spring.

ADBG. (2012), Gabon-Empress Eugenie Falls Hydroelectric Power Plant (CDI), Fougamou, Ngounié Province and the FE2 Falls Hydroelectric Power Plant, Okano River, Woleu-Ntem Province-ESMP Summary. African Development Bank Group (ADBG).

ADBG. (2018), Ruzizi III Hydropower Project (Rwanda)-Project Implementation. African Development Bank Group (ADBG). Available from: https://www.afdb.org/en/projects-and-operations/project-portfolio/p-z1-fa0-077/.

Agrawal, S., Yamamoto, S. (2015), Effect of indoor air pollution from biomass and solid fuel combustion on symptoms of preeclampsia/eclampsia in Indian women. Indoor Air, 25(3), 341-352.

Aigaforum. (2017), Ethiopia Hydropower Investments Q1 2017. Available from: http://www.aigaforum.com/news2017/asoko-on-ethio-hydorpower-project.htm.

Amegah, A.K., Jaakkola, J.J. (2016), Household air pollution and the sustainable development goals. Bulletin of the World Health Organization, 94, 215-221.

Ayemba, D. (2017), How Viable is Hydropower in Africa. Available from: https://www.constructionreviewonline.com/2017/04/viable-hydropower-in-africa/.

Barbarelli, S., Florio, G., Amelio, M., Scornaienchi, N.M. (2018), Preliminary performance assessment of a novel on-shore system recovering energy from tidal currents. Applied Energy, 224, 717-730.

Barta, B. (2018), South Africa Energy Storage: The Contribution of Pumped Storage Schemes to Energy Generation in South Africa. Available from: http://www.ee.co.za/article/the-contribution-of-pumped-storage-schemes-to-energy-generation-in-south-africa.html.

Bello, L.D. Africa's Hydropower Future. SciDev.Net. Available from: https://www.scidev.net/global/energy/data-visualisation/africa-hydropower-future-interactive.html#.

BHA. (2012), A Guide to UK Mini-Hydro Development. British Hydropower Association Bonface. Construction of Hydroelectric Power Stations in Gabon to Begin. Available from: https://www.constructionreviewonline.com/2016/02/construction-hydroelectric-power-stations-gabon-begin/.

BP. (2017), Statistical Review of World Energy. Available from: https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-full-report.pdf.

Breeze, P., editor. (2018a), Pumped storage hydropower. In: Power System Energy Storage Technologies. Ch. 2. Canada: Academic Press. p13-22.

Breeze, P., editor. (2018b), Pumped storage hydropower. In: Hydropower. Ch. 8. New York: Academic Press. p73-78.

Brimmo, A.T., Sodiq, A., Sofela, S., Kolo, I. (2017), Sustainable energy development in nigeria: Wind, hydropower, geothermal and nuclear (Vol. 1). Renewable and Sustainable Energy Reviews, 74, 474-490.

Burton, J. (2017a), The Poorest Countries in the World. Economics, World Atlas. Available from: https://www.worldatlas.com/articles/the-poorest-countries-in-the-world.html.

Burton, J. (2017b), The World's 10 Poorest Countries. Worldlas. Available from: https://www.worldatlas.com/articles/the-poorest-countries-in-the-world.html.

Castellano, A., Kendall, A., Nikomarov, M., Swemmer, T. (2015), Brighter Africa: The Growth Potential of the Sub-Saharan Electricity Sector. Retrieved from McKinsey and Company, Johannesburg, South Africa. Available from: https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/powering-africa.

CGGC. (2017), Contract for Mambilla Hydropower Station in Nigeria Signed. China Gezhouba Group Corporation (CGGC), Energy China. Available from: http://www.en.ceec.net.cn/art/2017/11/14/art_138_1514690.html.

Chafe, Z.A., Brauer, M., Klimont, Z., Van Dingenen, R., Mehta, S., Rao, S., Smith, K.R. (2014), Household cooking with solid fuels contributes to ambient Pm2.5 air pollution and the burden of disease. Environmental Health Perspectives, 122(12), 1314-1320.

Choukri, K., Naddami, A., Hayani, S. (2017), Renewable energy in emergent countries: Lessons from energy transition in Morocco. Energy, Sustainability and Society, 7(1), 25-35.

Clowes, W. (2018), Congo to Start $13.9 Billion Hydropower Project this Year. Pan African Visions. Available from: https://www.panafricanvisions.com/2018/congo-start-13-9-billion-hydropower-project-year/.

Codi, K. (2015), Zambia Electricity Shortage Highlights Africa's Hydropower Shortfalls. Waternews.

Conway, D. (2017), Hydropower in Africa: Plans for New Dams Could Increase the Risk of Disruption to Electricity Supply. The London School of Economics and Political Science. Available from: http://www.lse.ac.uk/GranthamInstitute/news/africa-hydropower-new-dams-increase-risk-supply-disruption/.

Das, I., Jagger, P., Yeatts, K. (2017), Biomass cooking fuels and health outcomes for women in Malawi. EcoHealth, 14(1), 7-19.

Davis, K.J. Africa's Renewable Energy Potential. Available from: https://www.africa.com/africas-renewable-energy-potential/.

Divas, B.B. (2006), Background Material: Fundamentals of Small Hydro Power Technologies. Nairobi, Kenya: Renewable Energy and Energy Efficiency Partnership.

Dvorak, P. (2018), Global Market Insights Reports that Pumped Hydro Storage Market to Surpass $350 Billion by 2024. Available from: https://www.windpowerengineering.com/electrical/pumped-hydro-storage-market-to-surpass-350-billion-by-2024/.

Ebhota, W.S., Inambao, F.L. (2016), Design basics of a small hydro turbine plant for capacity building in Sub-Saharan Africa. African Journal of Science, Technology, Innovation and Development, 8(1), 111-120.

Ebhota, W.S., Inambao, F.L. (2016), Electricity insufficiency in Africa: A product of inadequate manufacturing capacity. African Journal of Science, Technology, Innovation and Development, 8(2), 197-204.

Ebhota, W.S., Inambao, F.L. (2017), Facilitating greater energy access in rural and remote areas of Sub-Saharan Africa: Small hydropower. Energy and Environment, 28(3), 316-329.

Ebhota, W.S., Inambao, F.L. (2017), Smart design and development of a small hydropower system and exploitation of locally sourced material for pelton turbine bucket production. Iranian Journal of Science and Technology, Transactions of Mechanical Engineering, 2017, 1-24.

Ebhota, W.S., Tabakov, P.Y. (2017), Hydropower potentials and effects of poor manufacturing infrastructure on small hydropower development in Sub-Saharan Africa. International Journal of Energy Economics and Policy, 7(5), 60-67.

Ebhota, W.S., Tabakov, P.Y. (2018), The place of small hydropower electrification scheme in socioeconomic stimulation of Nigeria. International Journal of Low-Carbon Technologies, 13(4), 38.

ECOPROG. (2013), The World Market for Pumped-Storage Power Plants. ECOPROG GmbH. Available from: https://www.ecoprog.com/publikationen/energiewirtschaft/pumpspeicherkraftwerke.htm.

ENCO. Engineering Consultants. Classification of Mini Hydro Power Plants. Available from: http://www.minihydro.co/mini-hydro-power-plants/.

ESI. (2017), Nigeria: Zungeru Hydroelectric Power Plant, 47% Complete. ESI Africa's Power Journal. Available from: https://www.esi-africa.com/nigeria-zungeru-hydroelectric-power-47-complete/.

FocusEconomics. (2018), The Poorest Countries in the World. Available from: https://www.focus-economics.com/blog/the-poorest-countries-in-the-world#GDP%20per%20capita%202016-2022.

Fuentes-Bargues, J.L., Ferrer-Gisbert, P.S. (2015), Selecting a small run-of-river hydropower plant by the analytic hierarchy process (ahp): A case study of miño-sil river basin, Spain. Ecological Engineering, 85, 307-316.

Gagliano, A., Tina, G.M., Nocera, F., Patania, F. (2014), Technical and economic perspective for repowering of micro hydro power plants: A case study of an early 20th century power plant. Energy Procedia, 62(Supplement C), 512-521.

Gatte, M.T., Kadhim, R.A. (2012), Hydro power. In: Ahmed, A.Z. editor. Energy Conservation. Ch. 4. London, UK: InTech.

Gaudard, L., Avanzi, F., De Michele, C. (2018), Seasonal aspects of the energy-water nexus: The case of a run-of-the-river hydropower plant. Applied Energy, 210, 604-612.

Gent, D., Tomei, J. (2017), Electricity in central America: Paradigms, reforms and the energy trilemma. Progress in Development Studies, 17(2), 116-130.

Goldstein, A. (2015), What is the Link Between Carbon Emissions and Poverty? World Economic Forum. Available from: https://www.weforum.org/agenda/2015/12/what-is-the-link-between-carbon-emissions-and-poverty/.

Green, N., Sovacool, B.K., Hancock, K. (2015), Grand designs: Assessing the African energy security implications of the grand inga dam. African Studies Review, 58(1), 133-158.

Gregson, J. (2017), Poorest Countries in the World. Global Finance. Available from: https://www.gfmag.com/global-data/economic-data/the-poorest-countries-in-the-world?page=12.

Gronewold, N. (2009), One-Quarter of World's Population Lacks Electricity. Available from: https://www.scientificamerican.com/article/electricity-gap-developing-countries-energy-wood-charcoal/.

Haidar, A.M.A., Senan, M.F.M., Noman, A., Radman, T. (2012), Utilization of pico hydro generation in domestic and commercial loads. Renewable and Sustainable Energy Reviews, 16(1), 518-524.

Harris, M. (2016), Trends in Hydropower. Available from: https://www.hydroworld.com/articles/print/volume-24/issue-3/features/trends-in-hydropower.html.

Harvey, M. (2014), The food-energy-climate change trilemma: Toward a socio-economic analysis. Theory, Culture and Society, 31(5), 155-182.

Heffron, R.J., McCauley, D., Sovacool, B.K. (2015), Resolving society's energy trilemma through the energy justice metric. Energy Policy, 87(Supplement C), 168-176.

IEA. (2011), World Energy Outlook 2011, OECD/IEA. Paris: International Energy Agency. Available from: https://www.iea.org/publications/freepublications/publication/WEO2011_WEB.pdf.

IEA. (2012), Technology Roadmap: Hydropower. International Energy Agency. Available from: https://www.iea.org/publications/freepublications/publication/2012_Hydropower_Roadmap.pdf.

IEA. (2014), Africa Energy Outlook: A Focus on Energy Prospects in Sub-Saharan Africa. Retrieved from London. Report.

IEA. (2017), Energy Access Outlook: From Poverty to Prosperity. Paris, France. Available from: http://www.iea.org/publications/freepublications/publication/WEO2017SpecialReport_EnergyAccessOutlook.pdf.

IHA. (2015), Briefing: 2015 Key Trends in Hydropower. International Hydropower Association. Available from: https://www.hydropower.org/sites/default/files/publications-docs/IHA%202015%20Key%20Trends%20in%20Hydropower.pdf.

IHA. (2017), Pumped Storage Tracking Tool. International Hydropower Association. Available from: https://www.hydropower.org/hydropower-pumped-storage-tool.

IHA. (2018a), The 2018 Hydropower Status Report: Offers Insights and Trends on the Hydropower Sector. London: International Hydropower Association (IHA).

IHA. (2018b), World Water Forum: Hydropower's Role in Clean Energy and Water Systems. International Hydropower Association. Available from: https://www.hydropower.org/news/world-water-forum-hydropower%e2%80%99s-role-in-clean-energy-and-water-systems.

Ingram, E. (2018), Contract Awarded to Develop 350-MW Abdelmoumen Pumped Storage in Morocco. Available from: https://www.hydroworld.com/articles/2018/01/contract-awarded-to-develop-350-mw-abdelmoumen-pumped-storage-in-morocco.html.

IRENA. (2014), Renewable Power Generation Costs in 2014. Abu Dhabi: International Renewable Energy Agency (IRENA).

Johnson, F.X., Mayaka, E.K., Ogeya, M., Wanjiru, H., Ngare, I. (2017), Transitions Pathways and Risk Analysis for Climate Change Mitigation and Adaptation Strat. UK: TRANSrisk.

Kambou, G. (2018), Global Economic Prospects Broad-Based Upturn, But for How Long? Sub-Saharan Africa (Kindle Edition ed.). Northwest Washington: World Bank Group.

Kela, R., Usman, K.M., Tijjani, A. (2012), Potentials of small hydro power in Nigeria: The current status and investment opportunities. International Journal of Scientific and Engineering Research, 3(5), 1038-1042.

Kiersz, A. (2015), Global Poverty Rates Have Been Cut in Half Since 1981. Buiness Insider, South Africa. Available from: http://www.businessinsider.com/global-poverty-rates-have-been-cut-in-half-since-1981-2015-7?IR=T.

Korkovelos, A. (2017), A Geospatial Assessment of Small-Scale Hydropower Potential in Sub-Saharan Africa. The International Hydropower Association (IHA). Available from: https://www.hydropower.org/blog/a-geospatial-assessment-of-small-scale-hydropower-potential-in-sub-saharan-africa.

Li, Z., Lu, L., Lv, P., Du, H., Guo, J., He, X., Ma, J. (2017), Carbon footprints of pre-impoundment clearance on reservoir flooded area in China's large hydro-projects: Implications for ghg emissions reduction in the hydropower industry. Journal of Cleaner Production, 168, 1413-1424.

Lindeman, T. (2015), 1.3 Billion are Living in the Dark. Available from: https://www.washingtonpost.com/graphics/world/world-without-power/.

Liu, X., Tang, C.A., Li, L., Lv, P., Sun, R. (2018), Microseismic monitoring and stability analysis of the right bank slope at dagangshan hydropower station after the initial impoundment. International Journal of Rock Mechanics and Mining Sciences, 108, 128-141.

Lu, X., Wang, S. (2017), A GIS-based assessment of tibet's potential for pumped hydropower energy storage. Renewable and Sustainable Energy Reviews, 69, 1045-1054.

Majumder, M., Ghosh, S. (2013), Hydropower Plants Decision Making Algorithms for Hydro-Power Plant Location. Singapore: Springer. p15-19.

Mohammed, Y.S., Mustafa, M.W., Bashir, N. (2014), Hybrid renewable energy systems for off-grid electric power: Review of substantial issues. Renewable and Sustainable Energy Reviews, 35, 527-539.

Mohammed, Y.S., Mustafa, M.W., Bashir, N., Mokhtar, A.S. (2013), Renewable energy resources for distributed power generation in nigeria: A review of the potential. Renewable and Sustainable Energy Reviews, 22, 257-268.

Mongalvy, S., Doya, D.M., Sguazzin, A. (2018), Nigeria to Start Building $5.8 Billion Power Plant in 2018. Business. Available from: https://www.bloomberg.com/news/articles/2018-01-30/nigeria-to-start-building-5-8-billion-hydro-power-plant-in-2018.

Monks, K. (2017), Nigeria Announces $5.8 Billion Deal for Record-Breaking Power Project. CNN. Available from: https://www.edition.cnn.com/2017/09/14/africa/nigeria-china-hydropower/index.html.

Morrissey, J. (2017), Part 2-addressing energy poverty oxfam series. In: The Energy Challenge in Sub-Saharan Africa: A guide for Advocates and Policy Makers. USA: Oxfam Research Backgrounder.

Nganga, M.W. (2016), Understanding Africa's Energy Needs. World Economic Forum. Available from: https://www.weforum.org/agenda/2016/11/understanding-africas-energy-needs/.

NHA. (1996), Facts About Hydropower. National Hydropower Association (NHA), Wisconsin Valley Improvement Company. Available from: http://www.wvic.com/content.cfm?PageID=686.

OBG. (2016), The Report Morocco 2016: Hydropower Plays a Growing Role in the Development of Renewables in Morocco. Oxford Business Group (OBG). Available from: https://www.oxfordbusinessgroup.com/analysis/pumped-hydropower-plays-increasingly-significant-role-renewables-segment.

Onyia, C. (2013), Nigeria has 15,000 MW Hydropower Potential. Available from: http://www.thenationonlineng.net/nigeria-has-15000mw-hydropower-potential/.

Oyewo, S.A., Farfan, J., Peltoniemi, P., Breyer, C. (2018), Repercussion of large scale hydro dam deployment: The case of congo grand inga hydro project. Energies, 11(4), 972.

Pérez-Díaz, J.I., Chazarra, M., García-González, J., Cavazzini, G., Stoppato, A. (2015), Trends and challenges in the operation of pumped-storage hydropower plants. Renewable and Sustainable Energy Reviews, 44, 767-784.

Pérez-Díaz, J.I., Jiménez, J. (2016), Contribution of a pumped-storage hydropower plant to reduce the scheduling costs of an isolated power system with high wind power penetration. Energy, 109, 92-104.

PIDA. (2017), Sambangalou Hydropower Plant. Programme for

Infrastructure Development in Africa (PIDA). Available from: http://www.au-pida.org/view-project/747/.

Poindexter, G.B. (2015), Power Generation Begins at 1,870-MW Gibe III Hydroelectric Project in Ethiopia ADDIS ABABA, Ethiopia. HydroWorld.com. Available from: https://www.hydroworld.com/articles/2015/10/power-generation-begins-at-1-870-mw-gibe-iii-hydroelectric-project-in-ethiopia.html.

Popa, F., Popa, B., Popescu, C. (2017), Assessment of pumped storage plants in Romania. Energy Procedia, 112, 473-480.

Rehman, S., Al-Hadhrami, L.M., Alam, M.M. (2015), Pumped hydro energy storage system: A technological review. Renewable and Sustainable Energy Reviews, 44, 586-598.

REN21. (2018), Advancing the Global Renewable Energy Transition. Highlights of the REN21 Renewables 2018 Global Status Report in perspective. Paris: Renewable Energy Policy Network for the 21st Century (REN21).

Rusumo Falls Hydropower Project. (2017), Available from: https://www.hydroworld.com/hydro-projects/rusumo-falls-hydropower-project.html.

Salini-Impregilo. (2016), Koysha Hydroelectric Project. Available from: https://www.salini-impregilo.com/en/projects/in-progress/dams-hydroelectric-plants-hydraulic-works/koysha-hydroelectric-project.html#.

Salini-Impregilo. (2017), African Hydro Developments. International Water Power and Dam Construction. Available from: https://www.salini-impregilo.com/static/upload/wat/water-power-africa.pdf.

Sambo, A.S. (2010), Renewable Energy Development in Nigeria Development in Nigeria Paper Presented at the World Future Council/Strategy Workshop on Renewable Energy, Accra, Ghana.

Schenk, A. (2016), A Burning Issue: Woodfuel, Public Health, Land Degradation and Conservation in Sub-Saharan Africa: Wood Energy Fuelling the Future. Available from: http://www.birdlife.org/africa/news/burning-issue-woodfuel-public-health-land-degradation-and-conservation-sub-saharan.

Seifried, D., Witzel, W. (2010), Renewable Energy-the Facts. Washington, DC: Earthscan.

Sindelar, C., Schobesberger, J., Habersack, H. (2017), Effects of weir height and reservoir widening on sediment continuity at run-of-river hydropower plants in gravel bed rivers. Geomorphology, 291, 106-115.

Sinohydro. (2013), Nigeria, Zungeru Hydropower Plant. Available from: http://www.eng.sinohydro.com/index.php?m=content&c=index&a=show&catid=42&id=378.

Táczi, I. (2016), Pumped Storage Hydroelectric Power Plants: Issues and Applications. Budapest, Hungary: Paper Presented at the Energy Regulators Regional Association Secretariat (ERRAS).

Trotter, P.A. (2016), Rural electrification, electrification inequality and democratic institutions in Sub-Saharan Africa. Energy for Sustainable Development, 34, 111-129.

UEGC. Isimba Hydropower Project. Uganda Electricity Generation Company (UEGC) Limited. Available from: https://www.uegcl.com/business-operations/projects/isimba-hydro-power.html.

UN. (2015), Sustainable Development Goals. United Nations. Available from: https://www.sustainabledevelopment.un.org/?menu=1300.

UNIDO. (2013), World Small Hydropower Development Report 2013. United Nations Industrial Development Organization and International Center on Small Hydro Power.

Urpelainen, J. (2017), Electricity Access in 2030, According to the International Energy Agency. The Initiative for Sustainable Energy Policy (ISEP). Available from: http://www.sais-isep.org/?p=1894.

WEC. (2016), World Energy Trilemma. United Kingdom: World Energy Council (WEC), Company Limited by Guarantee. Available from: https://www.worldenergy.org/wp-content/uploads/2016/05/World-Energy-Trilemma_full-report_2016_web.pdf.

Wee, R.Y. (2017), World Facts: Countries With the Lowest Access to Electricity. Worldatlas. Available from: https://www.worldatlas.com/world-facts/.

World Bank. (2017), Economic Growth in Africa is on the Upswing Following a Sharp Slowdown. Available from: http://www.worldbank.org/en/news/press-release/2017/04/19/economic-growth-in-africa-is-on-the-upswing-following-a-sharp-slowdown.

World Bank. (2018a), Access to Electricity (% of Population). Available from: https://www.data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=SC-MW-BI-MU-GH-NG-ZA-KE.

World Bank. (2018b), CO_2 Emissions (kt). Available from: https://www.data.worldbank.org/indicator/EN.ATM.CO2E.KT?end=2014&locations=ZG&start=1960&view=chart.

World Bank. (2018c), Energy Intensity Level of Primary Energy (MJ/$2011 PPP GDP). Available from: https://www.data.worldbank.org/indicator/EG.EGY.PRIM.PP.KD?end=2015&locations=ZG-EU-Z4-ZQ-AS-8S&start=2015&view=bar.

World Bank. (2018d), Poverty. Available from: https://www.data.worldbank.org/topic/poverty?locations=ZG-Z4-8S-ZJ-ZQ-Z7.

World Bank. (2018e), World Bank Country and Lending Groups. Available from: https://www.datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

Wu, S.Y., Cao, W., Zheng, J. (2016), Analysis of working behavior of jinping-i arch dam during initial impoundment. Water Science and Engineering, 9(3), 240-248.

WWF. (2003), An Investor's Guide to Dams. World Wildlife Fund (WWF's) Dams Initiative. Available from: https://www.d2ouvy59p0dg6k.cloudfront.net/downloads/investorsguidedams.pdf.

Zhang, H., Chen, D., Xu, B., Patelli, E., Tolo, S. (2018), Dynamic of a pumped-storage hydropower plant with random power load. Mechanical Systems and Signal Processing, 100, 524-533.

Zhang, L.X., Tang, S.J., Hao, Y., Pang, M.Y. (2018), Integrated emergy and economic evaluation of a case tidal power plant in China. Journal of Cleaner Production, 182, 38-45.