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Power accessibility, fossil fuel and the exploitation of small hydropower technology in sub-saharan Africa

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ABSTRACT

This study overviews the power status, salient barriers to adequate power access and the role of small hydropower in improving power accessibility in the region. The study notes that – over 50% of the population in 41 countries in the region have no access to electricity; the prediction of electricity access growth rate in SSA from 43% in 2016 to 59% in 2030; about 607 people, which is 90% of world's population without access to electricity in 2030 will leave in the region and the rural areas access is below 20%; over 90% of the households in about 25 countries of SSA rely on waste, wood, and charcoal for cooking; the average grid power tariff in SSA is US$0.13 per kWh as against the range of US$0.04 to US$0.08 per kWh grid power tariffs in most parts of the developing world. Also, it was found that the sections of power supply system – generation, transmission and distribution facilities are affected by insufficient funding, poor maintenance and management and over dependence on foreign power supply technologies; and the region is endowed with huge SHP resource that is insignificantly tapped. Lack of workable SHP development framework; insufficient fund; effect of the electricity market in the region; lack of effective synergy among the stakeholders; insufficient and outdated hydrological information about SHP resources; inadequate human and manufacturing facility development were the identified factors responsible for SHP underdevelopment. Domestic development of SHP technology is required to effectively develop SHP to improve access to power in the region. This will require massive human capacity building and the use of locally soured materials and production facilities.

Keywords:

Small hydropower;
Power;
Turbine design;
Pelton turbine;
Propeller turbine;
Sub-Saharan Africa;

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1. Introduction

Energy poverty poses a serious obstacle to the socioeconomic development of sub-Saharan Africa (SSA). The power situation in sub-Saharan Africa (SSA) is in a pathetic state despite several intervention measures [1]. The challenges that trail the power sector in the region seem as fresh as they were two decades ago and even deepened in some areas. The level of energy inadequacy in the region negates the longstanding efforts to change the narrative. Truly, this is heart breaking considering the resources and efforts that have been expended. The electricity access rates of most countries in the region are about 20% and two-third of the population lack access to modern energy services. The population without access to electricity by region, is shown in Fig 1. The electricity demanded by the region, from 2000 to 2012, increased by 35% to reach 352 TWh and an average rate of 4% annual electricity demand increase is expected through 2040. In 2017, the International Energy Agency (IEA) reported that [2]: electricity access rate in SSA will grow from 43% in 2016 to 59% in 2030; and about 607 people, which is 90% of world's population without access to electricity in 2030 will leave in the region.

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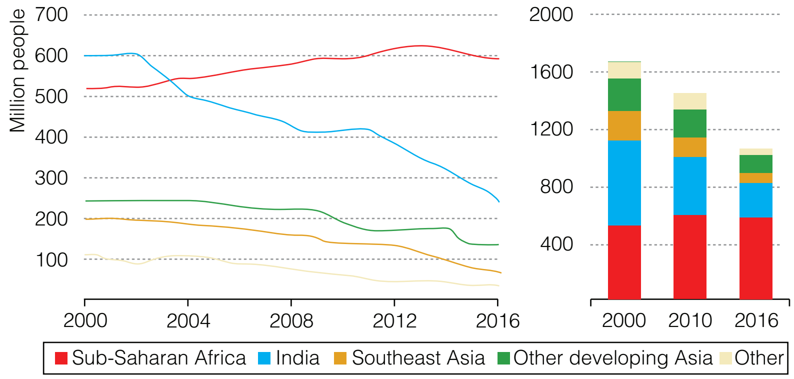

Figure 1: Population without access to electricity by region [2]

The residential sector average annual electricity consumption is about 488 kWh per capita, which equals only about 5% of the United States consumption [3]. Additional information about electricity in SSA are as follows:

- ✓ The region shares 13% of the world's population but accounts for only 4% of the world's energy demands.
- ✓ The total grid-connected power generation capacity in 48 countries in SSA is about 83 GW with South Africa accounting for 50%, generated mostly from coal [4].
- ✓ Only 13 countries in SSA have power systems capacities over 1 GW. These account for over 80% of the power capacity in SSA. While 27 countries have their grid-connected power systems less than 500 MW, 14 countries are below 100 MW [5].
- ✓ The installed capacity in SSA is 44 MW per a million people [5].
- ✓ The wide range of electricity generating sources in SSA include [2]; Renewable energies contribute (hydropower-22%, solar-1% and others, such as biomass, geothermal and wind -3%); Fossil fuel (natural gas-15%, diesel/heavy fuel-23%, and coal-35%) and Nuclear energy contributes 1%.

Power infrastructural development in emerging economies attracts international investments, supports and aids because of the dominant role access to electricity plays in the socioeconomic development of a country or region. Sadly, these interventions and supports are yet to give the expected results in some regions especially in the Southern India and SSA. Several research, review and opinion articles have been published on this and how energy can be provided to meet the demands [6-13]. These papers are often similar and at times with different approach for different countries and regions. Hence, this study will examine power access, to identify issues bordering on power access, the deployment of fossil fuel in SSA and their health consequences. The economic significance of the exploitation of small hydropower (SHP) in SSA and the various ways of developing SHP systems to change the narrative of power inadequacy will be presented.

2. Methodology

The present power issues in SSA in terms of accessibility, causes and consequences of inadequate access to energy will be examined. The study will take a look at the various sources of energy in the region, drawbacks of fossil fuels and the expected attributes of modern energy systems. Further, considerations will be given to the role of SHP in meeting greater power accessibility in the region and the attributes of modern energy systems that will promote the reduction of GHG emissions. The study will rely on centred on quantitative information and data taken from text books, government documents, published research articles, verified websites, news media, thesis, local and international organisations' reports and outlooks on power accessibility in SSA. The international organisations include International Renewable Energy Agency (IRENA), United Nations (UN), World Bank, REN21, International Energy Agency (IEA), and World Energy Council (WEC). The systematic steps and the layout of this study are shown in Fig 2.

Figure 2: The layout of this study

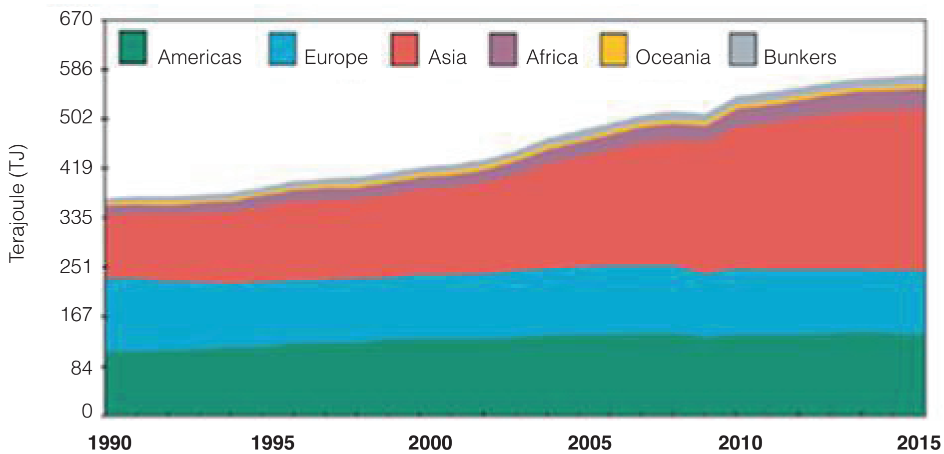

Figure 3: World TPES (TJ) from 1990 to 2016 by geographical region [16]

3. Electricity production, access, and consumption in SSA

3.1. Electricity access

The type of energy resource available for electricity generation in a region determines the source of power supply for the region to access. This section (subsections 3.1 to 3.3) takes a look at the share of SSA in the world's total primary energy supply (TPES), fossil fuel deployment and greenhouse gases emissions and electricity access

The International Renewable Energy Agency (IRENA) reported in 2012 that the average rate of electrification in SSA is about 35%. It added that the situation is worse in the rural areas which were below 20%. Further, over 50% of the population in 41 countries in the region had no access to electricity [14]. The region's share of the world totals primary energy supply (TPES) is very small, as shown in Fig 3. Although one billion sub-Saharan Africans are expected to have access to electricity in 2040, about 530 million people will lack access, especially in the remote areas [15].

3.2. Fossil fuel and biomass

Developing Asia and SSA dominate the over 2.8 billion people, which is about 38% of the global population, that lack access to clean cooking energy. Over 90% of the households in about 25 countries in SSA rely on waste, wood, and charcoal for cooking. The share of the population that primarily rely on different cooking fuels by region are shown in Fig 4.

3.3. Greenhouse Gases (GHG) emissions

The traditional practice of cooking with biomass coupled with the use of fossil fuel gave rise to drudgery, fires, burns, GHG emissions, poisoning, economic prosperity impediment, and respiratory diseases leading to premature death in the region. Population without access to electricity and clean energy for cooking across the SSA, are shown in Fig 5 (a) and 5 (b), respectively [2].

The Framework Convention on Climate Change (UNFCCC) of the United Nations has recognised the challenge of Greenhouse Gases (GHG). The goal of the Convention is to stabilise GHG concentrations to a level that would prevent hazardous anthropogenic meddling with the climatic condition of the atmosphere [17]. The world's CO_2 emissions from fuel combustion -1971 to 2016 and world's CO_2 emissions from fuel combustion - 1971 to 2016 by region measured in Metric tons of CO_2 equivalent ($MtCO_2$) are shown in Fig 6.

The use of energy was reported to be the highest source of GHG due to CO_2 emissions, a by-product of fossil fuel combustion. Coal accounts for 29% of the

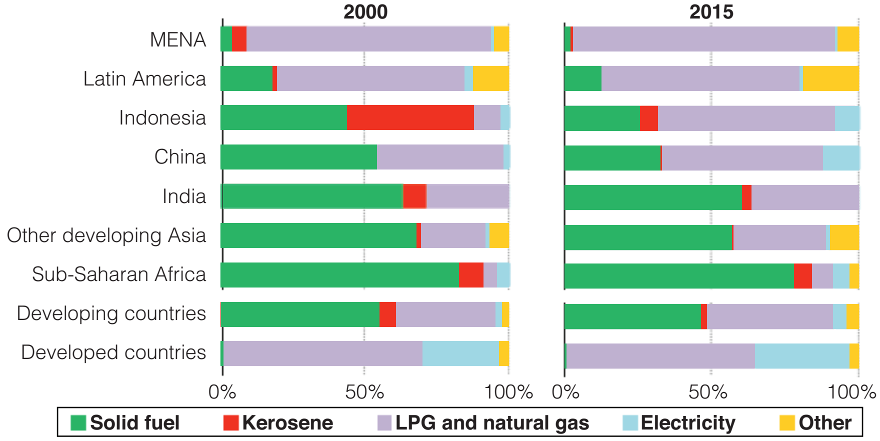

Figure 4: Share of population with that primarily rely on various cooking fuels by region [2]

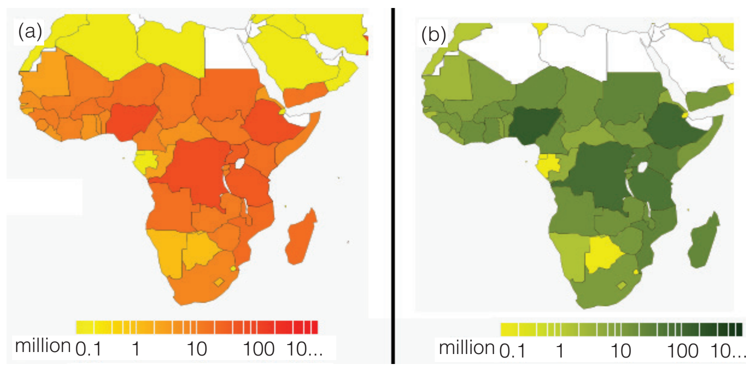

Figure 5 [2]: (a) Population without access to electricity; (b) clean energy for cooking across

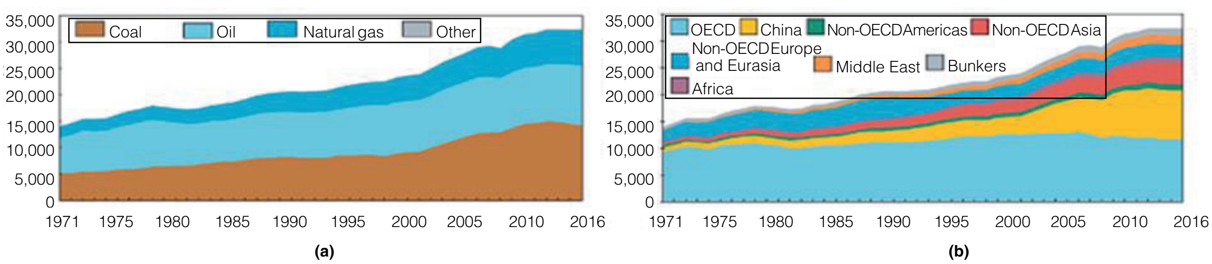

Figure 6 [18]: World CO_2 emissions from fuel combustion -1971 to 2016; (b) World CO_2 emissions from fuel combustion - 1971 to 2016 by region

global TPES but represents 44% of the world CO_2 emissions while carbon-neutral fuels represent 18% of TPES [19] (Fig 7 (a)). Greenhouse gas emissions in 2012 decreased in North America (-3.7 %), Annex II Europe (-0.5 %) and Annex I EIT (-0.8 %), but increased in China (3.1%), Africa (5.6%), Asia excluding China (4.9%) and the Middle East (4.5%) as represented by Fig 7 (b).

Amongst Africa's major forms of fuel for power generation, coal emits the highest GHG while hydro produces an insignificant amount, as represented in Fig 8 (a). In 2015, electricity and heat generation emitted about two-thirds of global CO_2 emissions which is about 42%, while transport accounts for 23% as illustrated in Fig 8 (b). Although the use of renewable energy has gained ground in SSA, the region still

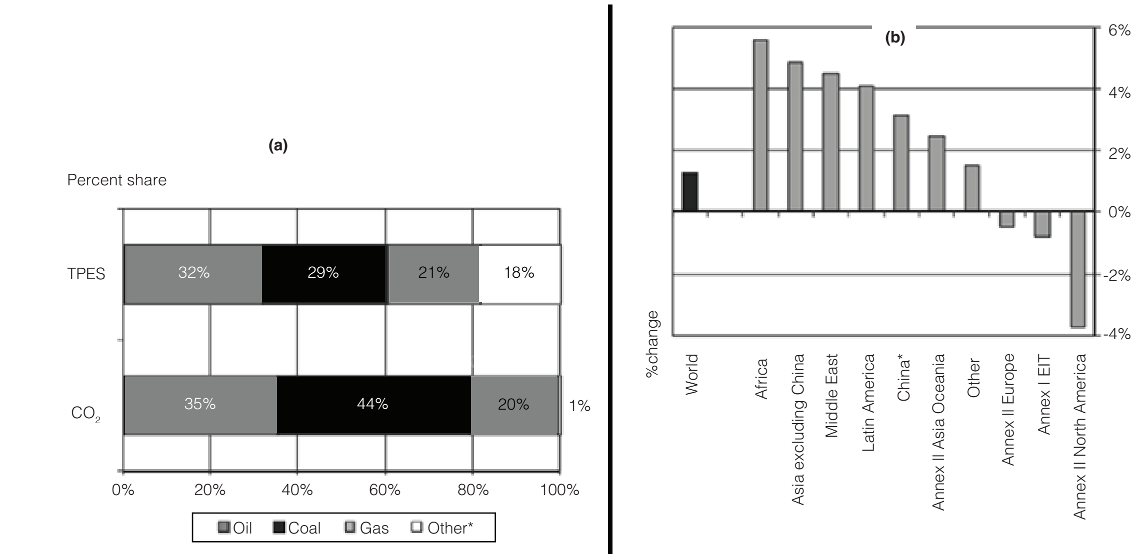

Figure 7: (a) Global primary energy supply and CO_2 emissions; Change in CO_2 emissions by region (2011-2012) [17]

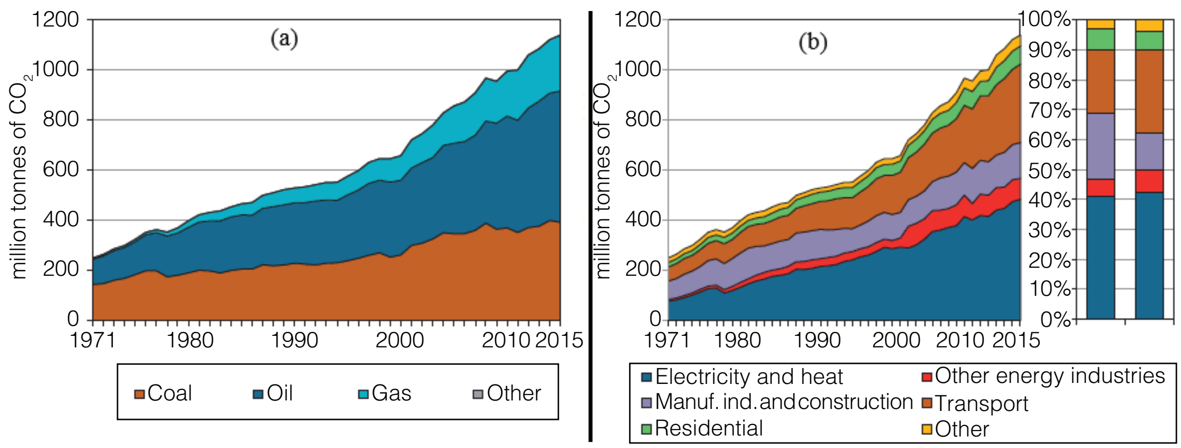

Figure 8: (a) CO_2 emissions by fuel: (b) CO_2 emissions by sector [18]

substantially relies on fossil fuel for electricity and heat generation

Global total primary energy supply (TPES) demand, which depends mainly on fossil fuels, doubled from 1971 to 2012, as depicted in Fig 9 [20]. According to IEA, a further increase is expected in the use of fossil fuel through to 2030 in the new policies scenario [2], as shown in Fig 9 (b) and this will result to CO_2 emissions increase.

4. Inadequate power supply impacts on the economy: high cost of running a business in SSA

The economy of SSA is starving of energy due to gross inadequate access to electricity resulting from insufficient power generation, transmission and distribution infrastructure [21]. Industries and others electricity users in the region that are connected to the power grid experience an average of 56 days of power outage annually and this represents 15% darkness yearly [22]. Consequently, firms lose 6% of sales revenues in the informal sector. The losses can be as high as 20% where back-up generation is inadequate [23]. Hence, the region is in desperate need of power for socioeconomic growth [22, 23]. Due to the inadequate installed capacity, there is low energy consumption [24] and access, as a result, the commercial sector is compelled to deploy expensive generators. These generators serve as backup power suppliers and in some cases the only sources of electricity.

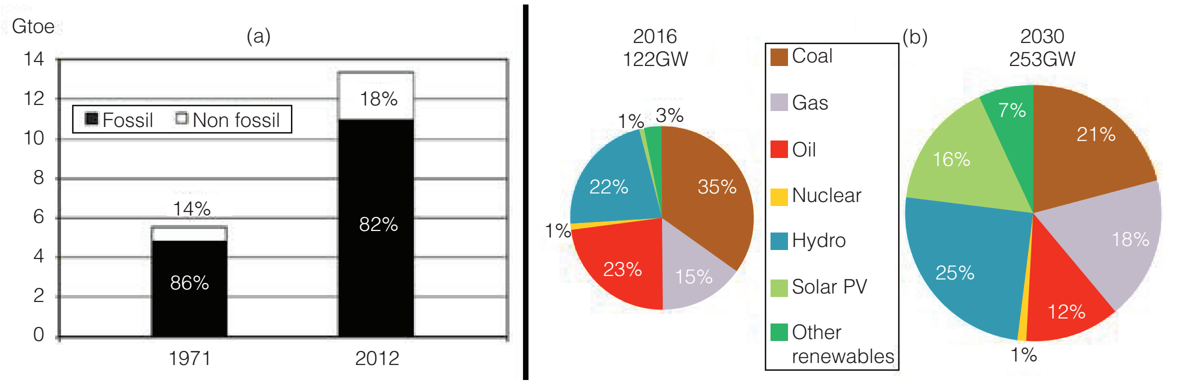

Figure 9: (a) World TPES [17]; (b) installed power generation capacity in SSA by fuel in the New Policiea s Scenario [2]

Nigeria has the largest number of diesel and petrol power generating sets market in Africa with a promising growth of 8.7% [25]. The Power generators importation, mainly from China, Germany and the United Kingdom to Nigeria is expected to grow from $450 million in 2011 to about $950.7 million by 2020 [26]. Although these generators are reliable, they run on fossil fuels (diesel and petrol) and this comes with consequences. These include air pollution and the high cost of doing business as the use of diesel or petrol generator costs about three times more than grid based supply. Annually, over $22 billion ($149 million for diesel, and $703 million for petrol) is spent on fuel for dedicated electric generators in Nigeria and this was described as the highest in the world [2, 27]. The average grid power tariff in SSA is US$0.13 per kWh as against the range of US$0.04 to US$0.08 per kWh grid power tariffs in most parts of the developing world [23, 28]. The estimated cost of power generated by diesel generating set is US$0.25/kWh [29]. The deployment of a generator for manufacturing impacts hugely on the production costs and air pollution, making businesses that operate in SSA with much higher running costs than their equals elsewhere. This holds for businesses across all sectors, such as telecommunication, manufacturing, bank, agricultural and business services. There is a direct correlation between the use of generators and emissions gases because the generators burn fossil fuel, either diesel or petrol, and emit a lot of GHG and pollutants to the atmosphere.

5. Salient causes of inadequate electricity access

According to the World Bank, the power systems infrastructure in the region cannot adequately generate sufficient electricity to meet the demand, as required by the growing population and urbanisation and for economic growth. The region's total installed capacity without South Africa (SA) is about 80 GW and this is equivalent to that of the Republic of Korea and one tenth of Latin America. South Africa generates around 40 GW while Nigeria which is over three times SA's population, generates only 7% of SA generation capacity. The factors responsible for power supply inadequacy in SSA are numerous and there are peculiarities and differences in these factors amongst the countries of SSA. These limitations are found in the main sections of a power supply system – generation, transmission and distribution. Across the region, facilities in these sections are experiencing insufficient funding, poor maintenance and management and over dependence on foreign power supply technologies and assistance, these have been identified by studies [30–33]. Other common factors are under developed manufacturing infrastructure, the exorbitant cost of power projects and under developed human capacity in the power sector[34]. This section, therefore, identifies and discusses the key factors that are responsible for SSA power access inadequacy in subsection 5.1 to 5.3.

5.1. Power supply facility

The chronic electricity shortages coupled with insufficient transmission and distribution networks are fundamentally the causes of inadequate electricity access and consumption in most countries in SSA. Many countries in SSA do not generate enough electricity to distribute to the populace and the little generated does not wholly get to the users. A large amount of power is lost along the transmission lines due to sub-standard, and maintenance of power transmission and distribution facilities issues. Across the entire region, step down and the step up transformers are

Figure 10: Half-hazard distribution line

often undersized, under service, sub-standard and overload. The power distribution cables or wires also experience the same technical issues and in many cases are in terrible forms, as shown in Fig 10. However, the situation is different in SA, as everything regarding power distribution cables in most cities seems to be right. This is one of the reasons that make SA accounts for 50% of the total power generated in the region.

5.2. Providing power sector investment funds

The power sector in SSA is receiving attention from both national and international players resulting in huge investments. Many power projects have been executed and several others are still on going and Table 1 presents significant power installations in 2013.

The estimated annual investment required to adequately boost power access is $40.8 billion, which is equivalent to 6.35% of Africa's GDP [5]. Government alone cannot bridge this large financial gap. Hence, the government-private partnership is needed to provide a substantial proportion of the fund needed under a long-term power purchase agreements (PPAs). If the investments in power generation, transmission, and distribution components are not stepped up, over 670 million people will lack access to electricity in sub-Saharan Africa by 2030.

5.3. Ineffective reforms

Since 2006, power sector reforms have been enacted in over 80% of SSA countries, this includes about 75% and 66% countries having their power sector privatised and corporatized state-owned utilities, respectively [33]. The utility performance continues to be dwindling despite the reform measures.

Table 1: Power generation installed capacity and gross domestic product (GDP), 2013 [5]

Country	Capacity (MW)	GDP (purchasing power parity, PPP), 2013
Nigeria	7,044	972.65
Sudan	3,038	153.09
Ghana	2,812	103.65
Congo, Dem. Rep.	2,444	50.47
Mozambique	2,382	28.40
Ethiopia	2,094	129.86
Zambia	1,985	57.07
Zimbabwe	1,970	25.92
Kenya	1,766	124.02
Tanzania	1,659	117.66
Côte d'Ivoire	1,521	65.55
Angola	1,509	166.11
Cameroon	1,238	69.98

6. Delivery of modern energy systems to SSA

The challenges that trail SSA meeting its power demand are complicated by the current global position on fossil fuel and the negative environmental impacts resulting from the use of large hydropower (LHP) systems. There is a global outcry for affordable, secure, available, and environmentally sustainable energy systems [35–38]. The United Nations have thrown its weight behind this by making energy for all by 2030 as one of the Sustainable Development Goals (SDGs). The World Energy Council (WEC) in its perspective, opines that modern energy supply should be governed by three pillars, called energy trilemma – energy security, energy equity, and environmental sustainability [39]. This is happening at the time that the region has the highest population that lack access to electricity and the highest poverty. It will be beneficial now and in the future and avoid waste of resources for SSA to concentrate more on the development of energy infrastructure that will promote energy sustainability:

i. GHG emissions reduction – supplying clean, reliable, and renewable energy with low or no GHG emissions.
ii. Deployment of low-cost and high power generation efficiency schemes
iii. Energy security - increasing access to clean, affordable and adequate energy in rural and urban cities of SSA.

6.1. Emerging power supply schemes

The electricity access challenge affects the rural dwellers most, as about 80% of the population in the rural areas have access to electricity. To overcome this scourge, things have been done differently from the grid connection. Electricity access in the region will be improved in remote and rural communities by the decentralised technologies, such as off-grid and mini-grid systems. These are emerging power schemes that have dominated the discussions, research, development and the deployment of renewable energy to urban, remotes and rural areas in recent time [40–51]. The decentralised electrification technologies exploit available RE resources in a given place to provide clean, adequate, affordable and reliable power supply. The main RE resources for electricity generation in SSA are hydropower, wind, solar, geothermal, wave and biomass. This study will only consider the significance of small hydropower system in improving electricity access and the wellbeing of the people in SSA. This power scheme has been tested and trusted in many countries and several studies have described SHP is a reliable electrification for rural areas in SSA [7, 11, 46, 52–57].

7. Developing Small hydropower in SSA

More development of SHP resources required in SSA to bridge power access inadequacy and to promote greater use of clean energy. Hence, this section discusses in subsection 7.1 to 7.3 – the SHP potential in SSA; a summary of systematic steps of SHP development; and the key limiting factors of SHP development in the region.

7.1. Small hydropower potentials in SSA

Small hydropower refers to the generation of electrical power from a water source on a small scale, usually with a capacity of not more than 10 MW. However, there is still no internationally agreed upon definition of small hydropower as capacity classification varies from country to country, as shown in Table 2 [58, 59]. For rural and electrification of remote areas in developing countries, SHP or micro–hydropower has been described as the most effective energy scheme [60]. A schematic of a hydropower plant is shown in Fig 11. The technology is environmentally benign, extremely robust and long lasting – lasting for 50 years or more with little maintenance [61]. Other striking benefits include [62, 63]: minimal vandalisation of power facility; reduction in transmission losses; reduction in network problems (especially during raining season); reduction in illegal electricity connections to the national grid; the resource is in abundance and largely untapped; it emits low GHG (CO_2) and is regarded as a clean renewable energy source; it can create jobs; and it encourages energy diversification of systems thereby enhancing energy supply reliability in the region, etc. The global quest for cleaner energy to replace or minimise the use of fossil fuels which are the bulk of electricity generation in SSA favours the use of SHP. This will consequently reduce GHG emissions [64]. Aggressive use of renewable energy in SSA will reduce CO_2 emissions by 27% in the region [1].

Hydropower is a part of the solutions required to overcome electricity inadequacies in both urban and rural areas. The use of hydroelectric lessens the global dependence on fossil fuels, promotes variable renewables via hybrid renewable energy system (HRES) and storage. Apart from power generation, hydropower provides several socioeconomic benefits that limit poverty and manage water effectively. The search for the best ways of supplying power to remote and rural areas and alternatives

Table 2: Various size classifications of SHP [59, 65]

Country	Micro (kW)	Mini (kW)	Small (kW)
United States	< 100	100-1000	1–30
China	–	< 500	0.5–25
USSR	< 100	–	0.1–30
France	5-500	–	–
India	< 100	101–1000	1–15
Brazil	< 100	100–1000	1–30
Norway	< 100	100–1000	1–10
Nepal	< 100	100–1000	1–10
Various	< 100	< 1000	< 10

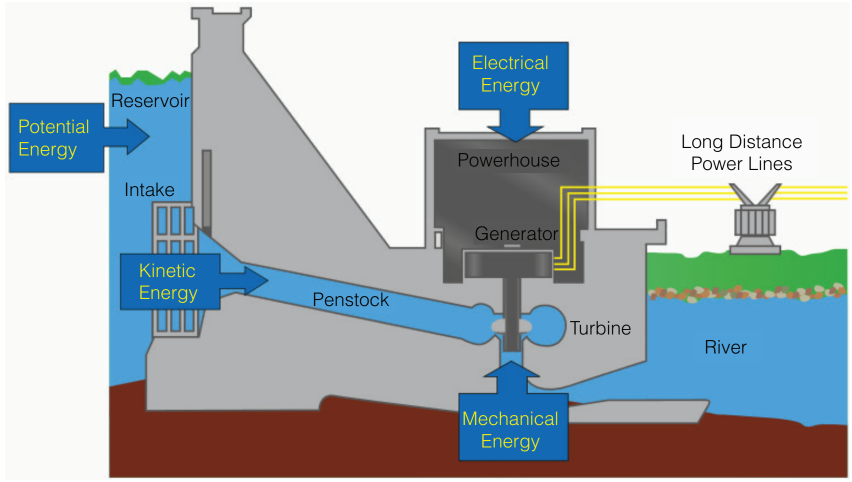

Figure 11: A schematic of a hydropower plant [67]

to fossil fuel in SSA is receiving tremendous attention. This has led to several power schemes utilising REs, such as solar, geothermal, wind and SHP. However, hydropower has been identified as a RE potential, second to solar in terms of abundance and distribution, capable of adding substantially to power access in the region. The World Bank has stated that only 8 percent of the hydropower potential in SSA has been developed [66].

The SHP scheme has been described as an efficient power supply system for rural area and stand–alone electrification. It is a RE generation system that produces electricity at low cost, between 0.02/kWh and 0.05/kWh USD [68, 69]. A geospatial assessment study [70] of small–scale hydropower potential defines mini and SHP as 0.1–1 MW and 1– 10 MW respectively. Fig 12 shows the potentials of mini and SHP in selected locations in 44 SSA countries. The study observed that:

i. About 10,216 mini hydropower potential sites were identified in SSA with an estimated generation capacity of 3,421 MW. Also, these mini potential sites are concentrated in central Africa countries with Congo DR and Angola having the highest exploitable potential of about 975 MW.
ii. There are around 5383 SHP identified sites across SSA, with the highest concentration in South and Central Africa. The estimated power capacity that can be generated by sites is 21,800 MW. About 33% of these sites are in DR Congo, South Africa, and Sudan. The estimated power pools of the sub regions in SSA is shown in Fig 13.

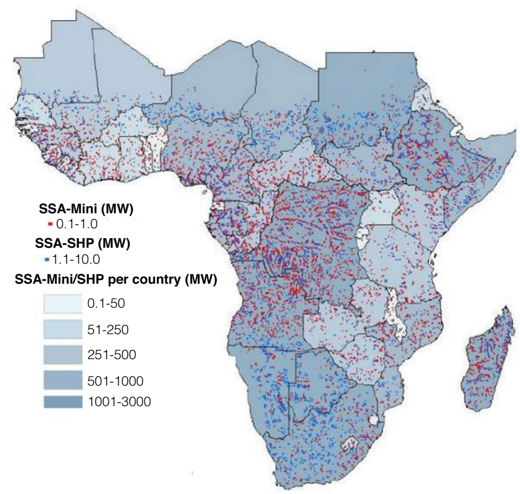

Figure 12: Mini and SHP potential in the selected points in SSA 44 Sub-Saharan countries [70]

7.2. Developing SHP site

The development of SHP system can be divided into site assessment, civil works activities and electromechanical section development. The site assessment involves the hydrological, geological, and topographical study of the natural resource, such as river. In the site assessment and evaluation, data collection is the first stage of the sequence of activities that SHP development requires. This stage can be divided into four phases: planning, project approval, construction and exploitation. The assessment establishes the economic viability of the site. Designing of the civil work components based on the site

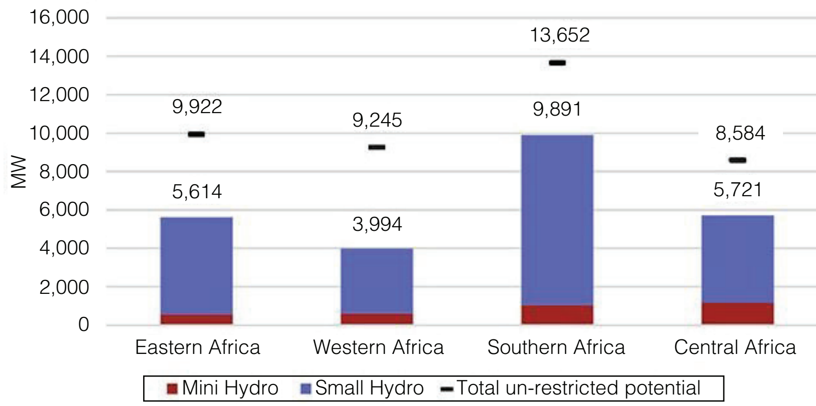

Figure 13: Small hydropower potential per African power pool [70]

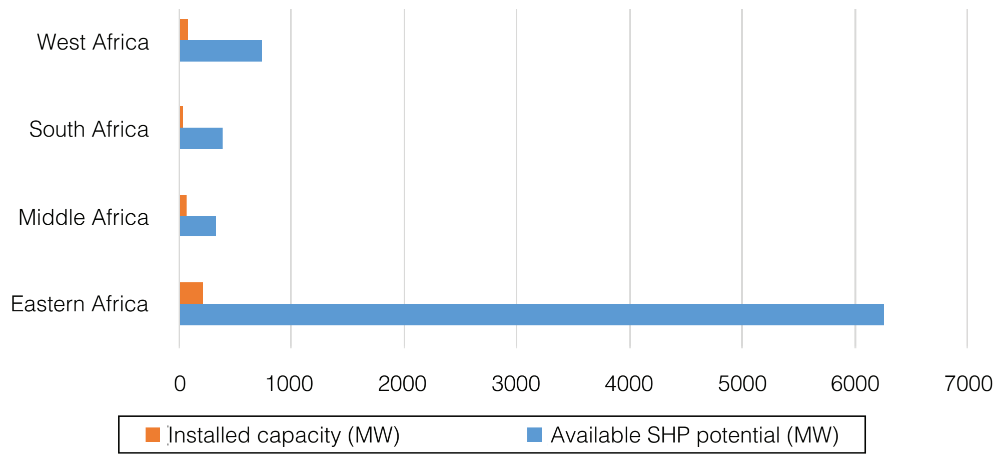

Figure 14: The distribution of SHP potential by regions of SSA [72]

evaluation results is followed. The selection and sizing of the hydro turbine and the generator or alternator are carried out based on the capacity of the water body obtained via the hydrological study.

7.3. Inadequate deployment and Challenges of SHP in SSA

The deployment of SHP scheme in rural areas, and standalone electrification will provide improved access to clean and affordable electricity, and diversification of energy in SSA. It meets the modern attributes of power source to replace or reduce the use of fossil fuel, which is the main source of electricity generation in the region [71]. Significant deployment of hydropower will reduce CO_2 emission by about 27% in the region[1]. Despite these known merits coupled with the energy poverty of SSA, the huge SHP resource in the region is insufficiently tapped, as seen in Fig 14 [72].

The deployment and development of SHP in SSA are limited by lack of technology capacity; insufficient fund; ineffective framework and regional trade agreements; inappropriate power generation and distribution policies; unreliable hydrological data of potential sites; insufficient domestic product manufacturing participation and competitiveness; inadequate and unorganised SHP research and development (R&D); and lack of regional political will. However, these limitations are sometimes different from one country to another [73]. Table 3 presents SHP development barriers peculiar to the difference regions in SSA [31, 34, 74].

Table 3: Region–based SHP development barriers in SSA [30, 74]

Regions of Africa	SHP Barriers in SSA
Eastern	Lack of hydrological and up to date data Insufficient awareness of SHP Lack of road infrastructure to access sites in the in remote areas Lack of public–private partnership with both domestic and foreign investors Inadequate human capacity Power distribution cost
Middle North	Lack of a clear cut renewable energy policy Lack of motivation and suitable SHP site Lack of SHP merits awareness by the public Lack of support policies and technical capacity
South	Lack of SHP components and system, insufficient human capacity on SHP Unfavourable climatic condition
West	Lack of reliable and up to date hydrological data Inadequate SHP project financing and no incentive to attract domestic and foreign SHP investors Various degrees of insufficient technical expertise for equipment design, manufacturing, civil construction, operation and maintenance Effect of climate change on water bodies like a river
Other common barriers	The long distance between potential sites and consumption points Low electricity demands due to low population density The long distance between consumers (scattered settlement) Low utilisation factor Prohibitive high capital costs

8. Steps to improve the development of SHP

The section takes a look at ways of enhancing the development of SHP systems in SSA and these are briefly discussed in subsections 8.1 and 8.2.

8.1. Benefits of domestic manufacturing of hydro turbines

Operation and maintenance (O&M) costs of hydropower projects have increased by 40% since 2007 at inflation of 16% over the same time period. The cost rise is more challenging for the small plants' O&M as more fund ($ per kWh) is required compared to larger counterparts [75]. There are several factors that account for the cost of SHP, which include electric market structure and source of equipment, the capacity of the project, availability of SHP technical personnel, the complexity of the site's topography, etc. Fig 16 shows that the cost of SHP electro-mechanical equipment is relative in countries in SSA. The cost of the SHP project is lowest in China and this is one of the reasons that makes the rate of SHP development in China very high.

The building of domestic capacity for hydro turbine manufacturing in the region will substantially reduce the cost of SHP projects, O&M and reduce downtime. The technical skills and manufacturing sector needed to develop SHP in the region are lacking and this creates challenges for domestic SHP components and system manufacturing. The building of SHP technical personnel and maximising of manufacturing capacities will systematically ameliorate and eliminate some of the identified issues, such as high cost of SHP project, and O&M [30]. China is making tremendous progress in SHP because they do not outsource; both the human expertise and the manufacturing facilities are abundantly available in the country

8.2. Other Steps to improve the development of SHP

It requires a multifaceted approach to overcome the present power challenges and to meet the future energy need of the region. The measures to address them must

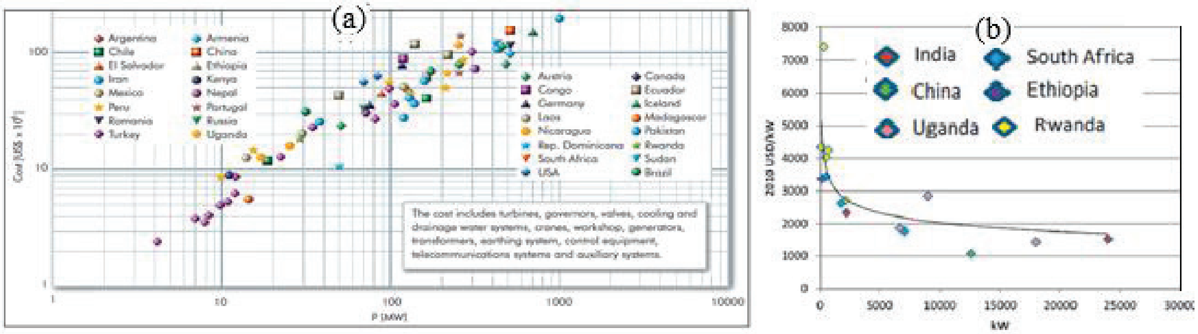

Figure 16: (a) Costs of hydro electro-mechanical equipment by country [76]: (b) small hydropower installed capital costs by capacity in developing countries [67]

be implemented simultaneously. China's SHP success model can be adopted by SSA to develop the huge SHP potential available in the region. This will require massive capacity building to improve the current SHP skill deficit and the development of manufacturing infrastructure to support domestic manufacturing of SHP components and systems. Other steps necessary to expedite the development of SHP include capacity building via reversed engineering and technology adaptive programmes; the use of locally sourced materials for turbine and other components fabrication [77, 78]; execution of SHP project through government-private partnership scheme; establishment of a regional joint programme to promote the development and the deployment of SHP; updated information on the potential sites should be provided; enactment of policy that compels existing power firm to provide fund for SHP R&D; and formulation of policy framework that limits the bureaucratic process in the development of SHP.

Domestic participation in the design and manufacturing of SHP devices and systems in SSA will promote access to clean, and affordable electricity required to stimulate the region's economy. The power supply in the region will always be threatened by: overdependence on foreign technology which comes with consequences of the high cost of power project execution, inadequate skilled personnel for installation, operation, maintenance and repair challenges. Domestic manufacturing of hydro turbine can be achieved through the regional joint SHP technology capacity building in the following areas: foundry technology; mechatronics; fluid mechanics; manufacturing processes; and material development engineering.

9. Conclusions

The sluggishness of SSA's economy is credited to the inadequate and epileptic power supply that is ravaging the region. Frankly, this is heart breaking considering the resources and efforts that have been put to change the situation. The electricity access rates of some countries in the region are about 20% and two-third of the population lack access to modern energy services. Industries and others electricity users in the region that are connected to the power grid experience an average of 56 days of power outage annually and this represents 15% darkness yearly. According to the World Bank, the power systems infrastructure in the region cannot adequately generate sufficient electricity to meet the demand, as required by the growing population and urbanisation and for economic growth. The chronic electricity shortages coupled with insufficient transmission and distribution networks are fundamentally the causes of inadequate electricity access and consumption in most countries in SSA. The challenges that trail SSA meeting its power demand are complicated by the current global position on fossil fuel and the negative environmental impacts resulting from the use of large hydropower (LHP) systems. There is a global outcry for affordable, secure, available, and environmentally sustainable energy systems. Globally, SHP has been identified as environmentally friendly, cost effective and simple renewable power scheme suitable for standalone and rural electrification. Domestic development of SHP parts and systems will lower SHP project cost and improve access to power in the region. This will require massive human capacity building and the use of locally soured materials and production facilities.

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References

[1] A. Castellano, A. Kendall, M. Nikomarov, and T. Swemmer, "Brighter Africa: The Growth Potential of the Sub-Saharan Electricity Sector," McKinsey & Company2015. Available: https://www.mckinsey.com/~/media/McKinsey/dotcom/client_service/EPNG/PDFs/Brighter_Africa-The_growth_potential_of_the_sub-Saharan_electricity_sector.ashx

[2] IEA, "Energy Access Outlook: From Poverty to Prosperity," Paris, France2017. Available: http://www.iea.org/publications/freepublications/publication/WEO2017SpecialReport_EnergyAccessOutlook.pdf

[3] J. Morrissey, *The Energy Challenge in Sub-Saharan Africa: A guide for Advocates and Policy Makers. Part 2 - Addressing Energy Poverty" Oxfam Series*. USA: Oxfam Research Backgrounder, 2017.

[4] M. S. Thopil, R. C. Bansal, L. Zhang, and G. Sharma, "A Review of Grid Connected Distributed Generation Using Renewable Energy Sources in South Africa," *Energy Strategy Reviews,* vol. 21, pp. 88–97, 2018/08/01/ 2018.DOI: https://doi.org/10.1016/j.esr.2018.05.001.

[5] A. Eberhard, K. Gratwick, E. Morella, and P. Antmann, *Independent Power Projects in Sub-Saharan Africa: Lessons from Five Key Countries.* Washington, DC International Bank for Reconstruction and Development / The World Bank, 2016.

[6] M. Aklin, S. P. Harish, and J. Urpelainen, "A global analysis of progress in household electrification," *Energy Policy,* vol. 122, pp. 421–428, 2018/11/01/ 2018.DOI: https://doi.org/10.1016/j.enpol.2018.07.018.

[7] T. Harlan, "Rural Utility to Low-Carbon Industry: Small Hydropower and the Industrialization of Renewable Energy in China," *Geoforum,* vol. 95, pp. 59-69, 2018/10/01/ 2018.DOI: https://doi.org/10.1016/j.geoforum.2018.06.025.

[8] E. Hartvigsson, M. Stadler, and G. Cardoso, "Rural electrification and capacity expansion with an integrated modeling approach," *Renewable Energy,* vol. 115, pp. 509-520, 2018/01/01/ 2018.DOI: https://doi.org/10.1016/j.renene.2017.08.049.

[9] M. Hossain, A. S. N. Huda, S. Mekhilef, M. Seyedmahmoudian, B. Horan, A. Stojcevski, *et al.,* "A state-of-the–art review of hydropower in Malaysia as renewable energy: Current status and future prospects," *Energy Strategy Reviews,* vol. 22, pp. 426–437, 2018/11/01/ 2018.DOI: https://doi.org/10.1016/j.esr.2018.11.001.

[10] S. Ma and J. Urpelainen, "Distributed power generation in national rural electrification plans: An international and comparative evaluation," *Energy Research & Social Science,* vol. 44, pp. 1–5, 2018/10/01/ 2018.DOI: https://doi.org/10.1016/j.erss.2018.04.002.

[11] M. Pang, L. Zhang, A. S. Bahaj, K. Xu, Y. Hao, and C. Wang, "Small Hydropower Development in Tibet: Insight from a Survey in Nagqu Prefecture," *Renewable and Sustainable Energy Reviews,* vol. 81, pp. 3032–3040, 2018/01/01/ 2018. DOI: https://doi.org/10.1016/j.rser.2017.06.115.

[12] T. Ptak, "Towards an ethnography of small hydropower in China: Rural electrification, socioeconomic development and furtive hydroscapes," *Energy Research & Social Science,* vol. 48, pp. 116–130, 2019/02/01/ 2019.DOI: https://doi.org/10.1016/j.erss.2018.09.010.

[13] L. De Santoli, S. Berghi, and D. Bruschi, "A Schematic Framework to Assess Mini Hydro Potentials in the Italian Regional Energy and Environmental Plans," *Energy Procedia,* vol. 82, pp. 615–622, 2015/12/01/ 2015.DOI: https://doi.org/10.1016/j.egypro.2015.12.009.

[14] IRENA. (2012, 19/03/2015). *Prospects for the African Power Sector: Scenarios and Strategies for Africa Project.* Available: https://www.irena.org/DocumentDownloads/Publications/Prospects_for_the_African_PowerSector.pdf

[15] IEA, "A Focus on Energy Prospects in Sub–Saharan Africa," *World Energy Outlook Special Report, International Energy Agency (IEA), France,* 2015.

[16] IEA, "Key World Energy Statistics," The International Energy Agency (IEA), Paris, France2018. Available: https://webstore.iea.org/download/direct/2291?fileName=Key_World_2018.pdf

[17] IEA, "CO_2 Emissions From Fuel Combustion Statistics Highlights," *IEA Statistics, 2014 Edition, International Energy Agency,* 2014.

[18] IEA, "CO_2 Emissions From Fuel Combustion Highlights ", International Energy Agency (IEA),Paris, France2017. Available: https://www.iea.org/publications/freepublications/publication/CO2EmissionsfromFuelCombustionHighlights2017.pdf

[19] M. Nachmany, S. Fankhauser, M. Townshend, T. Collins, T. Landesman, A. Matthews, *et al.,* "The Globe Climate Legislation Study: A Review of Climate Change Legislation in 66 Countries," *Globe International and the Grantham Research Institute, London School of Economics, London,* 2014.

[20] IPCC, "Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (1996 IPCC Guidelines)," *IPCC, Bracknell, UK,* 2007.

[21] A. S. Momodu, "Energy Use: Electricity System in West Africa and Climate Change Impact," *International Journal of Sustainable Energy Planning and Management* vol. 14, pp. 21–38, 2018.DOI: https://doi.org/10.5278/ijsepm.2017.14.3
[22] M. W. Nganga. (2016, 19/07/2018). *Understanding Africa's Energy Needs. World Economic Forum* Available: https://www.weforum.org/agenda/2016/11/understanding-africas-energy-needs/
[23] WorldBank. (2015). *Fact Sheet: The World Bank and Energy in Africa* Available: http://go.worldbank.org/8VI6E7MRU0
[24] M. Brito and T. Sousa, "Development of a “Current Energy Mix Scenario” and a “Electricity as Main Energy Source Scenario” for Electricity Demand Up to 2100," *International Journal of Sustainable Energy Planning and Management* vol. 02 pp. 63–80, 2014 DOI: https://doi.org/10.5278/ijsepm.2014.2.6
[25] I. A. Yusuf. (2014, 16/10/2017). *Nigeria: Overrun by Electric Power Generators.* Available: http://thenationonlineng.net/nigeria-overrun-by-electric-power-generators/
[26] C. Mgbeokwere (2013). *Generator Sales in Nigeria to Hit N151 bn by 2020* Available: https://www.vanguardngr.com/2013/04/generator-sales-in-nigeria-to-hit-n151bn-by-2020/
[27] GIZ, *The Nigerian Energy Sector: An Overview with a Special Emphasis on Renewable Energy, Energy Efficiency and Rural Electrification,* 2 ed. Abuja, Nigeria Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, 2015.
[28] AfDB. (2013, The High Cost of Electricity Generation in Africa.
[29] DFID. (2010, 06/10/2018). *A Potential Role for AMCs in Promoting Green Mini-Grids in Tanzania.* Available: http://www.vivideconomics.com/wp-content/uploads/2010/03/Tanzania_case_study.pdf
[30] W. S. Ebhota and F. L. Inambao, "Design Basics of a Small Hydro Turbine Plant for Capacity Building in sub-Saharan Africa " *African Journal of Science, Technology, Innovation and Development,* vol. 8, pp. 111–120, 2016.DOI: https://doi.org/10.1080/20421338.2015.1128039.
[31] W. S. Ebhota and F. L. Inambao, "Electricity Insufficiency in Africa: A Product of Inadequate Manufacturing Capacity," *African Journal of Science, Technology, Innovation and Development,* vol. 8, pp. 197–204, 2016.DOI: https://doi.org/10.1080/20421338.2016.1147206.
[32] F. Yang and M. Yang, "Rural electrification in sub-Saharan Africa with innovative energy policy and new financing models," *Mitigation and Adaptation Strategies for Global Change,* vol. 23, pp. 933–952, August 01 2018.DOI: https://link.springer.com/article/10.1007%2Fs11027–017–9766–8.
[33] IMF. (2008, Africa's Power Supply Crisis: Unraveling the Paradoxes. Available: https://www.imf.org/en/News/Articles/2015/09/28/04/53/socar052208c
[34] W. S. Ebhota, A. C. Eloka-Eboka, and F. L. Inambao, "Energy sustainability through domestication of energy technologies in third world countries in Africa," presented at the Industrial and Commercial Use of Energy (ICUE) 2014 International Conference, 2014.DOI: https://ieeexplore.ieee.org/document/6904197.
[35] R. J. Heffron, D. McCauley, and B. K. Sovacool, "Resolving Society's Energy Trilemma through the Energy Justice Metric," *Energy Policy,* vol. 87, pp. 168–176, 2015/12/01/2015.DOI: https://doi.org/10.1016/j.enpol.2015.08.033.
[36] M. Harvey, "The Food-Energy-Climate Change Trilemma: Toward a Socio-Economic Analysis," *Theory, Culture & Society,* vol. 31, pp. 155–182, 2014.DOI: https://doi.org/10.1177/0263276414537317.
[37] D. Gent and J. Tomei, "Electricity in Central America: Paradigms, reforms and the energy trilemma," *Progress in Development Studies,* vol. 17, pp. 116–130, 2017/04/01 2017. DOI: https://doi.org/10.1177/1464993416688826.
[38] W. S. Ebhota and P. Y. Tabakov, "The place of small hydropower electrification scheme in socioeconomic stimulation of Nigeria," *International Journal of Low-Carbon Technologies,* vol. 13, pp. cty038–cty038, 2018.DOI: https://doi.org/10.1093/ijlct/cty038.
[39] WEC and O. Wyman, "World Energy Trilemma Index - 2017: Monitoring the Sustainability of National Energy Systems ", The World Energy Council in partnership with global consultancy Oliver Wyman2017. Available: https://www.worldenergy.org/wp-content/uploads/2017/11/Energy_Trilemma_Index_2017_Full_report_WEB2.pdf
[40] M. C. Argyrou, P. Christodoulides, and S. A. Kalogirou, "Energy Storage for Electricity Generation and Related Processes: Technologies Appraisal and Grid Scale Applications," *Renewable and Sustainable Energy Reviews,* vol. 94, pp. 804–821, 2018/10/01/ 2018.DOI: https://doi.org/10.1016/j.rser.2018.06.044.
[41] B. Bogno, J.-P. Sawicki, P. Petit, M. Aillerie, J.-P. Charles, O. Hamandjoda, *et al.,* "230 VDC Elementary Block in Off-Grid Pv Systems," *Sustainable Energy Technologies and Assessments,* vol. 29, pp. 1–11, 2018/10/01/ 2018.DOI: https://doi.org/10.1016/j.seta.2018.06.013.
[42] F. Chen, J. Dai, N. Hu, and Z. Ye, "Sparse Bayesian Learning for Off-Grid DOA Estimation with Nested Arrays," *Digital Signal Processing,* vol. 82, pp. 187–193, 2018/11/01/ 2018. DOI: https://doi.org/10.1016/j.dsp.2018.08.004.
[43] M. B. Eteiba, S. Barakat, M. M. Samy, and W. I. Wahba, "Optimization of an Off–Grid PV/Biomass Hybrid System with Different Battery Technologies," *Sustainable Cities and*

Society, vol. 40, pp. 713–727, 2018/07/01/ 2018.DOI: https://doi.org/10.1016/j.scs.2018.01.012.

[44] E. Forde, "The Ethics of Energy Provisioning: Living Off–Grid in Rural Wales," *Energy Research & Social Science,* vol. 30, pp. 82–93, 2017/08/01/ 2017.DOI: https://doi.org/10.1016/j.erss.2017.06.018.

[45] J. Gorenstein Dedecca, S. Lumbreras, A. Ramos, R. A. Hakvoort, and P. M. Herder, "Expansion Planning of the North Sea Offshore Grid: Simulation of Integrated Governance Constraints," *Energy Economics,* vol. 72, pp. 376–392, 2018/05/01/ 2018.DOI: https://doi.org/10.1016/j.eneco.2018.04.037.

[46] M. E. Khodayar, "Rural Electrification and Expansion Planning of Off–Grid Microgrids," *The Electricity Journal,* vol. 30, pp. 68–74, 2017/05/01/ 2017.DOI: https://doi.org/10.1016/j.tej.2017.04.004.

[47] S. Kosai and E. Yamasue, "Cost-Security Analysis Dedicated for the Off-Grid Electricity System," Renewable Energy, vol. 115, pp. 871–879, 2018/01/01/ 2018.DOI: https://doi.org/10.1016/j.renene.2017.09.024.

[48] D. N. Luta and A. K. Raji, "Decision-Making Between a Grid Extension and a Rural Renewable Off-Grid System with Hydrogen Generation," *International Journal of Hydrogen Energy,* vol. 43, pp. 9535–9548, 2018/05/17/ 2018.DOI: https://doi.org/10.1016/j.ijhydene.2018.04.032.

[49] M. F. Müller, S. E. Thompson, and A. J. Gadgil, "Estimating the Price (in)Elasticity Of Off-Grid Electricity Demand," *Development Engineering,* vol. 3, pp. 12–22, 2018/01/01/ 2018.DOI: https://doi.org/10.1016/j.deveng.2017.12.001.

[50] B. Sergi, M. Babcock, N. J. Williams, J. Thornburg, A. Loew, and R. E. Ciez, "Institutional Influence on Power Sector Investments: A Case Study of on- and Off-Grid Energy in Kenya and Tanzania," *Energy Research & Social Science,* vol. 41, pp. 59–70, 2018/07/01/ 2018.DOI: https://doi.org/10.1016/j.erss.2018.04.011.

[51] S. Twaha and M. A. M. Ramli, "A Review of Optimization Approaches for Hybrid Distributed Energy Generation Systems: Off-Grid and Grid-Connected Systems," *Sustainable Cities and Society,* vol. 41, pp. 320–331, 2018/08/01/ 2018.DOI: https://doi.org/10.1016/j.scs.2018.05.027.

[52] J. Arias-Gaviria, B. van der Zwaan, T. Kober, and S. Arango-Aramburo, "The prospects for Small Hydropower in Colombia," Renewable Energy, vol. 107, pp. 204–214, 2017/07/01/ 2017.DOI: https://doi.org/10.1016/j.renene.2017.01.054.

[53] P. Breeze, "Chapter 6 - Small Hydropower," in *Hydropower,* P. Breeze, Ed., ed: Academic Press, 2018, pp. 53–62.

[54] P. Breeze, "Chapter 5 – Hydropower Generators," in *Hydropower,* P. Breeze, Ed., ed: Academic Press, 2018, pp. 47–52.

[55] C. Ioannidou and J. R. O'Hanley, "Eco-Friendly Location of Small Hydropower," *European Journal of Operational Research,* vol. 264, pp. 907–918, 2018/02/01/ 2018.DOI: https://doi.org/10.1016/j.ejor.2016.06.067.

[56] Y. Kong, J. Wang, Z. Kong, F. Song, Z. Liu, and C. Wei, "Small Hydropower in China: The Survey and Sustainable Future," *Renewable and Sustainable Energy Reviews,* vol. 48, pp. 425–433, 2015/08/01/ 2015.DOI: https://doi.org/10.1016/j.rser.2015.04.036.

[57] X.-z. Li, Z.-j. Chen, X.-c. Fan, and Z.-j. Cheng, "Hydropower Development Situation and Prospects in China," *Renewable and Sustainable Energy Reviews,* vol. 82, pp. 232–239, 2018/02/01/ 2018.DOI: https://doi.org/10.1016/j.rser.2017.08.090.

[58] BHA, "A Guide to UK Mini-Hydro Development," *British Hydropower Association* 2012.

[59] D. Basnayat, "Background Material: Fundamentals of Small Hydro Power Technologies," presented at the Renewable Energy and Energy Efficiency Partnership, Nairobi, Kenya, 2006.

[60] D. J. Obadote, "Energy Crisis in Nigeria: Technical Issues and Solutions," presented at the Power Sector Prayer Conference, Nigeria, 2009.

[61] O. Paish, "Small Hydro Power: Technology and Current Status," *Renewable and Sustainable Energy Reviews,* vol. 6, pp. 537–556, 2002/12/01/ 2002.DOI: https://doi.org/10.1016/S1364–0321(02)00006–0.

[62] v. d. W. Seline. (2013, 2/11/2015). Hydro in Africa: Navigating a Continent of Untapped Potential. *HRW-Hydro Review Worldwide.* Available: http://www.hydroworld.com/articles/print/volume-21/issue-6/articles/african-hydropower/hydro-in-africa-navigating-a-continent.html

[63] J. Cunha and P. V. Ferreira, "A Risk Analysis of Small-Hydro Power (SHP) Plants Investments," *International Journal of Sustainable Energy Planning and Management* vol. 02, pp. 47–62 2014.DOI: https://doi.org/10.5278/ijsepm.2014.2.5

[64] M. Kimani. (2008, 15/05/2018). *Powering Up Africa's Economies: Regional Initiatives can Help Cover Deficits (8 ed.).* Available: https://www.un.org/africarenewal/magazine/october-2008/powering-africa%E2%80%99s-economies

[65] BHA, *British Hydropower Association (BHA).* A guide to UK Mini-Hydro Development. Gussage St Michael, Wimborne, UK, 2012.

[66] K. Codi, "Zambia Electricity Shortage Highlights Africa's Hydropower Shortfalls," in *Circle of Blue* vol. 2015 ed. http://

www.circleofblue.org/waternews/2015/world/zambia-electricity-shortage-highlights-africas-hydropower-shortfalls/,2015.

[67] IRENA, "Renewable Energy Technologies: Cost Analysis Series," Abu Dhabi2012. Available: https://www.irena.org/documentdownloads/publications/re_technologies_cost_analysis-hydropower.pdf

[68] UNIDO, "World Small Hydropower Development Report 2013," *United Nations Industrial Development Organization and International Center on Small Hydro Power,* 2013.

[69] IRENA, "Renewable Power Generation Costs in 2014," *International Renewable Energy Agency (IRENA)*, 2014.

[70] A. Korkovelos. (2017, 22/07/2018). *A Geospatial Assessment of Small-Scale Hydropower Potential in Sub-Saharan Africa. The International Hydropower Association (IHA)* Available: https://www.hydropower.org/blog/a-geospatial-assessment-of-small-scale-hydropower-potential-in-sub-saharan-africa

[71] Mary Kimani, "Powering up Africa's Economies: Regional Initiatives can Help Cover Deficits," Africa Renewal, p. 8, 2008.

[72] H. Liu, D. Masera, and L. Esser, "World Hydropower Development Report 2013.," *United Nation Industrial Development Organisation (UNIDO) and Intertional Centre on Small Hydropower (ICSHP)*, 2013.

[73] M. Karatayev, S. Hall, Y. Kalyuzhnova, and M. L. Clarke, "Renewable energy technology uptake in Kazakhstan: Policy drivers and barriers in a transitional economy," *Renewable and Sustainable Energy Reviews,* vol. 66, pp. 120–136, 2016/12/01/ 2016.DOI: https://doi.org/10.1016/j.rser.2016.07.057.

[74] W. S. Ebhota and F. L. Inambao, "Facilitating Greater Energy Access in Rural and Remote Areas of Sub-Saharan Africa: Small Hydropower," *Energy & Environment,* vol. 28, pp. 316–329, 2017.DOI: doi:10.1177/0958305X16686448.

[75] U.-M. Rocío, M. J. Megan, and W. O. C. Patrick, "2017 Hydropower Market Report," The Water Power Technologies Office, Office of Energy Efficiency and Renewable Energy of the U.S. Department of Energy, USA2018.

[76] C. A. Alvarado-Ancieta. (2009, 11/10/2018). Estimating E&M Powerhouse Costs. Available: http://www.waterpowermagazine.com/features/featureestimating-em-powerhouse-costs/

[77] W. S. Ebhota, A. S. Karun, and F. L. Inambao, "Investigation of Functionally Graded Aluminium A356 Alloy and A356-10%SiCp Composite for Hydro Turbine Bucket Application," *International Journal of Engineering Research in Africa,* vol. 26, pp. 30–46, 2016 DOI: https://doi.org/10.4028/www.scientific.net/JERA.26.30.

[78] W. S. Ebhota, A. S. Karun, and F. L. Inambao, "Improving the Surface Properties of a Pelton Turbine Bucket via Centrifugal Casting Technique," *Advances in Mechanical Engineering,* vol. 9, p. 1687814017729087, 2017/10/01 2017.DOI: http://journals.sagepub.com/doi/abs/10.1177/1687814017729087.