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A REVIEW OF SUSTAINABLE HYDROPOWER GENERATION IN NIGERIA

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Abstract: Electricity is the core of every nation's socioeconomic development. Nigeria depends heavily on fossil fuel for electricity generation due to the vast deposits of crude oil and natural gas in the country. Nevertheless, the vast deposit of crude oil, Nigeria still generates less than 4000 MW of electricity with per capita consumption of about 0.03 kW. Hydropower, being one of the available sources of energy, can be transported instantaneously and pollution free to the consumers making it attractive as compared to other forms of energy. Hence, the authors reviewed the available literatures on hydropower generation to evaluate its sustainability in Nigeria context. The literature search was made as wide as possible to capture all relevant data required. The searches covered databases specific to scholarly articles on hydropower generation sustainability. From the studies, it is shown that the potentials of hydropower generation in Nigeria if fully exploited can significantly improve the energy mix of the country that would sustainably serve its population.
Keywords: Energy, Hydropower generation, Sustainability, Small hydropower

INTRODUCTION

Energy is one commodity on which the provision of goods and services depend. Its availability and optimal utilization are economic indices to measure countries' socioeconomic development. Recent researches have linked national standard of living to energy consumption showing that developed countries consume more energy than the developing countries. For the time immemorial, Nigeria is faced with acute shortage of power supply to its populace. The effect of epileptic power supply is conspicuous in the manufacturing sector where about 80% of factories are moribund. Statistically, the combined installed capacity of power stations in Nigeria is far below the country's electricity demand, resulting in epileptic supply of electricity. The situation is compounded by the failure of the existing power stations to operate at its installed capacity (Batalla *et al.*, 2004; Ajibola *et al.*, 2018; Akhator *et al.*, 2019). The sporadic supply of power in Nigeria affects every sphere of human endeavors. The catastrophic effects range from all forms of domestic discomfort to national humiliation. According to Ibe and Okedu (2015), maintaining a reliable electric power generation is therefore a very important issue in power system design and operation. Nigeria, being in the threshold of industrial development, has high energy demand. The country is endowed with rich reserves of conventional energy resources like: crude oil, natural gas, coal and hydro potential. However, coal, nuclear power, biomass and other renewable sources are presently not the major part of Nigeria's energy consumption mix. Meanwhile, most Nigeria electrical power stations currently are either thermal or hydropower. With the cost of oil being uncertain, alternative energy options need to be assessed and development plans expedited to enable a broad–based infrastructure. Electricity supply in the country has been through centralized generating station with high capacities. The supply was about 80% of the total electricity consumption in the country with about 6000 MW installed capacity from three large hydropower stations: Shiroro, Jebba and Kainji along with other five thermal power stations having maximum suppressed demand of about 3,500 MW.

The demand for electricity in Nigeria is shared between residential, industrial, commercial/street lighting in the proportions of 50:30:20 (Ismaila, 2017). It's estimated that 2 to 5% of the capacity of the national grid is contributed by private sector – Independent Power Producer (IPP). Private producers such as *Nigerian* Electricity Supply Corporation (*NESCO*), Shell, AES–Lagos, Bayelsa State gas turbine and Ajaokuta Steel Company sell power to Power Holding Company of Nigeria Plc (PHCN) for transmission and distribution to consumers. The other balance of power demand is being supplied by private generating sets.

The construction of the hydro plants often involves displacement of people and animals from their natural habitats and destruction of species of plants and animals. Therefore, its construction has substantial impact on its immediate environment. The impact may be positive that are useful to the environment or negative that are hazardous to the environment. The effective management of these impacts to ensure a conducive, balance and sustainable environment is highly desirable. These impacts can be hydrological, ecological, social, economic, cultural, meteorological or human health impacts. Sule and Salami (2013) reported that, the environmental ramifications associated with electricity generation, transmission and distribution have become of great importance in power systems planning, design and operations. In every technologically advanced countries of the world, public electricity distribution and supply dominates the industrial scene in the scale of its capital investment requirements, huge tonnage of primary fuel it consumes and its rapid growing demands for large, complex and technically sophisticated plants and equipment.

Globally, the most widely used form of renewable energy that accounts for 16% of world electricity consumption and 3,427 terawatt–hours of electricity production is hydroelectric energy (Samadi–Boroujen, 2012; Olukanni *et al.*, 2016). Hydropower generating stations generally depend on inflow of water and available net head (Okoro and Chikuni, 2010; Abdulkadir *et al.*, 2012). It is a flexible source of electricity since plants can be ramped up and down very quickly to adapt to changing energy demands. The current trend in hydropower system operations focus on multiple uses of water in order to maximize human needs and demands connected to economic and social activities of the community. Hydropower generation was estimated to be about 35.6% of the Nigeria's electricity sources with gas estimated at 39.8% and oil at 24.8% (Obadote, 2009). However, a range of factors limit hydropower potential which includes river discharge and its variation, landscape topography and environmental considerations, technical capacity, turbine design, limitations of the electrical transmission system, technical flaws and functionality of the energy market (Worman, 2012). Studies have shown that climate change may affect water resources which lead to significant variation of the potential for hydropower (Fahmy *et al.*, 1994; Nogueria *et al.*, 2008; Bosona and Gebresenbet, 2010).

The African continent is endowed with enormous hydropower potential that needs to be harnessed. Despite this huge potential which is enough to meet all the electricity needs of the continent, only a small fraction has been exploited. This could be due to the major technical, financial and environmental challenges that need to be overcome (Sambo, 2010). Hydropower currently makes about 20% contribution to the global electricity supply, second to fossil fuel. Nigeria depends heavily on fossil fuel for electricity generation due to the vast deposits of crude oil and natural gas in the country. Notwithstanding, Nigeria generates less than 4000 MW of electricity with per capita consumption of 0.03 kW (Ezirim *et al.*, 2016). This is the present situation despite the fact that the installed total capacity to generate electricity as far back as 1999 was put at 11,756 MW (Oparaku, 2007). Ohunakin (2010) highlighted that hydropower was the only source of electrical power in Nigeria before the discovery of crude oil. The shift in attention to fossil fuels due to the vast deposit of fossil fuel in the country led to the decay in the hydropower sector development. There is a growing concern that countries should reduce their dependence on fossil fuels for electricity generation and look to other cleaner technologies. Three major factors that improve the attractiveness of renewable energy sources, including hydropower: a growing global demand for electricity, the likely increase in fossil fuel prices, and the need for clean energy sources. Hydropower production is thus expected to increase threefold over the next 100 years (Sambo, 2010). Therefore, the likely obstacles to the sustainable hydropower generation such as climate change, sediment impact, dam and design capacities, are needed to be reviewed holistically. The aim of this study is to review published studies on sustainable hydropower generation in Nigeria with a focus on major hydropower dams in Nigeria.

HYDROPOWER DEVELOPMENT IN NIGERIA

Construction activities on the first hydropower station in Nigeria commenced in 1964 at Kainji on River Niger. The dam was commissioned in 1968 with an installed capacity of 320 MW, and by 1978, the station had 8 plants with total capacity of 760 MW. Later on, the tail water from Kainji dam was utilized to generate 540 MW at Jebba dam, 97 km downstream of Kainji dam. The third Hydro–Electric Power (HEP) station, the Shiroro dam in Niger State was commissioned in 1990 with an installed capacity of 600 MW bringing the total installed capacity of HEP in Nigeria to 1900 MW. There are a number of small hydropower stations, such as 3 MW plant in Bagel, 8 MW plant in Kura and 8 MW in Lere, 2 MW Station at Kwall fall on N'Gell River (River Kaduna) and 8 MW station at Kurra fall. The cumulative capacity of hydropower stations (small and large) is about 2000 MW. This accounts for 32% of the combined installed capacity of hydro, thermal and gas power stations in Nigeria (Zarma, 2006). The development of 2500 MW Mambilla hydropower station is in progress and the country still has potential for about 6000 MW hydropower station. Nigeria has just developed 23% of her feasible hydropower. This is very low compared to other African countries such as Lesotho which has developed 50% of her hydropower potential; Burkina Faso developed 46%, while Kenya has developed 34% of her hydropower potential (Zarma, 2006; Jimoh, 2009).

Potential Hydropower Sites in Nigeria

The power generation in Nigeria has been overwhelmed with various problems impeding its successful implementation. Nigeria has considerable hydro potential sources exemplified by her large rivers, small rivers and streams. Nigerian rivers are distributed all over the country with potential sites for hydropower scheme which can serve the urban, rural and isolated communities. Nigeria hydropower currently accounts for about 32% of the total installed commercial electric power capacity. The overall large–scale potential (exploitable) is in excess of 11,000 MW. An estimation of rivers Kaduna, Benue and Cross River at Shiroro, Makurdi and Ikom indicates that a total capacity of about 4,650 MW is available, while the estimate for the river Mambillla Plateau is put at about 2,330 MW. A large number of untapped hydropower potential of about 11,895 MW (Table 1) has been identified in various locations across the country (Ismaila, 2017).

Table 1: Hydropower potential locations and their capacities in Nigeria

Location	River	State	Potential Capacity (MW)
Mambilla	Danga	Taraba	3960
Lokoja	Niger	Kogi	1950
Makurdi	Benue	Benue	1060
Onitsha	Niger	Anambra	1050
Ikom	Cross	Cross River	730
Zungeru I	Kaduna	Niger	500
Zungeru II	Kaduna	Niger	450
Yola	Benue	Adamawa	360
Gurara	Gurara	Niger	300
Katsina Ala	Katsina Ala	Benue	260
Beli SE	Taraba	Kano	240
Donka	Niger	Adamawa	225
Afikpo	Cross	Ebonyi	180
Garin Dali	Taraba	Taraba	135
Gembu	Dongo	Taraba	130
Sarkin–Danko	Suntai	Taraba	45
Kiri	Gongola	Adamawa	40
Oudi	Mada	Benue	40
Richa I	Mosari	Nassarawa	35
Gwaram	Jama'are	Adamawa	30
Ifon	Osse	Ondo	30
Kashimbila	KatsinaAla	Benue	30
Korubo	Gongola	Adamawa	25
Kura I	Sanga	Kano	15
Richa II	Dafo	Kano	25
Mistakuku	Kurra	Plateau	20
Kura II	Sanga	Kano	25
Kafanchan	Kongun	Kaduna	5
Total			**11895**

(Source: Ismaila 2017; Akorede *et al.*, 2017)

Small Hydropower Potential of Nigeria

Small hydropower is considered a viable solution to the power challenges in Nigeria. Ohunakin *et al.* (2010) opined that Small Hydropower Potential (SHP) has been in existence in Nigeria since 1923 i.e., 45 years before the commissioning of the country's first large hydropower in Kainji. However, SHP technology is still at its infancy in Nigeria with the scheme operated in only three States of the country (Ohunaki *et al.*, 2011). If well deployed, SHP can be most affordable and accessible option to provide off–grid electricity services especially in rural communities (Akorede *et al.*, 2017). The Nigerian Electricity Supply Company (NESCO) was able to supply electricity to the old Benue–Plateau area from the mid–forties to the eighties with hydropower from the Kurra falls. Small hydro power plants are defined and classified as micro, mini or small. The definition of SHP and classification of capacity are dynamic and determined by indigenous development and growth in economy.

Indigenous development and growth in different countries economy has been the litmus test for definition and classification of SHP capacity. Hence, most countries have different definitions and classifications for SHP (Essan, 2007). In Nigeria, SHP is defined as hydropower station capable of generating up to 10 MW capacity as shown in Table 2. Plants with capacity up to 1 MW are considered as mini–hydropower, while micro–hydropower has capacity of up to 500 kW (Aliyu *et al.*, 2015).

Osokoya *et al.* (2013) recommended for Nigeria several units of small hydropower stations because of its affordability, maintainability, reduction in power losses through long transmission lines and avoidance of bureaucracy in government since they would be managed by smaller government units, i.e., the local government. Development of small hydropower projects would significantly reduce poverty and enhance quality of life in the communities they serve. Muhammadu and Usman (2020) highlighted factors affecting developments in the small hydropower sector, and efforts made to ensure capacity building for renewable energy, stimulation of the private sector, developing the markets for small hydropower, obtaining the necessary finance for small hydropower projects and the assistance of multilateral institutions in advancing small hydropower in the North central Nigeria.

Table 2: Classification of SHP in selected country and Organization

Country/ Organization	Micro (kW)	Mini (kW)	Small (kW)
Canada	Nil	<1,000	1001–1,500
China	<100	101–500	501–25,000
ESHA	Nil	Nil	<15,000
France	<500	501–2,000	Nil
IN–SHIP	<100	101–500	501–10,000
India	<100	<2,000	Nil
Japan	Nil	Nil	<10,000
Philippines	Nil	51–500	<15,000
New Zealand	Nil	<10,000	<50,000
Nigeria	≤500	501–1,000	1001–10,000
Sweden	Nil	Nil	101–15,000
UNIDO	<100	101–2,000	2,001–10,000
United Kingdom	<1000	Nil	Nil
USA	<500	501–2,000	<15,000
Zimbabwe	5–500	501–5,000	Nil

According to Energy commission of Nigeria (ECN, 2005), there was a survey which were carried out in 1980 to assessed SHP potentials in 277 locations (Table 3). The result shows that there are total potentials of around 734.3 MW in the surveyed locations. So far, about eight SHP stations (Table 4) with aggregate capacity of 37.0 MW have been installed in Nigeria by private companies and the government.

Table 3: SHP Surveyed States in Nigeria

State (Pre 1980)	River Basin	Total sites	Total capacity (MW)
Sokoto	Sokoto–Rima	22	30.6
Katsina	Sokoto–Rima	11	8.0
Niger	Niger	30	117.6
Kaduna	Niger	19	59.2
Kwara	Niger	12	38.8
Kano	Hadeija–Jamaare	28	46.2
Borno	Chad	28	20.8
Bauchi	Upper Benue	20	42.6
Gongola	Upper Benue	38	162.7
Plateau	Lower Benue	32	110.4
Benue	Lower Benue	19	69.2
Rivers	Cross River	18	258.1
Total		**277**	**734.2**
(ECN, 2005)			

Table 4: Existing Small Hydropower schemed in Nigeria

S/No	River	State	Installed Capacity (MW)
1	Bagel I	Plateau	1
2	Bagel II	Plateau	2
3	Kurra	Plateau	8
4	Lere I	Plateau	4
5	Lere II	Plateau	4
6	*Bakalor	Sokoto	3
7	*Tiger	Kano	6
8	*Oyan	Ogun	9

* Needs rehabilitation

Optimizing Hydropower Operation and Management

Special attention should be devoted to adaptation measures to cope with the varied climate environment. Two prime options are addressed on operation and management of hydropower generation to adapt climate change. The first option is to enhance the optimal operation of cascade hydropower stations or single hydropower station with reservoir. Scheduling optimization could reduce the water spill with available capacity and storage. Although the dry scenario examined in that study had 20% less runoff than the base historical hydrology, system–wide, revenues decrease by less than 14% through optimally re–operating storage and generation facilities within existing capacities. Scheduling optimization of hydropower station on a river or basin, is to make full use of water resource at all levels. It can also adjust and compensate for the effects on each single station due to inter annual climate variability during the year. In this case, the most important thing is to optimize the hydropower operation pattern to maximize the revenue with limited capacity and available ancillary facilities (Zhang *et al.*, 2012). The second option, and not mutually exclusive, is to conduct an in–depth risk analysis of climate change impacts on hydropower generation and prepare emergency plan for climate extremes. Changes in mean climate impact caused by global warming on hydropower are relatively limited and easier to be controlled, but the extreme weather events such as floods and drought will seriously affect the production, transmission and distribution of hydropower generation. The frequency and intensity of regional extreme weather caused by climate change is clearly evident. This places potentially severe stress and high risk on hydropower systems. Therefore, it is critically significant for hydropower planners and decision–makers to analyze the potential risk of climate extreme events during the operation. Based on hydrological model forecasts and predictions, emergency plans under different extreme conditions should be established. By optimizing power generation, operation and management, the more efficient hydropower stations could not only increase their generation revenue but also play a significant socio–economic role for society.

Cost Associated with Hydropower

The costs associated with developing hydropower are very site–specific. Meeting environmental issues and the need to design the power plant to maximize its output vary from area to area. However, compared to other depletable and non–depletable energy sources, hydropower is among the least expensive of all the energy resources. Although the initial costs to develop and construct these facilities are not small, they have lower maintenance and operation costs. Taken together, the cost of electricity from hydroelectric plants ranges between 0.03 and 0.06 cents per kWh. This makes these power plants attractive to meet the increasing need to supply electricity (Schwailer, 1996). Construction costs for new hydropower projects in most countries including Nigeria are usually less than US $2 million/MW for large scale schemes (> 300 MW), and US $2 to US $4 million/MW for small– and medium–scale schemes (<300 MW) (IEA, 2014). A typical classification of hydropower scheme is presented in Table 5. It is important to note that the initial investment needs for particular projects must be studied individually owing to the unique nature of each hydropower project.

Table 5: Classification of cost associated with hydropower schemes

Category	Output (MW)	Storage	Power use	Investment costs (US$ millions/MW)
Small	< 10	Run of river	Base load	2 to 4
Medium	10 to 100	Run of river	Base load	2 to 3
Medium	100 to 300	Dam and reservoir	Base load and peak	2 to 3
Large	> 300	Dam and reservoir	Base load and peak	< 2

(Source: IEA, 2014)

Social and Environmental Costs of SHP Plants

Ohunakin (2010a) emphasized that social and environmental costs of hydropower are more prevalent for large–dam projects. Small–scale hydro projects have the least social and environmental effects. Dudhani *et al.* (2006) expressed that SHP projects are generally considered to be more environmentally favorable than both large hydro and fossil fuel powered plants because they do not involve serious deforestation, rehabilitation and submergence. Meanwhile, some carbon dioxide is produced during manufacture and construction of the project. This is a tiny fraction of the operating emissions of equivalent fossil–fuel electricity generation. Small dams and micro hydro facilities create less risk, but can form continuing hazards even after they have been decommissioned. For example, the Small Kelly Barnes Dam failed in 1967, causing 39 deaths with the Toccoa Flood, ten years after its power plant was decommissioned in 1957.

Renewable Energy Policy on Hydropower

In order to benefit from the huge SHP potentials in Nigeria, a vibrant renewable energy portfolio standard has to be formulated along the following lines as contained in (Sambo, 2007). These policies include:

- nation shall fully harness the hydropower potential available in the country for electricity generation.
- nation shall pay particular attention to the development of the mini and micro hydropower schemes.
- exploitation of the hydro resources shall be done in environmentally sustainable manner.
- private sector and indigenous participation in hydropower development shall be actively and generously promoted.

DISCUSSION AND CONCLUSION

This paper presented a critical review of the status of sustainable hydropower generation in Nigeria, and the potential to utilize them in meeting the current energy crisis facing the country. The potentials of small hydropower plants in Nigeria have been explored and confirmed to be very huge considering the fact that experts had assessed many sites in the country to have favourable conditions for SHP development. It has been shown that the exploitation of SHP potentials in twelve states could raise the available megawatts by more than 20 percent and improve the energy mix in Nigeria. Further, recommendations of Osokoya *et al.* (2013) could be helpful in enhancing the small hydropower generation in Nigeria.

The costs associated with developing hydropower are very site–specific base on environmental situation and the need to design the power plant. Although, the initial costs to develop and construct these facilities are not small, however, they have lower maintenance and operation costs. The cost of electricity from hydroelectric plants ranges between 0.03 and 0.06 cents per kilowatt.hr. Construction costs for new hydropower projects in most countries including Nigeria are usually less than US $2 million/MW for large scale schemes (> 300 MW), and US $2 to US $4 million/MW for small– and medium–scale schemes (<300 MW).

Several factors such as sedimentation, climate changes and operation and maintenance of the hydropower can affect the sustainable generation of hydropower in Nigeria. Sedimentation affects hydropower generation due to a loss of reservoir storage or by damaging the mechanical components of the facilities. Sediment deposited in reservoirs may also present additional and compounding structural loads to a hydropower dam and may also become liquefied under dynamic loading from an earthquake. Methods of managing sediment at hydropower facilities fall under three general categories: those that divert sediment around or through the reservoir, those that remove deposited sediments, and those that minimize the amount of sediment reaching the facility. A variety of sediment management strategies have been employed at facilities in Nigeria, with many successful implementations documented. Appropriate sediment management at hydropower facilities can be achieved through consideration of sediment concerns during all phases of the project, design, construction and operation.

The operation and maintenance costs are relatively low for hydropower plants compared to other forms of power generation. However, many low to middle income countries such as Nigeria struggle to meet standard maintenance schedules through lack of resources which then leads to loss of performance. The required operation and maintenance varies widely, according to the scheme's location, capacity factor, generation strategy, whether the station is manned or unmanned, whether it is a storage or run of river scheme, the annual production, the number of starts and stops, as well as numerous other factors. Underfunded and neglected operation and maintenance reduces power output and shortens the life of the plants. In systems with adequate spare capacity outages of plant components can be planned, for their inspection and, if necessary, repair and replacement should be done to improve the performances of the hydropower.

It is very important to harness all the hydropower potential in Nigeria sustainably in order to boost the socio–economic development of the country. The selection, design, construction and operation of hydropower projects need to take into account it environmental and social impacts in a way that is sympathetic to the environment and society. The government should be committed to promote renewable forms of energy, especially the hydropower projects where it is feasible and practicable. In the rural area in the country where the livelihoods of people are underpinned by the presence of the healthy and diverse ecosystems that provide them with sustenance, the issue of sustainability is of paramount important.

Also, there can be no sustainable development without the demonstration of sound and equitable distribution of economic benefits. For this reason, economic considerations are central in the decision–making processes associated with hydropower projects. The efficient use of economic resources requires that the best options are selected and that the alternatives have been carefully evaluated. Furthermore, there are no hidden and unforeseen costs that could emerge in the future. Demand growth has been rapid and the availability of funds and grants is not keeping pace with the increasing capital requirements of the sector.

Development of Nigeria energy space will result in industrialization and improved standard of living if energy demands for various sectors of the economic is met. Igweonu and Joshua, (2012) emphasized that SHP potentials in Nigeria is massive considering the numerous sites assessed and certified by experts. Extensive review of hydropower generation in Nigeria proves not only to be a renewable source but also sustainable. However, energy demand is yet to be met thereby creating a vacuum for development of sustainable energy in Nigeria. It can be concluded that SHP systems would alleviate the unavailability of power and it could be enhanced by optimizing their design, construction and operation techniques. It is recommended that efforts and policy are required to encourage and develop the technical skills needed for the investors to be active in SHP.

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ISSN: 2067-3809