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Hydropower Potential for Clean Energy Development in Nigeria: A SWOT Analysis

[1] Yekini Suberu Mohammed, [2] Funsho Olowoniyi
[1, 2] TETFund Centre of Excellence for Clean Energy and Entrepreneurship Development, Federal Polytechnic Nasarawa, Nasarawa State, Nigeria

Corresponding Author: **Yekini Suberu Mohammed**

Abstract
Hydroelectricity can be planned on a small or large scale but a small-scale hydropower project can be integrated with other renewable and non-renewable energy to generate rural community-based electricity. The electricity scheme of a society is better managed if an approach is sustained in such a way that both supply and demand-side options can be balanced with minimum cost accruing to the project and energy delivery service. Hydropower sources are abundant in Nigeria and hydroelectricity development is a highly promising electrification option for both urban and rural areas of the country. While the existing large hydropower projects in the country belong to the Government then small-scale projects are predominantly owned by private investors. Thereafter, Hydropower development projects in the country especially on small-scale electric power potential for rural communities could be expanded through government-community or government-private-based partnership agreements. Thus, this paper focuses on the assessment of hydropower potential for renewable energy development in the country. It also examines some challenging factors of hydropower development and issues concerning the grid-independent application of small hydropower systems for hybrid electricity schemes based on the perspectives of strengths, weaknesses, opportunities, and threats approach. Conclusively, the work pinpoints some crucial recommendations for increasing the potential utilization of hydropower and other renewable energy sources (RES) in the country.

Keywords: Hydropower, Clean Energy, SWOT

1. Introduction

Currently, the potential of hydroelectric power in the entire mix of renewable and sustainable energy generation in the whole world, region of sub-Sahara Africa and Nigeria in particular is under-represented. This is converse to the fact that there exists a vast potential for hydropower sources on a global scale and less than half of the economic potential has not been exploited. Potential exploitation varies significantly from country to country. China has the highest installed capacity for hydropower and the highest total percentage representation in the world as shown in Table 1. Across different parts of Nigeria, there are different exploitable potential of hydropower sources ranging from small to large scales. Presently, the country is profoundly dependent on petroleum sources to provide for increasing energy demand in countenance of the nation's low oil output production. This has shrouded the country in a condition of overdependence on oil importation and consequently, huge spending on oil subsidies thereby causing inefficient national budgeting scheme. Surprisingly, there are vast renewable energy resources coupled with development opportunities. Up to this current time, Nigeria is highly engulfed in the condition energy crisis as the country stage-manages to generate just about 4000MW for more than 160 million populations. Earlier, a study conducted by [1] established that only about 40% of the 140 million Nigerians have access to electricity. The condition of access to electricity in Nigeria is more constrained in rural areas [2-5]. However, it has been proven beyond doubt that the provision of adequate, reliable, and affordable energy has been measured as a basis of development [6] of different kinds. In continuance, gaining access to modern energy systems (e.g. electricity or liquefied petroleum gas (LPG)) impacts human comfort by decreasing health and safety risks linked with traditional energy use [7-11]. Traditional energy used is vastly predominant in developing countries most especially in sub-Sahara Africa (SSA) and such energy production systems are usually achieved via direct combustion of plant and animal residues. Characteristically, direct combustion of combustible solid biomass in the open air is associated with low energy efficiency and indoor air pollution with a propensity to cause respiratory-related ailments such as cardiovascular infections.

Table 1: The contribution in total domestic electricity generation, producers, and installed capacity of hydroelectricity in the world [12-13]

Producers	TWh	% of world total	Installed capacity	GW	Country (top-ten producers)	% of hydro in total domestic electricity generation
China	616	18.5	China	168	Norway	95.7
Brazil	391	11.7	United States	100	Brazil	83.8
Canada	364	10.9	Brazil	78	Venezuela	72.8
United States	298	9.0	Canada	75	Canada	60.3
Russia	176	5.3	Japan	47	Sweden	48.3
Norway	127	3.8	Russia	47	Russia	17.8
India	107	3.2	India	37	China	16.7
Venezuela	90	2.7	Norway	30	India	11.9
Japan	82	2.5	France	25	Japan	7.8
Sweden	66	2.0	Italy	21	United States	7.1
Rest of the world	1012	30.4	Rest of the world	324	Rest of the world	13.9
World	3329	100.0	World	952	world	16.5

These days, pollution from energy generation using conventional oils and gas resources has become a curious issue for all sorts of stakeholders around the globe. This is due to the centrality of the atmosphere to the entire world. Unequivocally, the Intergovernmental Panel on Climate Change (IPCC) made a declaration that the global energy sector contributes the largest percentage of modern-day anthropogenic greenhouse gases (GHGs). The global atmosphere must be made conducive to the continued existence of sustainable development. On this track, there is an absolute need for renewable and sustainable sources of energy to ensure that the natural environment is protected based on international agreements in line with the clean development mechanism (CDM) of the Kyoto Protocols. A recent report as released by reference [14] indicated an abrupt rise in global temperature due to greenhouse emissions. The impacts of a temperature rise could be complex and catastrophic to human society through flooding consequential from a sudden rise in mean sea level caused by melting of snow and evaporation of natural glaciers. A critical glance at Fig 1 indicates that from now to the near future global temperature shall continue to rise. This major threat of environmental pollution orchestrated by modern energy has presented a spur of an unprecedented interest in low-carbon electricity. This idea has brought about increasing enthusiasm for exploiting varieties of renewable energy sources (RES) across different parts of the world. Most unfortunately, there is a very slow pace for RE development in many developing countries especially the region of SSA. This retrogression could be attributed to many different factors mainly including shortage of finance, national energy planning constraints, technical challenges and weak socio-political interest. These factors mentioned have particularly affected hydropower development in Nigeria. Hydropower is obtained from the combination of the potential and kinetic energy of falling water striking the surface of a water turbine and thereby rotating a connected shaft to generate electricity. Hydropower is a very vital source of energy for generating electricity all over the world due to its valuable characteristics such as being renewable, clean, less effective to the environment, inexpensive, and a national energy source [15]. In consequence, this paper presents an evaluation analysis of hydropower potential for renewable electricity in the country with a specific interest in grid-independent applications and further analyzes the situation of the strengths, weaknesses, opportunities and threats (SWOT) towards exploiting small and micro-scale hydropower sources in the country for hybrid electric power generation in rural communities.

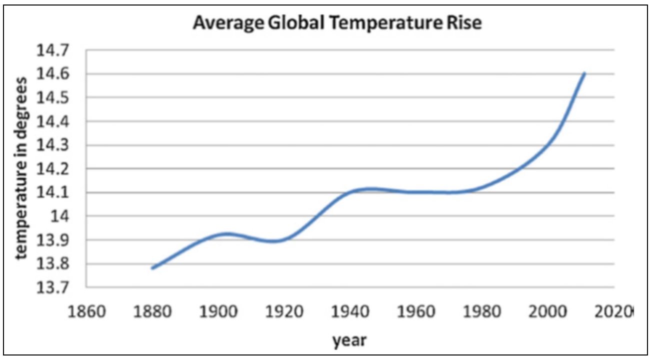

Fig 1: The graph of average global temperature rise [14]

2. Overview of Energy Supply Situations in the Country

The Nigeria electric power sector is currently entrusted in the hands of private companies, and power holding companies of Nigeria (PHCN). The idea behind the PHCN emergence was focused on breaking the previously existing monopolistic scheme of work in the energy sector of the country. Going by the reform strategy, the Electric Power Sector Reform (EPSR) Act 2006 unbundled the defunct National Electric Power Authority (NEPA) thereby advocating for the effective participation of private companies in the energy business of the country. One of the major objectives of the reform is to encourage an effective generation mix especially the use of renewable sources of energy for electric power generation. Despite the reforms, remarkable growths have not been observed in the nation's power sector as electricity generation capacity is not increasing. The situation now is that there is a greater mismatch gap between the demand and supply resulting in a persistent shortage of electricity thereby resulting in a looming national energy crisis. Natural gas is a predominant source of electric power generation in Nigeria due to its vast reserve deposit and attracting more attention as new power investors are relying on the construction of more thermal gas power plants across different parts of the country. There exists a great deal of gas flaring as waste in the country. In quite a lot of instances, natural gas supplies to power stations are not adequately supplied due to a high percentage of flaring and crisis in the Niger Delta, the oil-rich region of the country.

The main constraint is that the output electric power generated is usually less than expected because below one-third of the needed 1.2 billion standard cubic feet of gas supply per day [16] are disrupted. In line with the urgent demand by the Federal Government of Nigeria (FGN) to increase the electricity supply in the country, investors are ideologically obliged to implement any quick and large-scale alternative to a stable and increased supply of electricity without notable priority for renewable sources. On this ground, potential electricity investors in the country are taking advantage of the availability of sufficient gas supply, high operational flexibility and low life-cycle cost and short construction period of thermal gas power plants. At present there are 14 prominent power generating stations in the country with only three of the satations delivering large hydropower; Egbin (thermal power station-1320MW), Egbin AES (thermal power station-270MW), Sapele (thermal power station-1020MW), Okapi (thermal power station), Afam (thermal power station-702MW), Delta (thermal power station-840MW), Omoku (thermal power station-150MW), Ajaokuta (thermal power station-110MW), Geregu (thermal power station-414MW), Omotosho (thermal power station-335MW), Olorunsogo (thermal power station-335MW), Kainji (hydropower station-760MW), Jebba (hydropower station-540MW) and Shiroro (hydropower station-600MW). Noticeably, only three of the power stations run on hydro and the percentage representation of hydropower has remained all time lower than that of thermal gas used as shown in Fig 2. Until today, this percentage contribution has remained largely unchanged due to poor investment and lack of workable strategic plans in power generation in the country.

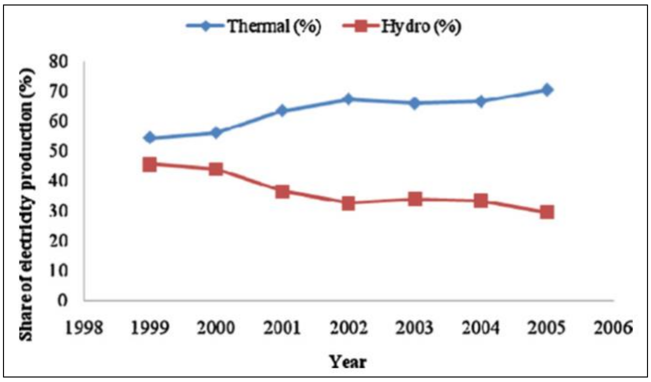

Fig 2: Percentage contribution of thermal and hydro in electricity supply in Nigeria 1999-2005 [17]

The combination of these power stations as mentioned here together with other small power stations in the country have a total installed electric power capacity of approximately 10,000MW but the available potential is usually less than 50% of the installed capacity. Vehemently, this had placed the country on a very low kW per capital consumption circumstances. This existing widespread inefficient performance in the sector can be ascribed to several prominent challenges like deprived funding scheme, weak investment strategies, aging of facilities and important power system equipment, poor system updating tendencies, limited technical know-how of the maintenance crew, inadequate maintenance schedule, endemic financial corruption in the sector and ineffective generation mix. Suggestions by [16] stated that to increase energy production, there is a need for enhancement of the existing sources and full exploitation and promotion of the country's huge renewable energy sources. Regrettably, uses of renewable energy sources in Nigeria are dominated by combustible biomass firewood as revealed in Fig 3. Firewood is used mainly for cooking and heating in rural and urban households in the country. There is a very worrisome situation regarding the increasing demand for fuelwood in the country due to its attendant effects on desert encroachment and land degradation. Fuelwood is fetched from forests and areas covered with shrubs without strict regulation. In actual sense, such practice is in reality obstructing the normal succession of forest resources and eventually resulting in low forest carbon stocking potential. In this respect, there are imperative need to confront such an increasing trend to avert unprecedented environmental destructive conditions. Moreover, the use of modern renewable energy technologies for electricity generation is basic towards reducing poverty in developing countries and enhancing sustainable development. Sustainable development is a goal that scores of countries all over the world aspire to achieve [18]. It will also help to preserve the environment and achieve realistic economic and social development [18].

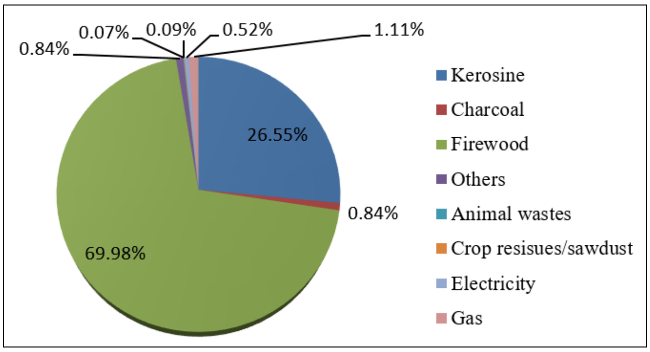

Fig 3: Shares of energy consumption by source in Nigeria [19]

3. Hydropower Dams and Contending Issues in Nigeria

3.1 Hydropower dams and water reservoirs in the country

A dam can be used for recreation, hydroelectricity, irrigation, fishing, or flood control. Nigeria is naturally endowed with lots of small and large sources of water with a reasonable network of streams, rivers, ponds, lakes and lagoons in coastal and non-coastal areas of the country. Unfortunately, ineffective planning as well as poor management and utilization of many of the water bodies in the country had affected the use of water for several purposes, especially for hydroelectricity generation. The mismanagement trends have resulted in a situation of enormous surface evaporation and excessive flooding across different parts of the country in recent times. The existence of natural or artificial dams is the main foundation for hydropower development. Most of the artificial dams in Nigeria were created in 1976 and the period was upward to impound surface water by the means of River Basins Development Authorities. In reality, hydropower plants rely on dams possessing the capability to hold back water thereby creating large reservoirs. Dams provide potential and kinetic energy required for electricity generation using the gravitational force of falling water. Hydropower has attracted a very important center of attention on the global energy development scene because of its immune characteristic to the cost of fuel and it is independent of fluctuations in the price of oils. Fig 4 presents a map of Nigeria showing major rivers and hydrological basins. However, the majority of dams and water reservoirs projects in Nigeria are used for water supply and irrigation schemes especially in the northern part of the country with a prolonged period of dry season while a very limited number of dams are used for hydropower generation.

Dams used for water supply in the Northern part are Zobe Dam (Katsina state), Tiga Dam (Kano state), Zauro Dam project (Kebbi state), Goronyo Dam (Sokoto state), Challawa Gorge Dam (Kano state), Bakalori dam (Sokoto state), Jibiya dam (Katsina state), Kafin zaki dam (Bauchi state), Kiri dam (Adamawa state), Ekuku dam (Kogi state) and Osara dam (Kogi state). Also, on the southern axis of the country where shortage of water is not a major challenge to the people, there are no well-known hydropower power projects in the region. The dams and water reservoirs in the regions (Southsouth, Southeast and Southwest) have long been neglected by the government. For example, Asejire Reservoir (Oyo state) and Ede-Erinle (Osun state) both in South-western Nigeria have a long history of neglect for hydropower projects. The dams mentioned so far occupy a surface area ranging from 4000-35000 hectares. Presently, there are just three major hydropower functional dams (Kainji, Jebba and Shiroro) and all are owned by the national government. In the extreme part of the southern region (South-south geopolitical region) of the country, there is a limit to the potentiality of harnessing hydropower sources due to unfavourable regional topography which must go along with the heavy cost of civil engineering construction. On the contrary, there could be tremendous potential for hydropower projects in the North-central, Northeast and Northwest parts of the country due to the mountainous landscape. A basic opportunity exists for hydropower development particularly SHP through the incorporation of electric power plants into the existing hydro dam infrastructures.

Fig 4: Map of Nigeria showing major rivers and hydrological basins [16, 20]

3.2 Hydropower concept and potential development in the country

3.2.1 Essentials of Conventional Hydropower Plant

A hydropower plant consists of six major essential components as illustrated in Fig 5. The construction of a hydropower station begins with a dam which is the most significant component of the power system. Dams for hydropower must be built with the purpose of impounding water on a river with a sufficient amount of water throughout the year regardless of the seasons. In addition, a fundamental requirement is that a sufficient head must be created to allow for sustainable potential energy for electricity generation. Another important component is the reservoir which is located behind the dam. In an ideal situation, the level of water level in the reservoir system must always be high enough to maintain sustainable potential energy which is a prerequisite for ensuring that the water flows maintain a high flow rate to produce a reasonable amount of electricity via the power generation scheme. Intake/control gates constructed inside the dam is to regulate the flow of water from the reservoir into the penstock. Water for power generation is controlled through the gates. The gates are also called inlet gates and water is moved into the turbine through the penstock due to gravitational force. The turbine is embedded into the power generation unit. There exists a direct connection between the turbine and the generator. The rotation of the turbine blades as they are struck with the force generated from the flowing water causes the shaft to rotate as well. The shaft is enclosed within the generator system which generates the electricity. Hydropower systems have several advantages and disadvantages based on economic, environmental and social perspectives which are summarized in Table 2. Applications of modern computer technologies in hydropower plant operations is making significant roadmaps towards solving some problems related to economic variability, water quality management, dam safety, operation and maintenance, energy management, and optimization of system operational configuration. An approximate electric power generation from a hydro source can be estimated using the formula:

$$P_{hydro} = \rho h \sigma g K \quad (1)$$

$P_{hydro} = Hydropower\ potential\ (W)$

$h = height\ (m)$

$\rho = density\ of\ water\ \left(\frac{kg}{m3}\right)$

$g = acceleration\ due\ to\ gravity\ \left(\frac{m}{s2}\right)$

K = coefficient of efficiency usually less than 1, $\sigma = flow\ rate\ \left(\frac{m3}{s}\right)$

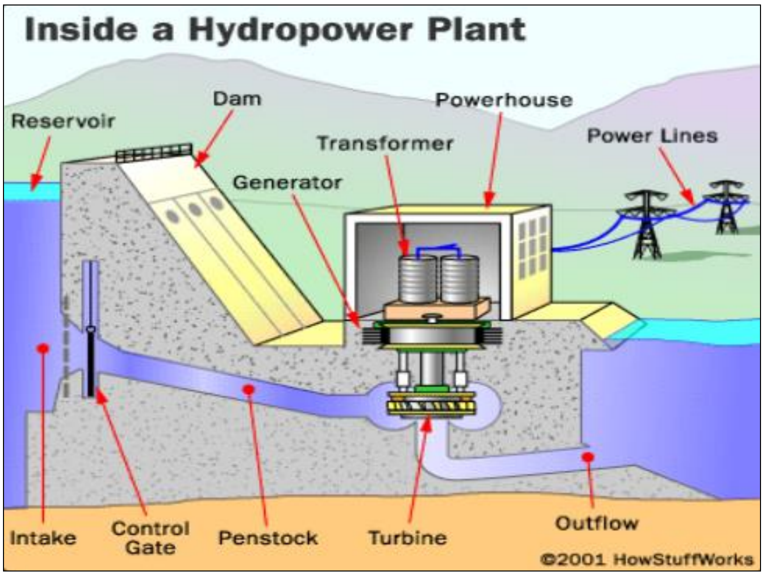

Fig 5: Generation of energy from hydro [21]

Table 2: Advantages and disadvantages of the hydropower [22-23]

Advantages	Disadvantages
Economic aspects	
Provides low operating and maintenance costs	High upfront investment
Provides long life span (50–100 years and more)	Precipitation
Provides reliable service	Requires long-term planning
Includes proven technology	Requires long-term agreements
Instigates and fosters regional development	Requires multidisciplinary involvement
Provides the highest energy efficiency rate	Often requires foreign contractors and funding
Creates employment opportunities and saves fuel	
Social aspects	
Leaves water available for other uses	May involve resettlement
Often provides flood protection	May restrict navigation
May enhance navigation conditions	Local land use patterns will be modified
Often enhances recreation	Waterborne disease vectors may need to be checked
Enhances accessibility of the territory and its resources	Requires management of competing water uses
Improves living conditions	
Sustains livelihoods (fresh water, food supply)	
Environmental aspects	
Produces no pollutants but only very few GHG emissions.	Inundation of terrestrial habitat
Enhances air quality	Modification of hydrological regimes
Produces no waste	Modification of aquatic habitats
Avoids depleting non-renewable fuel resources	Water quality needs to be managed
Often creates new freshwater ecosystems with increased productivity	Temporary introduction of methyl-mercury into the food chain needs to be monitored/managed
Enhances knowledge and improves management of valued species due to study results	Species activities and populations need to be monitored
Helps to slow down climate change	Barriers to fish migration, fish entrainment
Neither consumes nor pollutes the water it uses for electricity generation purposes	Sediment composition and transport may need to be monitored/managed

3.2.2 Small and large-scale hydropower projects in Nigeria

Generally, there are limited numbers of developed small-scale hydropower schemes in the entire region of SSA. A similar trend is also observed in Nigeria due to underprivileged potential development. The potential of a hydropower development depends on the availability and the volume in size of water, financial capital for investment, power demand and water head. Small hydropower (SHP) systems as the name implies are not conventionally different from other types of hydropower systems. The main difference is based on the potential installed capacity for electricity generation. Within the European concept of hydropower generation, a limit of 10MW electric power is considered for SHP [24]. At the moment, there is no standard definition as to the exact maximum capacity of SHP because in different countries along with organizations in charge of hydropower projects, there are differences of opinions as illustrated in Table 3.

Table 3: Classification of SHP in different parts of the world

Country/organization	SHP as defined by installed capacity (MW)	References
sBrazil	≤ 30	[25]
Canada	≤ 50	[25]
China	≤ 50	[26]
India	≤ 25	[27]
France	≤ 10	[25]
USA	≤ 30	[28]
Norway	≤ 10	[29]
Sweden	≤ 1.5	[30]
South Africa	≤ 10	[31]
European Small Hydropower Association (ESHA), Portugal, Spain, Ireland, Greece, Belgium,	≤ 10	[30]
United Kingdom	≤ 20	[30]
International Energy Agency	≤ 10	[32]
World Commission on Dams	≤ 10	[33]

A SHP can be generated either from a small dam or run-of-river type but depending on the magnitude of power produced. SHP could be further divided into smaller categories (pico, micro, mini, and small hydropower systems). SHP using run-of-river via the construction of a weir system could be less complex regarding the installation and reduced overall cost of the system. This is because there could be no need for profound civil engineering construction work which might engulf a very large part of the financial investment cost. Fig 6 shows a typical micro-hydropower station utilizing run-of-river as the source of water for driving the hydro turbine system. Run-of-river hydropower system is acknowledged to be appropriate for rivers with minimum flow variation or rivers that are regulated by large natural reservoirs [34]. Run-of-river hydropower projects have limited project construction activities due to their suitable economic issues [35] in addition to environmental benefits over other hydroelectricity generating systems of the same installed capacity [36-37]. A major disadvantage of run-of-river hydropower is that power output is easily affected by the variability of water flow from the river because there is no considerable impoundment of water. Normally, where it is certain that environmental factors such as seasonal drought could disrupt water flow and on the condition that it becomes necessary to maintain a stable degree of electric power output capacity to balance the demand profile, then poundage construction for water storage for a short-term as a viable alternative.

Fig 6: A 7kW micro-hydro project in Padisaw village (Afghanistan) using a run-of-river [38]

Nigeria is encountering a rapidly growing situation in the country concerning population and change in economic demand which is decidedly accounting for a continuous increase in the country's energy demand. The country is seriously striving towards meeting energy demand, especially in rural areas where the majority of the country's population lives and engages in peasant economic activities. Widespread poor access to electricity in rural areas has deeply affected the socio-economic well-being of the majority of the rural people such that they live below the poverty level with less than $2US per day. Nigeria has reasonable potential for SHP but till now the potential exploited so far is highly insignificant. Table 4 presents the potential SHP already developed in the country while Table 5 shows the potential surveyed across different parts of the country. A sum of 764.2 MW SHP from 286 sites was surveyed showing a rational potential considering the developing nature of the country. It is highly regretted that presently a potential of just 30 MW of the SHP is currently harnessed. The majority of the existing SHP sites are located in Plateau state, a North-central part of Nigeria and predominantly managed by the Nigerian Electricity Supply Corporation (NESCO), a private energy service company. The projected description of the demand for SHP in the country revealed a continuous growth in the demand for SHP in the country as shown in Fig 7. The indication is that there is a situation of gross underutilization of the naturally endowed SHP potential capability which is available in the country taking into account the fact that only a total of 30MW of the SHP installed capacity is currently in use in the range of 1 to 9MW.

Table 4: SHP in existence in Nigeria [39]

River	State	Installed capacity (MW)
Bagel I	Plateau	1
Bagel II	Plateau	2
Ouree	Plateau	2
Kura	Plateau	8
Lere	Plateau	4
Lere	Plateau	4
Bakalori	Sokoto	3
Tiga	Kano	9
Total		**30**

Table 5: Total SHP potential in surveyed states of Nigeria [40]

State	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-Jama'are	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
Cross River	Cross River	18	258.1
Total		**277**	**734.2**

A large hydropower system depends on the nature of the water head, site geographical characteristics, project size, electric power demand, and land use policy. Hydropower is one of the cheapest sources of electricity [41] with high energy efficiency of around 85% [42]. According to reference [43] the levilized cost of electricity (LCOE) for large hydropower is in the ranges of 0.02-0.19US$/kWh [42] and the reduced cost of energy can be attributed to the immunity of the system to the cost of fuel which is freely acquired from natural flowing water. It was established that the operation and maintenance cost of SHP in Nigeria is 1.6 €cent/kWh [44] which is quite low compared to some European countries such as Greece (2.4-4.2€cent/kWh), Spain (3.5-7€cent/kWh), UK (5-7€cent/kWh), Austria (3.6-14.5€cent/kWh) and Italy (5-10€cent/kWh) [45].

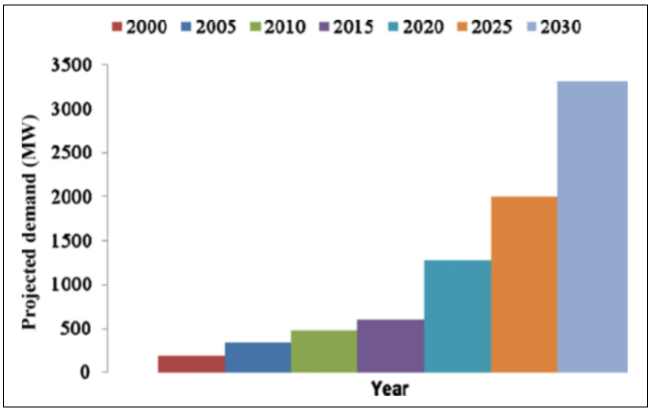

Fig 7: Projected demand of SHP in MW [46]

Large hydropower is most suitable for based load whilst small hydropower is appropriate for peak load operations. Large hydropower plants have the potential capability to enhance development as regional electricity projects to service and expand energy market creation due to their large power scale. It may facilitate the expansion of electricity interconnected power systems and the development of regional transmission infrastructure. Reference [47] (Table 6) provides an overview of different classifications of hydropower based on the potential of power delivery. Large-scale hydropower potential which has been developed in the country is located in Shiroro (600MW), Jebba (570MW) and Kainji (760MW). These hydropower plants are not generally operated to their installed capacity due to system failures and downtime maintenance periods. They are all concentrated in the central part of Nigeria and are generally favored by regional mountainous topography and the availability of sustainable heads. Besides the three large existing dams that are already in use for hydropower, the survey report also indicated that there are many other large-scale hydropower projects as shown in Table 7. The potential estimate was achieved by the efforts of the PHCN and assisted by the Energy Commission of Nigeria (ECN) which is a government organization saddled with the responsibility of development and maintenance of the National Energy Databank (NED). The ECN playing some of the mandate roles for coordinating and advising the government on the need to develop the hydropower sources in the country has used several opportunities available to conduct research and disseminate information regarding hydropower development based on the existing potential. The prevailing situation is that there are a lot of challenges to be overcome to achieve some reasonable levels of hydropower development in the country.

Table 6: overview of hydropower category description

Type of hydropower	Hydropower category description
Large hydro	More than 100MW and usually feeding a large electricity grid
Medium hydro	15-100MW (usually feeding into a grid)
Small hydro	1-15MW (usually feeding into a grid)
Mini hydro	Above 100kW and below 1MW (either standalone schemes or more often feeding into the grid)
Micro hydro	From 5kW up to 100kW (usually providing power for a small community or rural industry in remote areas away from the grid
Pico hydro	From a few hundred watts up to 5kW

Environmental and social issues are some of the major constraints confronting large hydropower projects in any part of the world. Based on a point of necessity, the establishment of a large hydropower demand requires that a comprehensive environmental and social impact assessment is conducted before project construction and equipment installations. Environmental effects of large hydropower plant construction could be experienced as displacement of human settlements, destruction of aquatic resources and water pollution. Execution of engineering framework in the construction of large hydropower stations such as land clearing and preparations, dams and road construction, power plant installation, and networking of transmission lines could be responsible for any of the negative changes to environmental dignity. From a social perspective, human means of livelihood could be destructed especially through water pollution and damage of aquatic resources which are capable of supporting the economic potential of any affected society. On this perception, engineers and project managers alike are obliged to take into consideration all the possible mitigated strategies on how to confront the challenges on the side of social and environmental effects.

Table 7: PHCN estimate of current exploitable hydropower sites in Nigeria (installed potential) [16, 40]

Location	River	Estimated installed potential capacity (MW)
Donka	Niger	225
Zungeru II	Kaduna	450
Zungeru I	Kaduna	500
Zurubu	Kaduna	20
Gwaram	Jama' are	30
Izon	Gurara	10
Oudi	Mada	40
Kafanchan	Kongum	5
Kura II	Sanga	25
Kura I	Sanga	15
Richa II	Dafo	25
Richa I	Mosari	35
Mistakuku	Kurra	20
Korubo	Gongola	25
Kiri	Gongola	40
Yola	Benue	360
Karamti	Kam	115
Beli	Taraba	240
Garin Dali	Taraba	135
Sarkin Danko	Suntai	45
Gembu	Dongu	130
Kasimbila	Katsina Ala	30
Katsina Ala	Katsina Ala	260
Makurdi	Benue	1060
Lokoja	Niger	1950
Onitsha	Niger	1050
Ifon	Osse	30
Ikom	Cross	730
Afokpo	Cross	180
Atan	Cross	180
Gurara	Gurara	300
Mambila	Danga	3,960
Total		**12,220**

3.3 Developmental challenges to overcome

3.3.1 High upfront capital cost

Conventional hydropower plants especially for large-capacity electricity require a lot of financial expenditures on dam construction and power plant installations and thus could result in huge initial capital investment. This has made large hydropower projects solitary realistic for big utilities with large and sustainable credit competence. Some factors could affect the cost implication of a hydropower project such as water flow rate, geographical topography, brick construction works, geological features, and powerhouse equipment. In large hydropower plant construction, all these directly account for high upfront capital investment costs amidst financial difficulties and unsatisfactory opportunities for feed-in tariffs in the country. This is because most of the projects are resting on public financing whereas the government is not providing a sufficient amount of capital to cushion the effect of risks perceived by potential investors, especially those involving hydrological uncertainties. The situation of volatile energy prices in the country has grossly affected hydropower financing mechanisms. With no doubt, the existence of government support for capital investment and development could exterminate this constraint. Nevertheless, there is vast domestic hydropower investment capacity and gloomy channelling for financing hydropower projects in Nigeria. Based on the ongoing power sector reforms that have guaranteed the effective participation of independent power producers (IPPs) and the ambition of the Federal Government of Nigeria to reduce the upfront cost for renewable energy through subsidy actions. A special fund called the Renewable Electricity Trust Fund (RETF), though not fully realized has been established by the Government to accelerate the expansion of renewable electricity in Nigeria [16]. The RETF which shall be managed under the Rural Electricity Fund (REF) according to the 2005 EPSR Act shall be to promote, support, and provide renewable electricity through private and public sector participation [48]. Also, the Federal Government through the NERC to guarantee unwavering pricing policy introduces feed-in tariffs for small hydro schemes not exceeding 30MW, solar and wind-based power plants, and all biomass cogeneration power plants irrespective of their sizes [49].

3.2.2 Hydrological uncertainties

The concept of hydrological uncertainty can be described as variability. An understanding of the risk connected to a hydropower plant is a very crucial factor in allowing for effective modelling and optimization of the impacts of climate change conditions. The very indispensable issue is not about the scenarios of future prediction but a better understanding of the uncertainties involved in making useful decisions. Nigeria is exceedingly susceptible to the impacts of climate change due to variations in the availability of water concerning seasonal rainfall conditions. There are several cases of prolonged seasonal drought have been reported by the National Emergency Management Agency (NEMA) and the report confirmed that the challenge is more prevalent in the Northern part of the country where more than 90% of the nation's dams are located. On the other hand, in the last few years, some cases of frequent flood accidents affecting human settlements in the country were witnessed and the worst ever experience happened in 2012.

Undisputedly, floods and droughts have considerable effects on water storage for hydropower generation. Excessive floods could damage hydropower system installations and loss of life while drought is capable of reducing the potential output power from a hydropower plant. Climate change forecasts for Africa envisage that the continent's weather outlines will become more variable, and severe weather procedures are expected to be more frequent and rigorous, with growing risk to health and life [50].

This includes the rising risk of drought and flooding in new areas [51], in addition to inundation due to sea-level rise in the continent's coastal areas [52]. Additionally, within the next 50 years, the number of populaces facing water stress will rise dramatically [53] coupled with other uncertainties connected to harsh climate change. Going by this perception, a conclusion can be drawn that large hydropower development in Africa and by extension in Nigeria could be vulnerable to changes in stream flow and concentration of rainfalls. Though, it is considerable to develop effective capacity for flood management and integrate climate alteration into the dam's design, and then efforts should be maintained to ensure that the shortage of water resulting from drought can be tackled using the pumped hydro energy storage (PHES) mechanism. PHES is a hydropower storage system whereby water is pumped from a lower reservoir to another one at a higher altitude through hydraulic gravitational potential energy offered by a difference in height between the two reservoirs. In most cases, the pumping mechanism is executed during an off-peak period with characteristic low electricity demand by the customers. In a high-peak scenario with a higher demand for electric power, water is released from the upper reservoir via a hydroelectric turbine to generate power and collected in the lower reservoir [54]. Fig 8 shows a schematic of PHES integrating other important hydroelectric power plant components. PHES is the most prominent large-scale energy storage system (ESS) for large power utilization [55] and the global potential has been estimated at 129GW capacity installed at diverse locations of more than 200 sites [56].

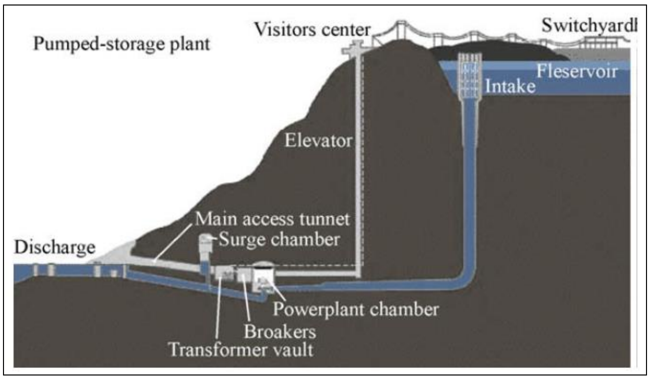

Fig 8: A schematic of pumped hydro energy storage [57]

Storage capacity and power potential of PHES is determined by the size in volume of the reservoirs and the height difference between the two reservoirs. Available space to build the two large dams [55] is another important factor that must be put into consideration. PHES can be used for leveling power variation associated with renewable energy. The use of PHES can be divided into 24 h time-scale applications, and applications involving more prolonged energy storage in time, including many days [58]. PHES has an elongated lifespan of about 30-50 years and efficiency of 65-75% [59] and capital costs of 500-1500 €/kW and 10-20 €/kW h [60]. In the United States, the cumulative capacity of PHES has been growing in the last five decades as revealed in Fig 9. It is a promising technology of the future because of the ability of the system to adjust its output to match the variable power demand of consumers coupled with the fact that the technology can deliver a large capacity of electric power above 100MW using a single system.

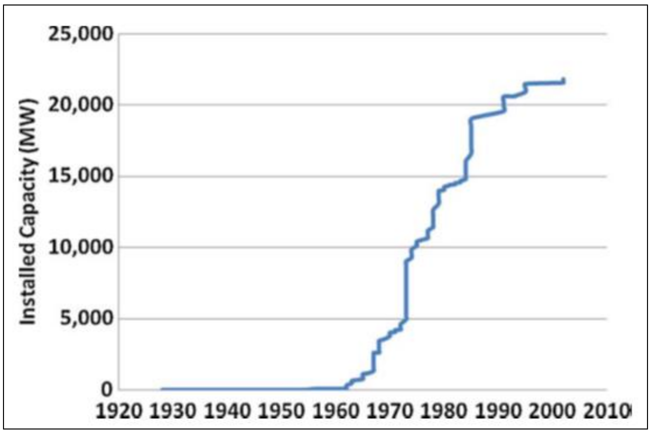

Fig 9: Installed PHES capacity in the United States by date [61]

3.3.2 Weak RE policy and regulatory barriers

Energy policies play a very crucial role by allowing the government to support and mainstream energy development objectives in a country. Nigeria returned to democracy in 1999 after a long period of military rule and began the process of economic development. On this hold, increasing energy generation capacity became paramount to sustain improved socio-economic demand situations. The economic target was clearly defined to be consistence with the National Economic Empowerment and Development Strategy (NEEDS) in addition to the intents of the Millennium Development Goals (MDGs). From that era of time to the present a lot of policy frameworks are still ongoing especially the passage of the National Electric Power Policy (2001), the National Energy Policy (2003), the Renewable Energy Master Plan (2005) and the Electric Power Sector Reform (EPSR) Act (2005) which are all drafted from the 1999 constitution of the Federal Republic of Nigeria. The Nigerian Electricity Regulatory Commission (NERC) was established by Act of law to oversee the activities in the power sector with better private sector participation to ensure effective management of operating licensing in the electricity industry, electricity generation, energy distribution, and tariff settings scenarios. There is an incontestable need to develop a proper policy framework and implementable environment to improve investment in renewable energy development. The policy issues should also cover sensitive areas like pricing and subjects related to tariffs. There is inadequate legislative support for hydropower generation in the country. Also, there exist some sort of restrictions to gaining permission to use water and land due to land ownership constraints coupled with existing traditional norms and indigenous heritage concerning water resources. Therefore, renewable energy policy should point out the basic legal framework for hydropower exploitation in the country.

3.3.3 Crude oil factor

The discovery of crude oil in Nigeria has greatly hampered renewable energy development. The country has a very high reserve of crude oil deposits and despite that, there have been noticeable downward fluctuations in the country's production capacity resulting from recurrent breakdown of the refineries coupled with incessant attacks on crude oil installations based on the socio-political agitations by the militants in the oil-rich region. Judging from the state of affairs in current power expansion programmes of the FGN based on gas supply, there are no nearby solutions to the widespread dominance of interest in oil and gas for power generation in Nigeria over the choice for renewable energy development.

3.3.4 Shortage of manpower and technical barriers

Nigeria currently suffers from a major shortage of indigenous manpower and technical experience required for hydropower infrastructural development. Generally, there are limited numbers of energy and related sector research institutes in the country and such is affecting the quality of industrial technologies in the power sector. There is a significant lack of capacity for manufacturing and maintenance of renewable energy system components in Nigeria. With the absence of such self-sufficient technologies in the country there could increase cost of purchasing parts from foreign countries due to the high cost of shipping thereby adding to the cost of energy produced. There could be more technical challenges because spare parts have to be purchased from abroad and maintenance service involving qualified and competent manpower is to be hired at high cost, especially in remote locations where renewable energy systems are usually located. There is a serious need for research and development guides for more efficient hydropower construction materials, innovative operations and maintenance, environmentally friendly equipment, cheaper equipment, and innovative designs. Some international organizations from developed countries could offer services on technical training, workshops, and collaborative research on hydropower development.

3.3.5 Maintenance of ecological significance of water

By tradition, the uses of renewable energy sources are likely to increase energy efficiency, promote energy use and minimize pollution of different sorts as a step forward towards decreasing greenhouse gas emissions. The ecological status of water is an issue of important concern in hydropower projects. The establishment of a hydropower scheme could degrade the aquatic environment especially the habitat for fish. Fishing migration and aquatic ecosystems are liable to destruction during hydropower installations. The stagnant nature of water in reservoirs could encourage undesirable growth of aquatic weeds and micro-algae which can obstruct the free flow of water. Perhaps, there must be guiding regulatory frameworks to ensure the protection of aquatic life and the ecosystem in general. Though, hydropower generation is one of the renewable energy options which is capable of reducing GHG emissions the project could also cause unconstructive impacts on riverine ecology. Nigeria being a developing country cannot mitigate some likely changes related to riverine ecological destruction.

At the point of planning for a hydropower project, it is crucial to consider landscape factors. In such a situation especially if there is a need for an expansion process, the construction could engulf existing human residences whereas the project cannot be accomplished unless there is a right to use the land and compensate the affected people. Then, settlements destroyed during the construction of the hydropower plant must also be resettled and possibly in a location with better welfare. However, challenges related to ecological composure could be tackled through initiatives of brainstorming agenda relating energy engineers, environmental experts, the scientific community, and representatives from important institutions and non-governmental organizations (NGOs). These stakeholders could come together to address opportunities to help produce comprehensive assessment reports and possible mitigated solutions to biodiversity and nature protection management in hydropower projects.

4. Hybrid renewable energy schemes and SWOT analysis

4.1 Synopsis of the general concept of hybrid electric power

A hybrid electric power system is an implementation of an electricity generation technique involving a combination of different energy systems including renewable and non-renewable but usually suitable for renewable energy sources to achieve optimal output configuration. Hybrid renewable energy systems [62-70] have been studied by diverse energy researchers and outstanding results related to economic sustainability, technical performance, and system adaptability have been established. In the last decade increasing number of literatures continue to emerge regarding hybrid power systems for renewable energy exploitation. A major reason behind such an increasing focus of interest on the system is that most renewable energy sources are subject to intermittent power output. Output power from solar and wind energy systems is not stable because the sources are not produced at will. A second factor lies in the rapid depletion of fossil-based energy and the associated characteristic variation in the price of fossil fuels. It was confirmed by [71-73] that the supply of electricity with diesel-based fuel turns out to be very expensive while hybrid/photovoltaic/wind generation becomes competitive with diesel-only generation. In rural areas where diesel-only power plants have been used to supply the electricity needs of the community, there is usually report of high operating and maintenance costs [74-76] and such development could present a great economic burden on the welfare of the people and may hinder on the continuous use of the plants mainly in most developing countries. More research accomplishments [77-79] have confirmed that hybrid renewable energy systems (HRES) in off-grid applications are economically feasible, especially in isolated rural locations. In consequence, the options of HRES application in many developing countries have become imperative.

4.2 Hydropower in Hybrid Power System

Most rural communities in the country are located close to the site of a watercourse and some of them can produce small-scale hydroelectric power. The priority of the Nigerian government to provide portable drinking water in rural areas is progressively slow which has forced inhabitants of many rural areas to locate their villages close to sources of natural water. Most of the rivers are capable of flowing throughout the year. In some of the rural locations, flowing water can be dammed artificially to hold a considerable quantity by volume of water to sustain their livelihood activities. The water can also be captured to generate a community-based small hydroelectricity. Hydroelectric power generated from such a watercourse can be combined with other power plant(s) to form a hybrid energy system for intermittency control and effective power plant sizing benefits. Figures 10 and 11 present block diagrams for hydropower-based hybrid power systems combine with other sources of energy.

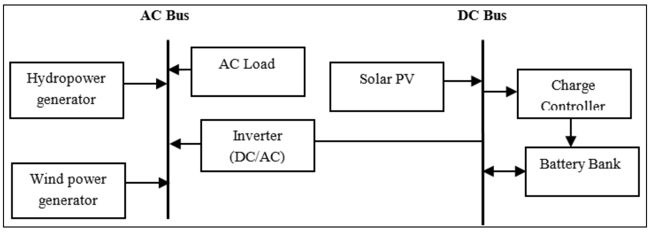

Fig 10: A block diagram of a hydropower-based hybrid power system with other renewable sources incorporating an energy storage system

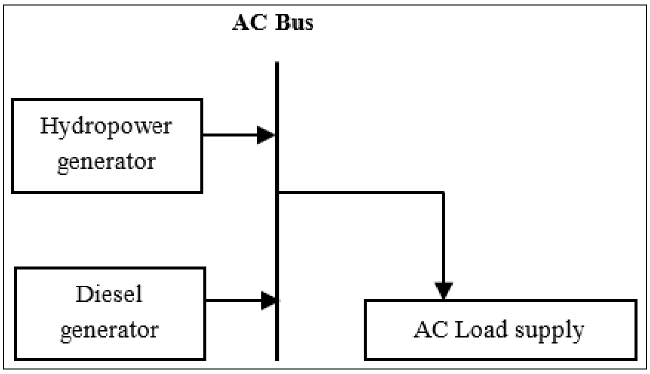

Fig 11: A block diagram of a hydropower-based hybrid power system with a diesel (fossil fuel) generator

Research studies have established the feasibility of using hydropower systems in combination with wind, solar and diesel power plants for hybrid power generation most especially for small-scale grid-connected and off-grid energy applications. It was confirmed in a study conducted by [80] that a hybrid wind/hydropower system can produce low-cost electricity. In another study, a hybrid hydro-PV plant [81] is an electricity generation system based on a hydropower plant and a PV plant working together to satisfy the electricity demand of a collection of consumer loads. Right now, hydropower based on a hybrid electric power system does not exist in the country but the ongoing quest for increased power supply in cost-effective scenarios could favor the development of the system. It could be more viable in the localities where the hybrid source of hydropower combined with other RES is available.

5. SWOT Analysis for Hydropower Development in Nigeria

5.1 SWOT analysis based on large and small-scale hydropower development

The strength, weakness, opportunity and threat (SWOT) approach is a structured planning mechanism that can be applied to a business activity and a project implementation. The technique was first used by Albert Humphery at the Stanford Research Institute (SRI), United States of America. It involves setting up objectives for any activities and making efforts to identify the internal and external factors that could impact the objectives as they are clearly defined. Strength provides the characteristics of the project that make it an advantage thereby allowing it to be implemented with less severe challenges. Weakness is the characteristic subject of the project activities to more disadvantaged situations. The concept of opportunity as used in the sense of SWOT analysis is the basics that the project could utilize to effective beneficiary conditions. Threat defines the factors in the locality of the project environment that could militate against the scheme of implementation of the project. Table 8 highlights a SWOT analysis based on the application of large and small-scale hydropower development while Table 9 presents a SWOT analysis based on the application of small hydro sources for hybrid electricity. Strengths and weaknesses of the uses of hydro sources for power generation culminate in internal factors whereas opportunities and threats observed represent external factors. In summary, the SWOT analysis aims to present fundamental issues that could impact the focus on development.

Table 8: SWOT analysis based on the application of large and small-scale hydropower development

Strengths
• High potential of hydropower source in Nigeria
• Possibility for the investors to use the funding from the Renewable Electricity Trust Fund (RETF)
• Possibility for increasing the energetic independence of the country
• Possibility to reduce air pollutants using large-scale hydropower systems hence creating better ecological conditions
• Significant reduction in the joblessness situation in the country
• Exploitation of foreign capital for renewable energy investment
• Diversification of energy resources in the country
• Promotion of local and regional economic interest
• Existence of a renewable energy master plan (REMP)
Weaknesses
• Lack of equipment manufacturing capacity
• Limited technical experience regarding operation and maintenance
• Low capacity for drafting enabling legislation in a well-timed situation
• Inadequate opportunity for investment in R&D
• Unattractive achievements in the area of RES application for investors in the country
• Limited opportunity for development in many rural communities of the country
• Limited regulatory framework related to renewable energy promotion strategies
• Low levels of R&D capacity in conjunction with weak technical knowledge
Opportunities
• Academic knowledge could boast research and development
• Benefit from emerging electricity generation technologies and innovation capacities
• Existence of public and private sector interest in RE
• Explore support for RE from international agencies and non-governmental organizations (NGOs)
• Benefits from carbon credits in line with Kyoto incentive mechanisms
Threats

• Liable to loss of interest on the account of a fall in the price of fossil fuels
• Hydrological uncertainty could endanger development
• It can be affected by natural hazards
• High initial cost of investment

Table 9: SWOT analysis based on the application of small hydro sources for hybrid electricity

Strengths
• Increase energetic dependency of off-grid rural communities
• Vast growth potential especially in rural communities
• Low capital investment
• Increase demand for low-carbon electricity due to emissions from fossil fuel consumption
• Resources are locally available
• System design is not complex
• Greater economic advantages for end users
Weaknesses
• Lack of finance for development
• Absence of required level of priority for direct development
• Absence of sufficient Government policy support for development
• Limited technical experience regarding operation and maintenance
• Lack of suitable financial incentives for investors
• Lack of equipment manufacturing capacity
• Limited public interest and awareness of the hybrid technology
• Limited energetic potential and constricted opportunity for expansion
• A bit longer time could be wasted on pre-investment agreements and procedures
Opportunities
• High opportunity for the use of energy storage systems like batteries and PHES
• The existence of many small rivers and the availability of other energy sources like solar, wind and diesel
• Public-private partnership for development
• A possibility to enhance new incentive measures for renewable energy development in the country
• Opportunity to take advantage of tax exemption for small-scale energy generation of less than 1MW
• Rising price of fossil-based energy could increase investment in HRES involving hydropower
• Provision of local employment opportunity
• Attract distinctive government support
Threats
• Inadequate management for the flow of information between the investors and government authority
• Tendency for the display of exclusive attitudes by the host community concerning the development
• High cost of generating other renewable sources of energy for hybrid power generation
• Increasing tendency for ecological restrictions
• Change in legal framework
• Restricted innovation and research resources
• Lack of substantial cooperation between energy investors and local community stakeholders

6. Concluding remarks and recommendations

There is a mounting international concern in countries about global warming at the moment. The energy demand of different kinds of societies is increasing very swiftly which is making humanities turn attention to RE applications. Existing energy situations are triggering the development and utilization of different kinds of renewable and sustainable energy resources. The potential for developing hydropower and other renewable sources of energy in the country is vast but much is still needed to be done with reverence to technical knowledge, funding mechanisms, awareness, investment strategies and policy/legislative framework. Since the country is fast growing in population and the socio-economic demand is expected to increase, then, efforts must be unrelenting to match the demand and supply of electricity even in the rural areas of the country. Conclusively, by the objectives of this framework, the following recommendations are observed:

- There should be urgent rehabilitation and sufficient operational improvement of the existing hydropower stations in the country.
- The government should seek ways to establish effective collaboration with international donor agencies like the United Nations Industrial Development Organization (UNIDO), World Bank, and United States Agency for International Development (USAID) for hydropower development in the country.
- The government ought to solicit technical and training assistance from international organizations such as the International Centre for Hydropower (Norway), International Energy Agency (Hydropower Competence Network), International Hydropower Association, and Hangzhou Regional Center for Small Hydropower under the sponsorship of the United Nations Development projects (UNDP).
- Local partnership programmes should be encouraged to allow for private sector participation in hydropower development.
- There should be a provision of capital subsidies to developers to cushion the challenges of high risk related to technical, social, commercial, economic and environmental issues to create extended access to electricity, especially in rural areas through hybrid hydroelectricity-based system implementation.
- There should be a means of encouraging capacity building for small hydropower projects in the country to help local investors utilize small hydro sources for hybrid power development.
- The government should develop hydropower incentive schemes for new power plant construction as a strategic increasing investment approach.

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