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Suitability of Pico-Hydropower Technology For Addressing The Nigerian Energy Crisis – A Review

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Abstract: - The energy crisis is global with various approaches being adopted by various regions of the world to tackle their peculiar situations. In Nigeria, several proposals and/or projections including rural electrification programmes have been made but they have largely remained in the pipeline like they say. The ragged energy mix in the country is literally at the mercy of saboteurs and the inexistent capacity to enforce environmental laws despite all the perceived and realistic global warming effects. The summary of all the approaches to the energy crisis is the development of smaller, smarter, decentralised systems and more efficient utilization of existing ones. These are less expensive, more environmentally benign and concede the control to the end user thereby reducing the exposure to influence of outsiders with whatever motivation. Among these category of energy systems is pico hydro technology. Most of the projections and hydropower activities do not directly consider this technology thereby excluding the majority of Nigerians living in the rural areas. However, an aggressive attention to the technology can contribute to the enhancement of the MDGs as well as Nigeria's vision 20 – 20 – 20 objectives. Farms and small and medium scale enterprises could be offered an ultimately cheaper and cleaner energy option over which they have more control. The adverse effect of the use of other energy sources on the environment and the potential threat of insurgent activitieson the largely centralised energy system will reduce.

Keywords: *Pico hydropower technology, energy crisis, suitability, rural areas, decentralised systems, vision 20-20-20.*

I. INTRODUCTION

The measure of development in any society of today is synonymous with the level of energy consumption. Energy is therefore recognized as a critical input parameter for national economic development [1]. Achieving the United Nations Millennium Development Goals (MDGs) will require significantly expanded access to energy in developing countries. In this scenario, Nigeria's vision 20-20-20 will remain a vision if more deliberate effort is not made to address the energy issue especially in the rural areas where majority of the population live.

Modern day energy demands are still met largely from fossil fuels such as coal, oil and natural gas. In total energy demand, the share of fossil energy is around 80%, while the remaining 20% are supplied by nuclear and renewable energy [2, 3]. However, CO_2 in the atmosphere is increasing as a result of the burning of fossil fuels and over the last few decades, a decline in fossil fuels reserves has been observed world-wide. Also, fossil fuels are not being newly formed at any significant rate, and thus present stocks are ultimately finite. To prevent disastrous global consequences, it would increasingly be impossible to engage in large-scale energy-related activities without insuring their sustainability [4 – 9]. This also applies to developing countries in which there is a perceived priority of energy development and use and electricity generation over their impact on the environment, society, and indeed on the energy resources themselves [10 – 11].

Access to electricity is a prime key to development as it provides light, heat and power for productive uses and communication. A vast majority of the people in developing countries, especially in rural areas, do not have access to electricity [5, 13 – 16]. This number keeps increasing despite the rural electrification programmes because they are not sufficient to cope with the population growth or the political will in some of the places is not strong enough or absent [17]. Moreover, despite the fact that about 80% of the world's population lives in developing countries, they consume only about 20% of the global commercial energy [18, 19]. According to the World Bank, most of the world's poor people spend more than 12% of their total income on energy, which is more than four times what a middle-income family in the developed world spends [20, 21].

A recent study on access to energy and consumption patterns among Nigerian households indicated that about 40% had access to the national grid with more than 45% not having access to any form of electricity. More than 6% have supported their access to the grid with self-diesel generators and more than 3% completely relied on self-generator. Also, about 1.1% of households have access to the rural electrification programmes while more than three-quarters of Nigerians still depend on firewood as their cooking fuel with about 20% relying on kerosene. This is not surprising given the low access to the modern form of energy (electricity) and low reliability of electricity services in Nigeria. These findings show the urgent need for efforts for further developments of the overall Nigerian electricity sector as well as rural electrification programmes to ensure rapid economic development [22, 23].

Electricity brings many benefits but its generation has also caused massive environmental and social problems. There is a need to revolutionize the way energy is produced and used to reduce these impacts while providing energy services to the billions of people who have inadequate or no access to electricity [8, 24 – 26]. Population growth makes the challenge even harder. The energy revolution will require moving from electricity systems based on large-scale fossil fuels, large hydro and nuclear fission plants to the ones based on new renewable sources and massive improvements in the efficiency of production, transportation, storage and use energy. Some research and development sectors visualize that power systems of the coming decades could consist of autonomous self-supplying energy systems with a high penetration of renewable sources [2, 4, 5, 27 – 34]. Generally, some researches are focussed on decentralised and hybrid energy systems. Many PV-hybrid systems have been proposed in the past for electrification of remote areas or grid connected sites, but the vast majority had been based on PV-diesel or PV-wind systems. Many tools are also available for sizing and simulation of PV-hybrid systems. However, fewer include hydro resources. More recent approaches have adopted the PV-hybrid system including a hydro resource from an equatorial area [32, 35, 36].

The liberalization of the electricity market and environmental issues such as the consequences of the continued release of huge amounts of greenhouse gases on the environment, caused by the combustion of fossil fuel, gives the impetus for the development and implementation of such systems [5, 24, 37 – 42]. Environmental concerns have continued to drive the search for cleaner technologies as well as higher energy conversion efficiencies [43 – 45]. Besides, fossil fuel reserves tend towards exhaustion in the near future not to mention the volatile nature of the oil industry as shown by youth restiveness in the Niger Delta in Nigeria and the instabilities in the Gulf region [46, 47]. Within this scenario, renewable energies must be used as a key tool in the contribution towards sustainable development in the less developed regions of the world [4, 48 – 50]. Furthermore, the substitution of conventional sources of energy such as traditional biomass for cooking, diesel and petrol generators, kerosene lamps and biomass stoves with renewable energies like small hydro power (SHP) can help decrease CO_2 emissions thereby contributing to climate change mitigation. It will also contribute to poverty alleviation and economic development by supplying electricity needs for lighting, water pumping and operating small workshops [24, 51].

II. HYDROPOWER

Of all the renewable sources of energy, water is the better choice because a small-scale hydropower is one of the most cost-effective and reliable energy technologies to be considered for providing clean electricity generation. Hydro power is a renewable, economic, non - polluting and environmentally benign source of energy. Hydro power stations have inherent ability for instantaneous starting, stopping, load variations etc, and help in improving reliability of power system [4, 5, 52, 53]. Hydro stations are the best choice for meeting the peak demand. The generation cost is not only inflation free but reduces with time. Hydroelectric projects have long useful life extending over 50 years and help in conserving scarce fossil fuels. They also help in opening of avenues for development of remote and backward areas [29, 30, 54 – 60].

Hydropower throughout the world provides around 17% of electricity from the currently installed capacity as well as the ones under construction, making it by far the most important renewable energy for electrical power production. It has been predicted that hydropower production is set to increase threefold over the next century [27, 57 – 59, 61, 62]. According to a recent publication of Focus on Renewable Energy, hydropower remains the renewable source of energy that contributes most to electricity generation. It puts the total global installed capacity at the end of 2010 at around 1,031 GW, with around 39 GW of new capacity being installed in 2010. The total estimated annual power generation from hydropower (as of the end of 2010) amounted to some 3,618 TWh/y [57 – 59, 63, 64].

The hydropower potential of Nigeria is very high and hydropower currently accounts for about 29% of the total electrical power supply. The first hydropower supply station in Nigeria is at Kainji on the River Niger where the installed capacity is 836MW with provisions for expansion to 1156 MW. A second hydropower station on the Niger is at Jebba with an installed capacity of 540 MW. It has been estimated since the 1990s that for Rivers Kaduna, Benue and Cross River (at Shiroro, Makurdi and Ikom, respectively) the total capacity stands at about 4,650 MW. Only the Shiroro site has been exploited till date. Estimates for the rivers on the Mambila Plateau are put at 2,330MW. The overall hydropower resource potentially exploitable in Nigeria is in excess of 11,000MW [65]. The foregoing assessment is for large hydro schemes which have predominantly been the class of schemes in use prior to the oil crisis of 1973 [66, 67].

Hydroelectric power plants despite having many advantages over other energy sources, has potential environmental impacts that are negative [68, 69]. Since it depends on the hydrological cycle, hydropower is not a reliable source of energy [70, 71]. Also, global climate change will increase rainfall variability and unpredictability, making hydropower production more undependable. Increased flooding due to global warming also poses a major hazard to the safety of dams [72]. In addition, all reservoirs lose storage capacity to sedimentation which can in many cases seriously diminish the capacity of dams to generate power. Hydropower projects alter the habitats of aquatic organisms and affected them directly [62, 73 – 78]. Several millions of people have been forcibly evicted from their homes to make way for dams losing their land, livelihoods and access to natural resources and enduring irreparable harm to their cultures and communities [79 – 84]. Further, growing evidence suggests that reservoirs emit significant quantities of greenhouse gases especially in the lowland tropics [30, 69, 85]. Also, there is growing evidence that hydropower is often falsely promoted as cheap and reliable, are prone to cost overruns and often do not produce as much power as predicted [86]. The foregoing demerits are more directly applicable to large hydropower schemes.

Future plans for new hydroelectric plants, however, will need to consider three major factors. Private capital may not favour hydropower, since such facilities do not have short repayment periods and high returns. Such investments are best suited for public investment, which have to compete for other social services [87, 88]. Secondly, there is growing evidence that hydroelectric plants based on large dams are not environmentally neutral. Thirdly, potential declining river flows due to climate change impacts may lead to declining hydropower production, which in turn, will have an impact on the financial viability of such schemes. Large hydro schemes in several developing countries could play a major role in providing an alternative electricity source [72, 79, 89 – 94].

Small and Micro Hydropower Schemes

There is a strong case for small hydropower (SHP) systems as means of more effectively supplying energy. SHP is a renewable energy source and is suitable for rural electrification in developing countries. The contribution of SHP to the worldwide electrical capacity is more of a similar scale to the other renewable energy sources with about 53% of this capacity in developing countries. The technology is proven and it can be connected to the main grid, used as a stand-alone option or combined with irrigation systems and can adequately contribute to the electricity needs of the developing world. SHP is in most cases 'run-of-river'. Figure 1 shows a run of river scheme. This means that any dam or barrage used is quite small, usually just a weir, and little or no water is stored. Small and mini hydro projects have the potential to provide energy in remote and hilly areas where extension of grid system is un-economical. These projects are economically viable, environmentally benign and need a relatively short time for implementation [65, 95 – 97]. Overall, SHP can contribute to achieving the MDGs as far as certain key conditions are seriously considered in SHP electrification in developing countries. It has been strongly advocated in Nigeria that since small-scale hydropower systems possesses obvious advantages over large hydro systems and that problems of topography are not excessive; they can be set up in all parts of the country so that the potential energy in the large network of rivers can be tapped and converted to electrical energy. In this way the nation's rural electrification projects can be greatly enhanced [65].

There have been growing interests in research and development into pico-hydro systems especially in Asian countries. This could have largely been as a result of the need to diversify from fossil fuels such as coal, the necessity of off-grid options for better access to rural communities and the natural obstacle which the topography imposes against large scale developments. Implementation is highly advanced leading to significant commercial activities [17, 35, 89, 60, 96 – 107]. At the recent International Hydropower Association (IHA) World Congress tagged IHA 2011 which played host to around 500 delegates from 71 countries, discussions were intensive and included many different perspectives, from personal experiences that highlighted the needs of indigenous people, to the requirements of power intensive industries. Priorities focused on the need for strategic approaches, and a broader engagement when it comes to energy and water planning. There is also growing interest in the use of pumps as turbines (PATs). This basically involves the use of centrifugal pumps working in the reverse mode [108 – 117]. More attention is also currently being given to the pumped-storage hydropower system to supply high peak demands by moving water between reservoirs at different elevations [118, 119].

Small-scale hydropower is a robust and comparatively environmentally benign power generation technology [55, 98, 120 – 125]. However, on this scale, many schemes incur disproportionately high capital costs per installed unit of power. Generally, small hydropower systems may be classified into mini-, micro- and pico-hydro technologies. Micro- and pico-hydro technologies are used in developing countries to provide electricity to isolated communities where the electricity grid is not available, whereas mini-hydro tends to be grid connected. In most cases, no dam or reservoir storage is involved in pico-, micro- and mini-hydro schemes. Micro- and pico-hydro can also differ from mini-hydro in a number of ways. In the first two cases, scheme design can be approached on a per household basis or at village level often involving local materials and labour whereas mini-hydro schemes require traditional engineering approaches [36, 97, 106, 120, 122, 124, 126 - 132]. Also, mini-hydro schemes will usually require an access road to be built for construction materials and heavy electro-mechanical equipment to be delivered to the site, whereas most micro-hydro schemes can be built with purely manual labour in more remote locations. Another crucial difference is in terms of load control. Since the electricity from micro- and pico-hydro schemes can be supplied directly to households, there is no large grid to control the frequency and voltage of the supply, hence only a local load controller is necessary [133]. For pico-hydro, the turbine/generator set can be bought as a modular, off-the-shelf unit, unlike the equipment for larger schemes (micro-hydro and upwards) where the specific requirements are taken into consideration in the design/selection of the turbine/generator [99,120, 131, 134 – 140].

Where it is not feasible to extend the main grid to remote rural communities, the decentralized generation of hydroelectricity can contribute significantly to improving the economic conditions of isolated populations. Several renewable energytechnologies, such as micro- and mini hydropower plants, may provide cost-effective energy alternatives to grid extension or isolated diesel mini-grids in rural areas.The building of small-scale hydro is generally not regretted when the grid finally reaches the remote area and it does not become obsolete. It will simply be integrated to the central grid. In fact, the most fundamental influences on the total costs and benefits of hydropower projects are the site-specific conditions, and not the scale of the project [35, 36, 97, 98, 106, 126, 127, 130, 132, 137, 141 – 145].

Actualizing the comparative advantage of the small-scale hydro has already resulted in the thousands of small dams encountered all over the world. Small hydro installations are widespread in Asia, where there is a significant resource potential for further development [138 – 140, 144, 146 – 152]. The installed small hydropower capacity in Vietnam is 61.4 MW, with an estimated potential of about 1,800 MW. Some 3,000 sites have been identified for micro hydro installations in the range. These sites will serve irrigation and drainage needs, in addition to generating electricity for 2 million households. Many areas in Vietnam do not have access to the electricity grid, due to the high extension costs. In these areas, micro hydro units are used by individual families for lighting and battery charging for future use. It is estimated that more than 3,000 family units of 1 kW or less are installed in Vietnam. Other Asian countries with micro-hydro resources include Laos, Bangladesh, The Philippines, Papua New Guinea and Indonesia. In 1998, the Indonesian Government announced its intention to electrify 18,600 villages using small and micro-hydro schemes [97, 98, 147, 153]. There are also projects in Africa. The Republic of Guinea has identified 150 mini- and micro-hydro sites; Nigeria plans to develop 700 MW of capacity in 236 different projects [65, 67]. In parts of Africa such as in Malawi, Ethiopia, Tanzania or Uganda, topographical and hydrological conditions would also allow the implementation of small or medium-sized hydropower plants [150, 154].

Small river sections with geological stability, no vulnerable species, a high head within a short horizontal distance and where there is strong support for development from the local population represent regions with good candidate sites for technically, environmentally and economically sound hydropower development. The proportion of small sites that combine all of those qualities is quite small and, individually, each of the few chosen sites will not produce much electricity. But the number of candidate sites is enormous. The advantage lost in terms of economies of scale is partially compensated by the great number of prospective sites. The small hydro option depends for its success on competence in the wise choice of the best sites. However, favouring or funding small projects simply on the basis of their scale would be a pitfall because all factors need to be added into the equation [121, 131, 151, 155]. Furthermore, in developing countries, there might be institutional constraints as well as a lack of experts to undertake the required studies for several hundred small projects, whereas one large scheme might be easier to handle from an institutional point of view [35, 149, 154, 156,157].

A small hydro generating station can be described under two main headings which are civil works, and electrical and mechanical equipment. The main civil works of a small hydro development are the diversion dam or weir, the water passages and the powerhouse. The diversion dam or weir directs the water into a canal, tunnel, penstock or turbine inlet. The water then passes through the turbine, spinning it with enough force to create electricity in a generator. The water then flows back into the river via a tailrace. Generally, small hydro projects built for application at an isolated area are run-of-river developments, meaning that water is not stored in a reservoir and is used only as it is available. The cost of large water storage dams cannot normally be justified for small waterpower projects and consequently, a low dam or diversion weir of the simplest construction is normally used. Construction can be of concrete, wood, masonry or a combination of these materials. Considerable effort continues to be spent to lower the cost of dams and weirs for small hydro projects, as the cost of this item alone frequently renders a project not financially viable [138, 143, 148, 157 - 159].

The powerhouse contains the turbine or turbines and most of the mechanical and electrical equipment. Small hydro powerhouses are generally kept to the minimum size possible while still providing adequate foundation strength, access for maintenance, and safety. Construction is of concrete and other local building materials. Simplicity in design, with an emphasis on practical, easily constructed civil structures is of prime concern for a small hydro project in order to keep costs at a minimum [28, 135, 143, 158].

The primary electrical and mechanical components of a small hydro plant are the turbine(s) and generator(s). A number of different types of turbines have been designed to cover the broad range of hydropower site conditions found around the world. Turbines used for small hydro applications are scaled-down versions of turbines used in conventional large hydro developments. Turbines used for low to medium head applications are usually of the reaction type propeller turbines. Impulse turbines include the Pelton, Turgo and crossflow designs. Small hydro turbines can attain efficiencies of about 90%. Care must be given to selecting the preferred turbine design for each application as some turbines only operate efficiently over a limited flow range. For most run-of-river small hydro sites where flows vary considerably, turbines that operate efficiently over a wide flow range are usually preferred. Alternatively, multiple turbines that operate within limited flow ranges can be used. There are two basic types of generators used in small hydro plants - synchronous or induction (asynchronous). Induction generators with capacities less than about 500 kW are generally best suited for small hydro plants providing energy to a large existing electricity grid [96, 141, 142,147, 151, 159].

The canal-based SHP scheme is one which is planned to generate power by utilizing the fall and flow in the canal. These schemes may be planned in the canal itself or in the bye-pass channel. These SHP sites are divided into three categories by head as low head (3 – 20m), medium head (20 – 60m) or high head (more than 60m) with each category requiring different designs. A large number of sites identified for small hydro development normally in irrigation works are in the low-head category. These suggested limits are not rigid but are merely a means of categorizing the sites. Low-head SHP plants can be located close to end users and provide electricity reliably and cost effectively by achieving higher conversion efficiency and avoiding transmission and distributions losses [57, 141, 155, 160].

A hydropower system using a siphonic ductwork configuration enables installation of the turbine across an existing impound structure, such as a weir, bypassing the requirement for a breach of the structure. This is an innovation which could reduce the complexity of the civil works, which often account for a major proportion of capital costs of other forms of turbine installation. An advantage over more integrated technologies is that a comparatively small, replaceable, high-tech generation unit is combined with a comparatively large, low-tech and locally serviceable civil works component [96, 158, 161]. Whilst a number of tethered drop in, open-flow concepts have been proposed, a system that constrains the flow can be preferable due to the increased power density and efficiency [162]. Therefore this specific installation arrangement has widespread potential. In England and Wales, the Environment Agency has identified nearly 26,000 existing impoundment structures or 'barriers' as providing an opportunity for hydropower development [163]. With national governments introducing so-called feed-in tariff schemes to encourage micro generation like that implemented by the UK government in April 2010 [164], the siphon turbine could satisfy an increasing demand for hydropower systems that are straightforward to install.

Several authors have opined that small-scale hydro installations in rural areas of developing countries can offer considerable financial benefits to the communities served, particularly where careful planning identifies income-generating uses for the power. The major cost of a scheme is for site preparation and the capital cost of equipment. In general, unit cost decreases with a larger plant and with high heads of water. It could be argued that small-scale hydro technology does not bring with it the advantages of economy of scale, but many costs normally associated with larger hydro schemes are avoided in micro hydro systems to bring the unit cost in line with bigger schemes [123, 153, 156,165].

The development of small hydro projects typically takes from 2 to 5 years to complete, from conception to final commissioning. This time is required to undertake studies and design work, to receive the necessary approvals and to construct the project [60, 120, 129]. Once constructed, small hydro plants require little maintenance over their useful life, which can be well over 50 years. The technical and financial viability of each potential small hydro project are very site specific [155, 160, 165, 167,168]. Power output depends on the available water (flow) and head (drop in elevation). The amount of energy that can be generated depends on the quantity of water available and the variability of flow throughout the year. The economics of a site depends on the power (capacity) and the energy that a project can produce, whether or not the energy can be sold, and the price paid for the energy. In an isolated area the value of energy generated for consumption is generally significantly more than for systems that are connected to a central-grid. However, isolated areas may not be able to use all the available energy from the small hydro plant and, may be unable to use the energy when it is available because of seasonal variations in water flow and energy consumption [65, 95, 96, 153, 170].

A conservative rule-of-thumb relationship among others is that power for a hydro project is equal to seven times the product of the flow (Q) and gross head (H) at the site ($P = 7QH$). The hydro turbine size depends primarily on the flow of water it has to accommodate. Thus, the generating equipment for higher-head, lower-flow installations is generally less expensive than for lower-head, higher-flow plants. The same cannot necessarily be said for the civil works components of a project which are related much more to the local topography and physical nature of a site [65, 96, 139].

Practical Action, an arm of the Schumacher Centre for Technology and Development in the United Kingdom, outlined some innovations intended for better utilisation of the potentials of small hydro [60, 96, 97, 135].

The environmental impacts that can be associated with small hydro developments can vary significantly depending on the location and configuration of the project. The effects on the environment of developing a run-of-river small hydro plant at an existing dam are generally minor and similar to those related to the expansion of an existing facility. Development of a run-of-river small hydro plant at an undeveloped site can pose additional environmental impacts. A small dam or diversion weir is usually required. The most economical development scheme might involve flooding some rapids upstream of the new small dam or weir [168, 169, 171, 172].

There is enormous exploitable hydropower potential on the African continent, but despite this, Africa has one of the lowest hydropower utilisation rates. Currently, less than 7 % of the potential has been harnessed. Eastern, southern, central and parts of Western Africa have many permanent rivers and streams providing excellent opportunities for hydropower development. While large-scale hydropower development is becoming a challenge due to environmental and socio-economic concerns, and more recently its vulnerability to changing climates, small hydropower development continues to be an attractive resource, especially in remote parts of Africa. It is a proven technology that can be connected to the main grid, isolated grids or as a stand-alone option, or combined with irrigation systems. Small hydro can adequately contribute to the electricity needs of African countries [66, 156, 167, 173 – 175].

The challenges facing small hydropower exploitation are many and most of them are part of the larger picture of general barriers for the uptake of renewable energy and independent power producers. These generic barriers can be summarised into the lack of clear-cut policies on renewable energy and associated requisite budgetary allocations to create an enabling environment for mobilising resources and encouraging private sector investment, and the absence of lost-cost, long-term financing models to provide renewables to customers at affordable prices while ensuring that the industry remains sustainable [173, 175].

Large scale implementation of small hydro in Africa is hindered by lack of access to appropriate technologies in the mini, micro and pico hydro categories, lack of infrastructure for manufacturing, installation and operation and lack of local capacity to design and develop small hydropower schemes for areas sometimes considered too remote66, 176].According to [175], several initiatives are on-going to help developing small hydropower in Africa. Both UNDP and UNEP are active in support programmes to remove barriers to the harnessing of the large small hydro potential, small hydro support centres are established or in the process of being established in a number of countries and a number of national rural electrification programs do include electricity generation by small hydro [67, 156, 173, 176].

The United Nations Environment Programme (UNEP) is implementing a Global Environment Facility (GEF) funded project that looks at the possibilities of applying small hydro at tea estates to generate electricity in the Eastern Africa region. Starting from the premises that tea does need altitude and water to grow, which are requirements for hydropower as well, a collaboration of the East African Tea Trade Association (EATTA), UNEP and the GEF is currently looking in setting up a facility to accelerate the uptake of hydropower [156, 173, 174, 176]. First indications show huge interest by the tea estates due to the current unreliable power supply from the national electricity grids. The project aims to establish 6 small hydro power demonstration projects in at least three of the EATTA member countries, preferably with an attached rural electrification component, as well as to prepare additional pre-feasibility studies. Both studies and planned installations will serve as training grounds for the entire tea sector in the region. The project includes a special financing window to assist individual tea processing plants to move into “green power generation”.

In West Africa, the UN Development Programme (UNDP) is implementing a GEF project that will promote decentralise off-grid rural electrification in 10 countries in Africa with micro hydropower systems as a key element in creating viable rural economies. For each of the participating countries, the project intends to strengthen the institutional, regulatory and operational capacities of key agencies to provide decentralised micro hydro-based electricity access to remote rural areas and it will deploy 36 hydro plants in rural areas. The lessons learned at national level will be shared among the 10 participating countries in order to effectively develop viable delivery models [174, 175].

United Nations Industrial Development Organization (UNIDO)’s rural energy initiative through renewable energy is designed to help achieve the Millennium Development Goals. UNIDO has established institutions that help promote small hydro power projects and provide training and capacity building in developing countries in regard of its main objectives. UNIDO’s renewable energy for rural ICTand telecom aims at bridging the digital divide in rural areas to improve information dissemination, economic and SME opportunities, good governance (increased transparency), education (distance learning), health (especially for women and children), environment, tourism (create and enhance income), rural connectivity for better communications, agricultural productivity, and early warning system for natural disasters.To create more capacity for small hydro development in Africa a number of initiatives to create knowledge and training centres are currently under way, with the inauguration of the UNIDO Regional Centre for Small Hydro Power for ECOWAS Region at Abuja, Nigeria on 22 May 2006 as a key achievement. Very encouraging is the fact that several countries have included small hydro in their rural electrification plans that are currently implemented with international assistance from bi- and multilateral donors. Tanzania and Ethiopia for example have included small hydro in their rural development plans, while in Madagascar the E7 foundation in collaboration with others is currently developing the Lokoho small hydro plant with mini grid that will be run as an IPP [65, 175].

Small hydro has proven itself as a major contributor to electrification in developing countries, with China as an example where small hydro has been developed in large parts of the country [65, 123]. The interest in small hydro on the African continent as emerged over the last couple of years has resulted in a number of projects that will pave the way for large scale introduction of small hydro. The current interest by African Governments, international donors, development banks and the private sector in increasing energy access in Africa will facilitate the uptake of this robust, environmentally friendly form of energy. The challenge now is to maintain the momentum created and ensure that the current interest will be translated into more small hydro plants installed [65 – 67, 174, 175].

As earlier mentioned, SHP can contribute to achieving the MDGs as far as certain key conditions such as the following are seriously considered in SHP electrification in developing countries:

(i) The creation of national institutional, legal and financial frameworks for rural electrification,
(ii) Identification of target areas and definition of SHP electrification programmes,
(iii) Strengthening of local technical capacities,
(iv) Establishment of higher level of expertise in the local agencies of funding institutions,
(v) Expansion of support for local networking between stakeholders such as rural developers, bankers, institutional and private sectors, etc., and
(vi) Development of tools for local private sector development [65, 123, 156, 160, 165, 176].

Pico hydropower Schemes

Pico hydro schemes (< 5 kW) are recognized as viable options to electrify remote areas, considering economic, environmental, and social perspectives. They have been successfully implemented in remote regions in the world. It is useful in small, remote communities that require only a small amount of electricity. Pico-hydro setups typically are run-of-stream, meaning that dams are not used, but rather pipes divert some of the flow, drop this down a gradient, and through the turbine before being exhausted back to the stream. Like other hydroelectric and renewable source power generation, pollution and consumption of fossil fuels is reduced but there is still typically an environmental cost to the manufacture of the generator and distribution methods [167, 177 – 183]. Their common objective is to provide a cost effective and simplified alternative to supply electricity to areas that are relatively far from the electrical grid [184]. Normally, pico-hydro power systems are found in rural or hilly areas [103, 182, 185 – 189]. The types of turbines and generators vary depending on the local conditions, budget, and equipment availability [190].

Seasonally fluctuating water levels can also inhibit pico-hydro units from being used all year around in some areas. The units do not generate power when there is too little water in the dry season and are in danger of being swept away in the rainy season. Typical usage varies from eight or nine months to all year around and varies annually as well [103, 104, 191].

For high water head (H > 30 m) areas, a common approach is to locally manufacture Pelton turbines [180, 189]. For low head sites (< 2–3 m), run - off - the - river schemes include the mass-produced Pico-hydro propeller (PHP) turbine coupled to a synchronous permanent magnet generator [186]. These PHP units are found in markets and hardware stores and their capacity ranges from 0.2 kW to 3 kW [192].

Very small hydro plants do not suffer from such environmental and social problems as larger ones generally due to the scale of the technology the insignificant storage of water. Normally these schemes do not form a barrier to the passage of aquatic life, especially fish. Mini, micro and pico hydropower are now recognized as key technologies in bringing renewable electricity to rural populations in developing countries, many of whom do not have access to electric power [36, 103, 104, 167, 185]. A recent report on electrification technologies by the World Bank Energy Unit shows that, of the options currently available for off-grid generation, pico hydro is likely to have the lowest cost. For mini-grid power, probably only biogas plants provide more cost-effective electricity than micro hydro [21]. These figures agree with those of [180], who calculated scheme costs in rural Kenya of US 15¢/kWh for 1–2 kW pico hydro against US $1.09 for a nominal 20 Wh solar home system. The costs for PV systems have fallen in the meantime, and should continue to reduce, but are still likely to be 3–4 times greater than the costs for pico hydro. However, pico hydro is not an easy technology to transfer and disseminate in rural areas because it is site specific and often requires co-operation within a community in order to manage the scheme successfully [194].

Pico and micro hydro power systems are cheaper and simpler because of different approaches in the design, planning and installation than those which are applied to larger systems. Recent innovations in the technology of these systems have made them to become an economic source of power even in some of the world's poorest countries and most in accessible places [185, 194, 195]. Besides providing power for domestic lighting and cooking needs, village hydro schemes can also be used for charging batteries or income generating activities like grain milling. Globally, there exists a very substantial market in the developing countries for these systems. One of the reasons is that despite the high demand for electrification, grid connection of small communities even in countries with extensive grid electrification remains unattractive to utilities due to the relatively low power consumption [103, 104, 106, 192]. Other reasons may include

(i) Only small water flow is required,
(ii) The equipment is small and compact, and hence can be easily transported to remote and inaccessible places,
(iii) Local manufacture is possible because the design principles and fabrication processes are easily learned,
(iv) Carefully designed systems have lower cost per kilowatt than solar or wind, and though diesel/petrol systems are initially cheaper than pico - hydro schemes, they have a higher cost per kilowatt over their lifetime,
(v) Since it is non-consumptive in nature, the water can be available for other such uses as small scale irrigation and possibly water supply, and
(vi) Hydro systems provide constant energy during times of normal rainfall[49, 177, 192, 194 – 196].

[180] compared pico hydro systems to solar photovoltaic systems in Kenya and determined that the former was more cost effective on a per-household basis with a 15% lower cost per kWh. With lower material costs and careful consideration of distribution and power management, pico hydro was found to be affordable for most low-income households. These findings were consistent with average annual costs in Vietnam [197] and Laos [191]. Capital costs for renewable energy systems, including pico hydro, tend to be higher than conventional fuel systems. [145] reviewed 16 micro hydro projects (micro hydro systems yield comparable per unit capital costs to pico hydro systems) in Sri Lanka, Nepal, Peru, Zimbabwe, and Mozambique and found capital costs per kW capacity of micro hydro electrical generation schemes to be significantly higher than previously predicted in literature due to the incorrect evaluation of non-monetary input costs such as 'sweat equity' or community labour. Despite the higher capital costs they still concluded that investment in pico hydro can be recovered and be profitable. Moreover, the economic success of hydroelectric projects is greatly dependent on a high load factor. Therefore, innovative means to better utilize the generation equipment must be incorporated to improve the economic viability. Unlike large scale hydropower, there is low environmental impact with pico hydro systems, mainly due to the exclusion of large water containment. Associated large civil works, flooding of habitats and the modification of downstream flow are not required for the operation of pico hydro systems. In addition, negative impacts of large reservoirs such as siltation, increased mercury levels, and off-gassing of greenhouse gases from submerged decomposing organic material are avoided [198].

[199] conducted a life cycle analysis comparing a 3 kW pico hydro system, a diesel generator, and grid extension and connection for a rural village in Thailand. Measured impact categories included global warming potential, acidification potential, depletion of non-living resources, and energy demand, amongst others. The analysis found that pico hydro had the lowest impact, by a significant margin, in all categories. The largest impact contributors for the pico hydro system were transmission lines, distribution, and the penstock.

Pico hydro has positive social impacts. There is a greater potential for active participation of the beneficiaries and the associated social benefits from rural electrification using pico hydro than with other technologies. In addition, since large damming is unnecessary, the displacement of inhabitants and restructuring of livelihoods are avoided.Disadvantages of pico hydro systems include the site specific nature of installations, high capita costs as barriers for adoption, and little or no support from government institutions [191]. In addition, as with any technology, capacity training and proper management of the systems is required. This has been lacking in numerous incidences and has led to the failure of systems and the wasting of limited resources.

Micro and pico hydropower are unlikely to undergo significant further development from a technological point of view [104, 106, 194]. Along with other small-scale renewable energy, a major effort is now required to disseminate successful technology for use in rural electrification. There have been a number of demonstration projects, but so far there has been a lack of widespread commercial dissemination of these technologies. A recent report by [200] discusses ways to unlock the potential of renewable energy technologies as a means to alleviate rural poverty. It identifies a lack of awareness as a key issue. Due to this, national policy framework s are not effective in supporting rural energy, there is a lack of financial mechanisms to support local projects, a lack of technical expertise and hence, particularly for solar, some poor quality installations are being done [104].

Several micro and pico hydro case studies in Nepal and Kenya are discussed by [201] in the context of expanding access to modern energy services. They identify this technology as having good potential because of relatively low capital costs and flexible power production for electrical and/or mechanical equipment. The design of these schemes is based on the Pico Power Pack and pump as a turbine technology, demonstrating reliable energy production over a number of years. The need for involvement of local non-government organizations (NGOs) and the need for good management of schemes at a local level were stressed, echoing the works of [202] and [203].

[203] researched the factors that lead to the success or failure of rural electrification schemes. Data was collected from 14 villages in Peru, a country with one of the lowest rural electrification coefficients in the continent. The sample was spread throughout the country, half with diesel generators and half with micro-hydro plants. The questionnaires and technical data collected for each village were designed to identify possible ‘‘Critical Factors’’ for the success of such schemes. Questions were designed to collect key data to assess the influence of different factors. The results corroborate the World Bank findings, that diesel schemes often run for only short times during the evening because of the high cost of fuel. This limits the potential for the electricity to contribute to income generating activities. Overall, the research in Peru revealed that the management of the scheme is the most critical factor on which successful finance, operation and maintenance of the schemes depend. Apart from management, the only other factors that were identified as critical were local and national technical capacity. Local capability is required for the day-to-day maintenance of the scheme, whereas some national capacity is required for installation, training and technical support for scheme repairs.Alongside this research, a management model has been developed, based on experience at several villages in Peru [202]. This model promotes the community ownership of the scheme, whilst a privately-owned company, run by entrepreneurs from within the community, carries out the day-to-day management.

However, experience in Kenya suggests that there needs to be more co-operations between national NGOs and local entrepreneurs, for example in passing on from the districts where the entrepreneurs are active. Nevertheless, community pico hydro schemes are now being constructed as commercial projects, not just as demonstrations [104, 180 – 182].

Although the technology is almost identical between projects in different countries, the approach to dissemination and management of the technology often needs to be adapted to the needs of the particular country. According to [204], the special needs of the Pacific Island Communities mean that the expansion of renewable energy through private enterprise is not appropriate. Certainly, the programmes promoted by the Village First Enterprise Group, which have a focus of promoting women’s empowerment, have been successful within this context.

Expansion of micro-hydro programmes is planned in Uganda, in Indonesia and across the francophone countries of Sub-Saharan Africa, following successful demonstrations in Madagascar. Even countries with good grid coverage such as peninsular Malaysia, have discovered the potential of micro hydro to meet the energy requirements of remote rural communities [194].

[190] presented a proposal of a system which will operate using upper water reservoir which is a few meters high from ground. From the reservoir, water flows downhill through the piping system. The head developed in this way allows the water to accelerate for prime moving the system. The main function of the system is to store the generated power by means of battery charging for future use particularly during electricity blackouts. The proposed system was expected to have a maximum capacity of 10W which is very much less compared to other pico-hydro power systems.

[205] designed, fabricated, and tested a cross-flow turbine for a low head site in Malaysia. The scheme produced 100 W while operating with a head of 1.2 m and flow rate of 20 l/s with the aid of a gear transmission (12:108) to link the turbine and generator. The cylindrical dimensions of the cross-flow turbine were 450 mm diameter and 300 mm length.

[206] devised and applied a qualitative and quantitative selection criteria approach and determined that a single jet turgo turbine would be the most suitable technology for 1.3 kW power generation with a 3.5 m operating head, 304 rpm running speed, and 435 mm diameter wheel. Optimization of the design before field testing and grid connection is underway.

Presently there are numerous pico hydro propeller turbine manufacturers mainly in China, Vietnam, and Indonesia. Costs have been cited to be very low for these systems but they are considered to be unreliable and inefficient. The development of these units has helped advance rural electrification in Southeast Asian countries where they have been extremely popular [206]. [191] estimated nearly 60,000 low-head pico-hydropower units have been installed in Laos, and up to 130,000 units in Vietnam, where there is a relatively higher electrification rate. Asian Phoenix Resources Ltd. (APRL), situated in Vietnam and Canada, sells a range of pico hydro systems. The nominal generating capacity of the propeller turbines are 200 W, 500 W, and 1 kW with efficiencies ranging from 38.8% to 52.3%.

A 5 kW low head propeller turbine with an overall efficiency of 67%, designed to operate at 850rpm with 5m head, was developed at the Department of Civil Engineering at the Indian Institute of Science in Bangalore. The propeller consisted of 8 helical blades of constant thickness. Disadvantages of this design included low speeds, the difficulty of manufacturing a complex helical blade shape, and non-standard dimensions The Mechanical Engineering Department of the Papua New Guinea University of Technology developed a prototype propeller turbine. Eight constant thickness blades were machined using computer numerically controlled machinery. The turbine power output was 200 W at 200 rpm with 1.5 m head and 0.06 m^3/s flow rate. The system coupled the propeller shaft to a generator-gear box assembly. The Department of Mechanical Engineering of the University of Canterbury developed a propeller turbine with a 2.8 m operating head, 0.4 m3/s flow rate, and a speed of 612 rpm. The output power was 3.7 kW with an overall efficiency of approximately 37%. The turbine was fabricated using mild steel [206].

Heitz with Nottingham Trent University designed and constructed a unit equipped with 5 guide vanes and 4 runner blades of constant thickness steel plates. The design output was 1 kW at 2100 rpm operating under 2.9 m head and 0.06 m3/s flow rate. This design was adapted and installed at a low head site in London, UK. The adapted turbine operated at 650 rpm and employed a belt transmission to drive a 4-pole induction generator. The turbine efficiency was 24%. The runner was redesigned with 6 blades instead of 4 and showed an improvement in performance [203].

Development Technology Unit (DTU) of the University of Warwick developed a "simple-to-make" low head propeller turbine, claimed to produce 200 W with 2.5 m head and 0.04 m^3/s flow rate (20% overall efficiency)[203].

[133] and [204] developed low head turbines operating between 4 m and 12 m with efficiencies above 68%. The designs were axial, radial, and mixed flow turbines and incorporated features to simplify manufacture and improve resistance to blockage. Flat blades were used for the axial and mixed flow designs, while blades curved about a single axis were used for the radial flow design.

[110] designed and tested a five blade propeller turbine that produced 810W (73.9% hydraulic efficiency) at 900 rpm while operating under a head of 1.75 m and flow rate of 0.064 m^3/s. This design was optimized by trialling different inlet and exit blade angles of the runner. They also investigated the impact of blade height and blade number on performance. Increases to blade height caused an increase in friction, while increasing blade number, the parameter with relatively greater influence, was found to improve flow guidance but adversely affected performance due to the augmentation of axial flow velocity and the decrease in tangential flow velocity.

At the Nottingham Trent University, in 1997a propeller turbine with up to 1 kW power output was developed. The turbine consisted of an enclosed spiral casing and guide vanes guiding flow to a propeller runner directly coupled to an overhung generator. The enclosed casing enables a short shaft to directly drive the generator. Optimizations were made to the design based on numerical analysis were later conducted at about 2004. A 5 kW (65% overall efficiency) version was installed in Peru in 2006 with tapered rectangular profile spiral casing, 6 guide vanes, and a runner with 4 blades constructed using bent and twisted steel plate. The work was extended towards an open source propeller turbine design guide by [194].

The governments in African countries have done little to promote adoption of renewable energy [35, 208]. Due to this inaction, non-governmental organizations (NGOs) have played a significant role in the promotion, financing, and installation of small renewable energy systems for rural electrification, including a number of pico hydro systems. Mid to high head turbines have been applied specifically incorporating Turgo, Pelton, and cross-flow type turbines. There is no formal record of the number or functionality of pico hydro sites in Cameroon, however, high failure rates have been known to occur with some of these designs.

[193] conducted a feasibility study on pico hydro and solar photovoltaic hybrid systems incorporating biogas generation in the Cameroon context. The results of the simulation showed that pico hydro is a key component for the viability of renewable energy systems used for rural electrification in Cameroon at the low power range (10 kW – 50 kW).

[208] and [209] presented a concept propeller turbine design based on 2 m head and 25 l/s flow rate conditions yielded a 117 mm tip diameter, 64 mm hub diameter, 5 to 6 blades, and was forecasted to produce 363 W at 78% hydraulic efficiency. Conceptual sizing parameters and performance estimates for the preliminary cross-flow and propeller runners were obtained. These conceptual designs were used as part of the communication process during field research in Cameroon.

Generally, the factors that determine the feasibility and achievability of pico-hydro systems include:

(i) The amount of power available from the water flow inside the pipelines which depends on the water pressure, amount of water available and friction losses in the pipelines,
(ii) The turbine type and availability of required generator type and capacity,
(iii) The types and capacity of electrical loads to be supplied by the pico-hydro system, and
(iv) The cost of developing the project and operating the system.

The basic equations associated with the system are shown in equations 1 and 2 below.

$$P_{in} = H \times Q \times g \quad (1)$$

$$P_{out} = H \times Q \times g \times \eta \quad (2)$$

where P_{in} = Input power (Hydro power), P_{out} = Output power (Generator output), H = Head (meter), Q = Water flow rate (m/s), g = gravity (9.81 m/s^2) and η = efficiency [180, 213]. According to [182], water flow available is normally more than that needed since the flows for pico-hydro are small. Also, they gave 50% efficiency to estimate the potential output power as a rule of the thumb. This takes care of the losses in the pipe (or penstock) and in the generator.

To determine the head, gross (static) head and net (dynamic) head must be considered. Gross head is the vertical distance between the top of the penstock and the point where the water hits the turbine. Net head is gross head minus the pressure or head losses due to friction and turbulence in the penstock. Head losses depend on the type, diameter, and length of the penstock piping, and the number of bends or elbows [134]. Gross head can be used to estimate power availability and determine general feasibility, but net head is used to calculate the actual power available. According to [210], there are many methods of head measurement. One of the simplest and most practical methods for head measurement is by using a water-filled tube and calibrated pressure gauge. Through this method, the pressure gauge reading in psi can be converted to head in meters using equation 3.

$$H = 0.704p \qquad (3)$$

where, H = Head (meters) and p = Pressure (psi). The water pressure represents the net head of the system that is useful to calculate the actual power available.

The most simple of flow measurement for small streams is the bucket method [210]. In this method, water is allowed to flow into a bucket or barrel and the time it takes for the container to fill recorded. The volume of the container is known and the flow rate is simply obtained by dividing this volume by the filling time.

Consideration on the pipe length and diameter to handle the amount of water flow and piping accessories to convey the water to the turbine is very important to minimize the friction loss for the piping scheme between the source and the turbine of the pico-hydropower system. This can be done by appropriately selecting the diameters and types of bends, fittings and valve and minimizing the use of these accessories. Moreover, it is necessary to minimize the piping system length between the water source and the turbine [190]. [134] presented a work which focused on penstocks for the micro hydro region at heads lower than Pelton Wheels. The principles and equations will however apply equally well for penstocks of higher heads into the Pelton Wheel range. They also concluded that at the other end of the scale, at very low heads of about 2m, the penstock will be relatively short, and while the equations still apply, the penstock cost becomes insignificant when compared to that of the rest of the installation, and the optimum penstock cost is not such an important issue. A particular goal of their work was to find the most economic penstock solutions for micro hydro schemes. To achieve this, equations have been developed and equations have also been given to enable a sensitivity analysis of any penstock choice with the hope that it will provide all that is necessary for a competent practitioner to arrive at the most economic penstock solution for low head micro hydro sites.The generating system for a hydro power scheme is selected based on the following concerns:

(i) The estimated power of a hydropower system,
(ii) Type of supply system and electrical load (AC or DC),
(iii) Available generating capacity in the market, and
(iv) Generator which is cost effective.

According to [210], pico-hydro systems use AC generator either induction or synchronous machine type. This is because the system is used to supply AC electrical appliances and DC generator with size above 2kW is said to be expensive and has brush gear that requires appreciable maintenance. In addition, DC switches for the voltages and currents concerned are more expensive than their AC equivalents [190].

The selection of turbine to be used is very important in the design and development of a hydropower system. In general, reaction turbine is fully immersed in water and is enclosed in a pressure casing. The runner or rotating element and casing are carefully engineered so that the clearance between them is minimized. In contrast, impulse turbine can operate in air and works with high-speed jet of water. Usually, impulse turbines are cheaper than reaction turbines because no specialist pressure casing and no carefully engineered clearance are needed. It has been highlighted that Pelton turbine is commonly used in a small scale hydropower system [210], and particularly in pico-hydro system [181, 182, 189] due to its suitability. One of convenient methods for selecting a turbine for particular hydro system is given by [210] in the form of a nomogram. The turbine type is selected based on the speed range and power capacity of alternator to be used [190, 211].

[211] described the design of four different specific speed micro hydro propeller turbines operating at heads between 4 m and 9 m, and their application to a wider range of heads and outputs by scaling. The features are specifically tailored for ease of manufacture and uniquely resistant to debris blockage. They described test machines and test results were given with hydraulic efficiencies of over 68% achieved in all test models despite the fact that these turbines' blades are planar, further simplifying manufacture. Their theoretical models show how closely these flat blades can be made to approach the ideal blade shapes. These turbines are the axial flow members of a family of turbines developed to cover the micro hydro range from 2 m to about 40 m of head.

[207] presented a work in which turbines and penstocks were charted with their electrical controls representing the most economical solutions that are likely to be found. A primary motivation for it was to provide isolated communities in Third World environments with the fairest hydro power deal that research can provide. Until now there has been no benchmark to say whether or not the cost of a particular scheme has been justified though they believed that these designs could become that benchmark. While not insisting on the use of the schemes presented in any particular case, they concluded that in terms of $/kW for the sites matching the charted turbines, these schemes potentially provide the most economic solutions.

One of the areas of interest in the application of pico hydro systems is the use of centrifugal pumps working in the reverse mode as a turbine. Under such conditions they are called Pumps as Turbines (PATs). PAT involves passing water through pumps in reverse, to turn the pump impeller, which turns an attached generator to generate electricity. The main advantage of this alternative is increased accessibility due to availability of mass produced water pumps and widespread distribution networks in some locations [208].

[212] first published a work regarding pumps running in abnormal conditions. This work was retaken by [213] to outline the use of standard pumps running in reverse for electrical power generation. They stated the advantages of the PAT and remarked that radial, mixed and axial centrifugal pumps can be successfully operated in reverse when a design review of the pump characteristics is done to ensure proper operation under turbine operating conditions. [214] also presented a brief description of PAT operation and related equations though experimental data was not provided to validate the model. [114] presented a thorough theoretical model for mixed flow PATs in which several dimensioning parameters of the pump are required to calculate the expected efficiency. Their results show a precise model to characterize low specific speed turbines (15–55 rpm). Similarly, [215] presented a complementary framework for units ranging from 10 to 200 rpm and the turbine/pump operation based on the unit's specific speed (N), flow rate (Q), head (H), and Torque (M). Additionally, [216] presented a Computational Fluid Dynamics (CFD) simulation for a mixed flow PAT (N = 94 rpm). However, the results cannot be generalized since further modelling is required. Case studies of applications in developing countries are presented by [180] and [189]. [217] provides a review of PAT development while applying selection frameworks for a concept PAT application in Laos.

From a practical perspective, [218] presented a remarkable guide for sizing PAT units, the empirical equations to calculate the expected output, and a brief troubleshooting guide. The guide also mentions the alternative of reducing the impeller's diameter to reach a closer to optimal operating point for the pump running in reverse. [181] and [178]presented successful PAT projects used for rural electrification in developing countries. [219] presented a procedure for selecting a reversed centrifugal pump as a turbine.

III. PRESENT HYDROPOWER SITUATION IN NIGERIA

According to [220], Nigeria has a large hydropower potential of about 11,250MW with only about 1900MW installed capacity and only about 58% available as at 2011. The corresponding potential for small hydropower is about 3,500MW with only about 64.2MW exploited. As far back as 2010, the projected access to grid electricity by household is expected to rise from average of 82.3% in 2015 to 93.3% in 2030 [220, 221]. To achieve this, the projected electricity supply by 2015 is expected to reach 11,207MW by large hydropower and 12,132MW by 2030. For small hydropower the figures are respectively 319.9MW and 3502.1MW [222]. Generally, the government have set targets for the power sector overhaul in short term (2015), medium term (2020) and long term (2030).

Specific energy related actions/projections by the government in the hydropower sector according to [220] include

(i) Reactivation of existing three large hydropower plants at Kainji(760MW), Jebba(540MW) and Shiroro(600MW) to deliver optimum power and concession to private concerns.
(ii) 30MW Gurara I hydropower plant completed and power evacuation network being put in place.
(iii) 300MW Gurara II hydropower plant under planning.
(iv) 40MW hydropower plant across river Katsina-Ala in Taraba state, 55% execution to be completed by 2014.
(v) 700MW Zungeru hydropower plant contract signed with a Chinese Firm 2012 and to be completed in 48months.
(vi) 2,600MW Mambilla hydropower plant-feasibility and environmental impact assessmentstudies done.
(vii) 30 MW SHP NESCO, Jos which is and the oldest
(viii) 2x75kW Waya Dam SHP in Bauchi completed through collaboration with UNIDO, ECN, RBDA andBauchi state.
(ix) 1x30kW Ezioha –Mboro Dam SHP, Enugu completed through collaboration with UNIDO, ECN and RBDA.
(x) 2x200kW Tunga Dam SHP, Taraba State with the machines on site(UNIDO).

(xi) 34MW DadinKowa Dam, Gombe State, Hyropower plant concessioned to private sector but yet to commence operation.

(xii) Capacity building in hydropower R&D.

In line with the Power Sector Road Map, Government is in the process to concession the hydro power components of the dams whose feasibility studies are completed to private investors for the development and operation of the Small and Medium Hydro Power Plants. Transaction adviser who will assess concession bids to be submitted by investors for development and operation of the small and medium hydro power plants at the dams is to be appointed by Government. As soon as the transaction adviser is appointed, government will call for bids from technically and financially competent investor[223].

However, in spite of so much hype by the political class on power sector achievements, the majority of Nigerians in the rural areas are still unable to have access to power of any significant consequence. There is no particular mention of the picohydro option in all the projections and targets of the government and its energy related organs which in direct contrast to the provisions of the National Energy Policy which approved by the Federal Executive Council 2003. The policy articulates for the use of all viable energy sources for sustainable national development and with the active participation of the private sector in line with government's economic policy. Renewable energy is one of the energy types articulated in the policy. The policy also covers energy efficiency and conservation, amongst many other issues [220, 222]. Most of the efforts are focused on large and small schemes with the attendant environmental issues affecting human and aquatic life as well as the enormous requirements for the civil works of such systems[224 – 226]. This is ultimately counter-productive especially as regards reaching the majority of Nigerians domiciled in the rural areas with the basic power for livelihood, small economic activities, healthcare delivery and education.

IV. CONCLUSION

Energy plays a very important role in economic development but its application could pose several issues bothering on the environment. Apart from the adverse effect on the environment, several of the energy resources in use especially the fossil ones are depleting so that sustainability is not guaranteed while exploration of new deposits also compound the effects on the environment. This has brought about growing interests in and clamour for the use of the so called renewable energy sources. Also, interest is growing in smarter and smaller energy systems which will utilize these renewable sources as well as the conventional ones more efficiently. These systems convey more control to the end user. This will create more sense of responsibility with regards to the maintenance and security of the system, especially with the prevalent activities of saboteurs as a result of terrorism and/or restiveness among groups and regions where energy sources are located. Also, development of systems that generate the required power at or very close to the point of application has the potential of mitigating attacks on supply structures particular with the growing restive nature of regional groups in developing countries like Nigeria partly due to economic imbalance and poverty. Maintenance of the supply structure is also entirely eliminated.

Hydropower has numerous advantages over other renewable energy sources but the large schemes which are generally predominantly in use in Nigeria and other developing countries also pose a lot of environmental problems. These include harm to aquatic animals and habitat, possibility of enhancement of disease to the neighbouring communities, as well as displacement of settlements. Large to small hydro which depend on flowing water sources are affected by the hydrological cycle (seasonal fluctuation) which translates to blackouts and significant power outages at some periods of the year. Also, debris and silt blockages often arise which also affect power supply. Interest is recently growing in research on very small hydro and pumped storage hydro. Developing a means of applying the advantages of hydropower while greatly minimising the operational and natural shortcomings will be a step in the right direction. Pico-hydro power provides a very good option. It suits the general characteristics of smarter, smaller systems which can be utilized in locations where larger more conventional systems cannot be optimally located. It has become a very useful option in the Asian developing countries where the topography has imposed great natural barrier to the uptake of more conventional grid – connected energy systems. There are many sites suitable for pico hydro development in Nigeria as in many other African countries but deliberate focus has not been given to its development by articulating realisable policies geared towards achieving solutions to the energy crisis. Moreover, it has been verified that seasonal fluctuations of water levels also affect the operation of the conventional pico hydro schemes. Low water levels do not allow optimal operation while very high ones can sweep the units away.

Nigeria like many African countries needs development, and indeed sustainable development, driven by sustainable energy supply in order to eliminate poverty and advance the living standard of the citizens in the long run. The huge renewable energy potentials that abound in the country in the form of water bodies, large and small, need be harnessed and transformed into electricity, modern fuels, and process heat required for driving the economy.However, appropriate policies and legislations must be put in place with relevant technologies such as picohydro acquired and utilized as well as attract private investments in order to fully realize the potentials.

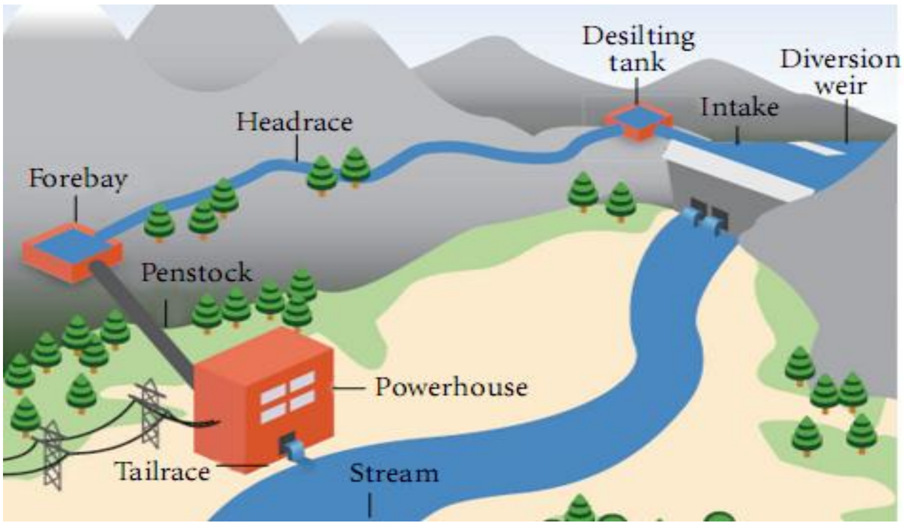

Fig.1: Schematic view of a typical Run-off-the-River Hydropower Scheme [227].

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