QUALITY STANDARDS: PANACEA FOR A SUSTAINABLE DEVELOPMENT OF SMALL HYDROPOWER PROJECTS IN NIGERIA

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ABSTRACT

Sustainably developed and managed small hydropower has enormous potential to contribute to sustainability energy goals. To achieve this, the International Hydropower Association (IHA) has developed Sustainability Guidelines, and an associated Compliance Protocol that provides a clear framework for good practice. Also, quality standards for small hydropower have been developed for countries like India, Sweden, Brazil, USA, Canada etc taking into consideration there local environments. Since prospects for Small Hydro Power (SHP) in Nigeria have led to increase in number of SHP local consultants and SHP equipment manufacturers, the need to defining quality standards for hydro power development in Nigeria is inevitable. Therefore the Small hydropower quality standards has been suggested in this paper to define the quality requirements of SHP projects in the areas of planning, design, supply and installation works in Nigeria. This is to ensure competitive bidding of SHP projects that will guarantee quality finish and performance. For a speedy and successful development of small hydropower, use of standards and guidelines in planning, designing and execution is necessary. A general awareness of the codes, standards and guidelines, especially for small hydropower projects is also emphasized. For quality assurance of the small hydropower stations, establishment of a special hydropower research institute in Nigeria has been suggested to initiate performance testing of any hydropower project.

Keywords: *Small Hydropower, Quality Standards, Competitive Bidding, Codes, Performance Testing.*

1. INTRODUCTION

Energy is one commodity on which the provision of goods and services depend. Its availability and consumption rate is an economic index to measure the development of any community [1]. [2] submitted in his article that power outages cost Nigerian's economy approximately $1 Billion dollars per year. Access to electricity is one of the keys to development, as it provides light, heat and power for productive uses and communication. Achieving the United Nations "Millenium Development Goals" will require significantly expanded access to energy in a developing country like Nigeria.

World Small Hydropower Development Report 2013 (WSHPDR 2013) reported by [3] defines small hydropower as plants with a capacity of up to 10 MW per plant. However, the term 'small hydropower' has a different meaning from country to country. He further stressed that the hydropower potential of Nigeria is high and hydropower currently accounts for about 32% of the total installed commercial electrical power capacity. Small hydropower potential sites exist in virtually all parts of Nigeria. According to [4], there are over 278 unexploited sites with total potentials of 734.3 MW. So far about eight (8) small hydropower stations with aggregate capacity of 37.0 MW have been installed in Nigeria by private companies and the government. This shows that the technically exploitable small hydro capability in Nigeria is high but underutilized. [2, 5] also agreed that instability in the generation and supply of electricity (hydro) in Nigeria can be attributed to non-utilization of available exploitable sites.

[6] quoted in his paper, the National Agency for science and engineering infrastructures (NASENI), the agency developing capacity in the manufacture of SHP equipment that the total Small Hydropower (SHP) potential in the country could reach 3,500MW, representing 23% of the country's total hydropower potential. With this potential in SHP, yet more than 60% of Communities, mostly in the rural areas of Nigeria, do not have access to electricity and there will be a growing demand for local capacities in the development of SHP technology in the nation. He also stressed further that the Federal Government of Nigeria plans to generate approximately 525MW from SHP by year 2015.

Although electricity is treated as an essential social service, the present supply is characterised by erratic power supply to industries, inadequate coverage in terms of geographic spread, leaving out large number of villages and covering less than 40% of the population, with a record low per capita consumption [7]. About 60 percent of the population approximately 80 million people are not served with electricity while Per capita consumption of electricity is approximately 100kWh [8].

The situation in the rural areas of the country is that most end users depend on fuelwood. Fuelwood is used by over 60% of Nigerians living in the rural areas. Nigeria consumes over 50 million metric tonnes of fuel wood annually, a rate, which exceeds the replenishment rate through various afforestation programmes. Sourcing fuel wood for domestic and commercial uses is a major cause of desertification in the arid-zone states and erosion in the southern part of the country. The rate of deforestation is about 350,000 hectares per year, which is equivalent to 3.6% of the present area of forests and woodlands, whereas reforestation is only at about 10% of the deforestation rate [9].

The development of energy from small, mini and micro hydropower projects are being encouraged and supported worldwide because of its relative advantage of being a safe and clean renewable source of energy that can be developed and managed by local communities [10, 11, 12].

Theoretical electrical power ranging from 5.13 kW to 5,000 kW which is enough to cater for average rural community loads is realizable in Nigeria if the identified small hydropower sites are developed [13].

Within this scenario, renewable energy like small hydropower must be used as a key tool towards sustainable development suitable for rural electrification. It is a proven technology that can be connected to the main grid, used as a stand-alone option or combined with irrigation systems and can adequately contribute to the electrification needs in Nigeria. : Projected Nigerian small hydro power demand as shown in figure 1 has been suggested to increase from 190MW in year 2000 to 3500MW in year 2030 [1].

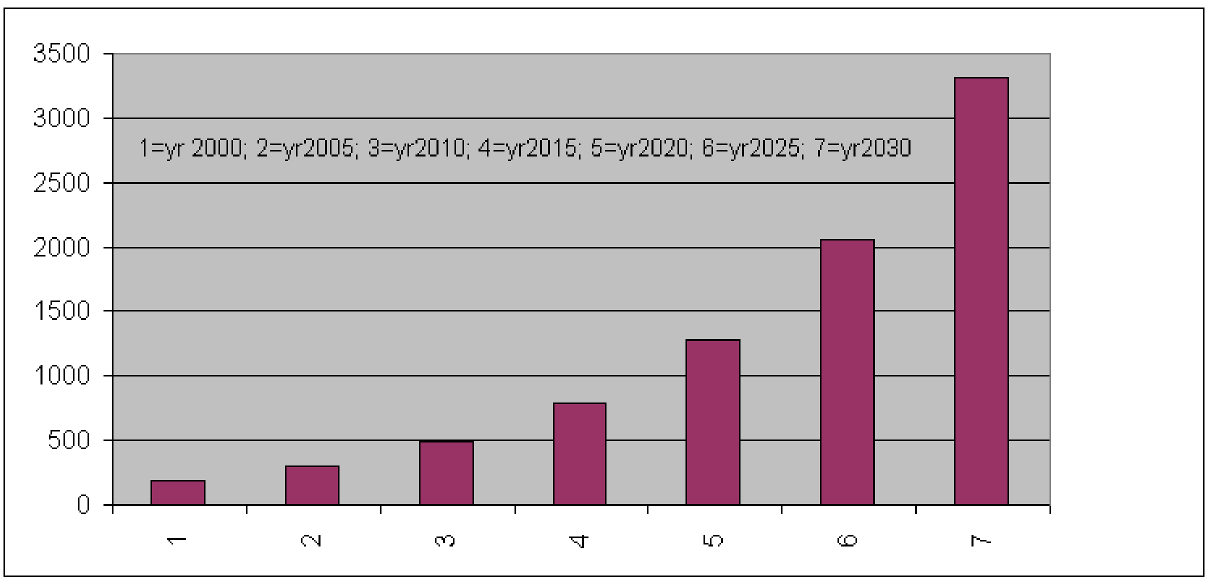

Fig. 1: Projected Nigerian small hydro power demand Source [1]

As a rule, large hydropower station schemes involve large-scale environmental integration activities, which have subsequent consequences. These problems are almost non-existent in the case of SHP up to 10 MW. In general, SHP can be integrated more easily into local ecosystems. Small hydro power stations require modern dedicated equipment to meet the high requirements regarding energy generation efficiency and simplicity and environmental protection [14].

Quality standards for small hydropower have been developed for countries like India, Sweden, Brazil, USA, Canada etc taking into consideration there local environments. Since prospects for SHP in Nigeria have led to increase in number of SHP local consultants and SHP equipment manufacturers, the need to defining quality standards for hydro power development in Nigeria is inevitable.
This study was initiated in response to concern that people in rural areas of Nigeria were not progressing toward modern energy use most especially hydroelectricity. The overall purpose of the present proposal for quality standards

and specifications is to optimise the quantity, quality and safety of the electricity services provided by SHP installations so as to meet the societal needs effectively and efficiently.

2. SMALL HYDROPOWER POTENTIALS IN NIGERIA

The country's outstanding total exploitable hydro potential, listed in Table 1.0 currently stands at 12,220 MW. Added to the 1930 MW (Kainji, Jebba and Shiroro), already developed, the gross hydro potential for the country would be approximately 14,750 MW. Current hydropower generation is about 14% of the nation's hydropower potential and represents some 30% of total installed gridconnected electricity generation capacity of the country.

From a 1980 survey of 12 of the old States of the Federation, namely; Sokoto, Katsina, Niger, Kaduna, Kwara, Kano, Borno, Bauchi, Gongola, Plateau, Benue and Cross River, it was established (Table 1.1), that some 964 MW of SHP can be harnessed from 277 sites. The potential would of course increase when the rest of the country is surveyed. It is presently estimated by the Inter-Ministerial Committee on Available Energy Resources (2004) that the total SHP potential could reach 3,500 MW, representing 23% of the country's total hydropower potential [14].

Table 1.0: NEPA Estimate of Current Exploitable Hydro Power Sites in Nigeria

Donka	Niger	225
Zungeru II	Kaduna	450
Zungeru I	Kaduna	500
Zungeru	Kaduna	20
Gwaram	Jamaare	30
Izom	Gurara	10
Gudi	Mada	40
Kafanchan	Kongum	5
Kurra II	Sanga	25
Kurra I	Sango	15
Richa II	Daffo	25
Richa I	Mosari	35
Mistakuku	Kurra	20
Korubo	Gongola	35
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	1,060
Lokoja	Niger	1,950
Onitsha	Niger	1,050
Ifon	Osse	30
Ikom	Cross	730
Akikpo	Cross	180
Atan	Cross	180
Gurara	Gurara	300
Mambilla	Danga	3,960
	Total	**12, 220**

Table 1.1 Small hydro potential in surveyed states of Nigeria

S/No	State (pre-1980)	River Basin	Total Site	Total Capacity (MW
1	Sokoto	Sokoto - Rima	22	30.6
2	Katsina	Sokoto - Rima	11	8
3	Niger	Niger	30	117.6
4	Kaduna	Niger	19	59.2
5	Kwara	Niger	12	38.8
6	Kano	Hadeija-Jamare	28	46.2
7	Borno	Chad	28	20.8
8	Bauchi	Upper Benue	20	42.6
9	Gongola	Upper Benue	38	162.7
10	Plateau	Lower Benue	32	110.4
11	Benue	Lower Benue	19	69.2
12	Rivers	Cross River	18	258.1

Listed in Table 1.2 are the small hydro schemes under operation in the country. As indicated, the projects are developed only in three states of the federation, namely; Plateau, Sokoto and Kano. Of the total 30 MW installed capacity, 21 MW (or 70%) is generated from 6 sites in Plateau State by the Nigerian Electricity Supply Corporation Ltd. (NESCO).

Table 1.2: Existing small hydro schemes in Nigeria

1	Bagel I	Plateau	1
	Bagel II	Plateau	2
2	Ouree	Plateau	2
3	Kurra	Plateau	8
4	Lere I	Plateau	4
	Lere II	Plateau	4
5	Bakalori	Sokoto	3
6	Tiga	Kano	6
		Total	**30**

3. TECHNICAL ASSESSMENTS

3.1 Overview of Technology

The Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee, classified small hydro schemes as follows:

i Run-of river schemes: These plants use little, if any, stored water to provide water flow through the turbines. Although some plants store a day or week's worth of water, weather changes—especially seasonal changes—cause run-of-river plants to experience significant fluctuations in power output.

ii Schemes with the power house located at the base of a dam: These plants have enough storage capacity to off-set seasonal fluctuations in water flow and provide a constant supply of electricity throughout the year. Large dams can store several years' worth of water.

Iii **Schemes Run-of-river integrated on a canal or in a water supply pipe:** Canal derivation is often used on river bends. A canal can shorten the natural river passage in order to achieve a greater head. The features of such a system include upper inlet and tail-water canals. The tail-water canal takes the water down to the river bed [15].

3.2 General Description of SHP Schemes

The diversion weir diverts water from the stream through the Intake to the desilting Tank which removes silt, stones and other debris. The headrace; a water canal or water pipe conveys the water to the Forebay. From the Forebay; temporary water storage, the penstock conveys the water to the turbine in the power house. Electricity is generated; water goes back to the stream through the tailrace (see figure 2).

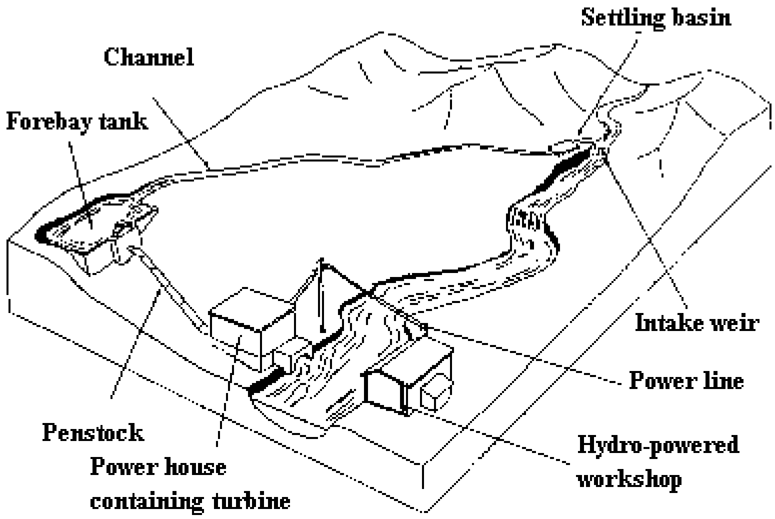

Figure 2: Layout of a typical micro hydro scheme [16]

The three elements comprising the SHP system are:

- **Civil works***:* these consist of diversion works, channels and piping to convey river, stream or spring water to the power generation equipment, the power house building and water exit channel

- **Power generation equipment:** this consists of a turbine, a drive system linking the turbine to a generator and/or mechanical devices, a generator, a generator controller and switchgear

- **Power distribution system:** this involves distribution of electrical power by a line system. A line system normally comprises one or more main power distribution lines to central points, then by sub-distribution lines and consumer service connections to consumption points.

3.3 Energy Potential

Potential and kinetic energy of a mass of water flowing from a higher level to a lower level can be converted into electrical energy. The hydrological potential of water is determined by two parameters: head (H) and flow (Q). Head is crucial, especially for SHP. It is not really necessary to have the water flowing rapidly.

The Gross Head (H) is the maximum difference between the levels of falling water. The turbine's actual head is less than the maximum, due to losses caused by friction with construction elements and the internal friction of the water. Sites are classified according to head size:

- low head', for $H < 10$ m,
- medium head', for H ranging between 10 - 50 m,
- high head', for $H > 50$ m

The Flow (Q) - expressed in m^3/s - is the volume of water flowing through a given cross-section of the stream per second.

SHP is also classified in terms of output power as:

- Pico 5KW and below/
- Micro 100KW and below
- Mini 2000KW and below
- Small 2500KW and below [15,16].

Electrical power and energy: Energy is the amount of work done in a fixed time interval. A turbine converts water pressure energy into the mechanical energy of the turbine shaft, which drives a generator to produce electrical energy. The energy unit is Joule (J); and the electrical energy unit is the kilowatt-hour (kWh): 1 kWh = 3600 J.

Power is the amount of energy per time interval unit. Therefore, the electrical power of the generator is defined by the following formula:

$P = \eta \cdot \rho \cdot g \cdot Q \cdot H$ [16] (1)

where:

P - electrical power [W],

η – hydraulic efficiency of the turbine

ρ – water density, $\rho = 1000 kg/m^3$

g = acceleration due to gravity, $g = 9.8 m/s^2$

Q = flow-volume of water flowing through the turbine in time unit [m^3/s]

H = head-effective pressure of water flowing into the turbine [m].

Turbine technology is a mature technology characterised by relatively high efficiency. The efficiency of large hydropower units reaches the level of 80 - 90%. The efficiency of smaller hydro units (<100kW) is about 10-20% less. When estimating the power of small hydro units (e.g. micro-turbines), turbine efficiency is usually assumed to be η = 70-75%. Thus, electrical power can be estimated by the following formula:

$P \approx 7 \div 8 \cdot Q \cdot H$ [16] (2)

P = [kW], Q = [m^3/s], H = [m].

To estimate energy, assume 4 500 working hours with power output defined by equation 2:

$E \approx 4500 \cdot P$ [16] (3)

where: E = energy [kWh].

4. QUALITY STANDARDS, CODES AND GUIDELINES IN SHP

With reference to the regulatory bodies like the World Commission on Dams (WCD), the International Electrotechnical Commission (IEC), the Institute of Electrical and Electronics Engineers (IEEE), the American National Standards Institute (ANSI), the American Society of Mechanical Engineers (ASME) and the Bureau of Indian Standard (BIS). The standards/guidelines are developed specifically for small hydropower for the following reasons:

- Standardisation leads to uniformity in design, manufacture, and construction as well as to reduction in inventory. It can also ensure safer and better operation and easier maintenance of the power station.

- Standards for civil works of SHP projects are used for planning, design and construction of civil works thus ensuring the safety, integrity and longevity of the civil structures.

- Standards for equipments are aimed at achieving optimum performance and a long useful life.

- Standardised equipment and uniform construction practices can bring significant economy and reliability, and speed up the growth of small hydropower, which is considered an effective vehicle of rural development [17, 18, 19, 20, 21].

4.1 General SHP Standards and Codes

- IEC-62111(1999): Specification for Use of Renewable Energies in Rural Decentralised Electrification.

- IEEE Standard 1020 (1988): Guide for Control of Small Hydroelectric Power Plants.

- CBIP Publication No. 175: Small Hydropower Stations – Standardisation, Central Board of Irrigation and Power, New Delhi, 1985.

- Guidelines for Development of Small Hydro-electric Schemes, Central Electricity Authority, Govt. of India, New Delhi, 1982. Standards/guidelines developed for large hydropower installations are being discretely used for SHP installations:

- REC- Rural Electrification Construction Standards, Rural Electrification Corporation, New Delhi, 1993. Standards/guidelines developed for the testing of large hydropower installations are being used for testing of small hydropower equipment selectively:

4.2 Planning

This involves typical arrangement of SHP. As earlier stated, SHP schemes are planned based on the nature of site. Therefore, a scheme can be Run-of-river, integrated on a canal or in a water supply pipe**,** and schemes with the power house located at the base of a dam.

Other key issues in SHP planning and development include"

- Data on hydrology
- Acquisition of land
- Rehabilitation
- Government clearance
- Safety of existing dam
- Agreement on sharing of public property
- Agreement on interconnecting works
- Selection of equipment
- Power evacuation
- Time scheduling
- Cost control
- Operational
- Cash flow aspect.

4.2.1 Planning Standards and Codes

• WCD Guidelines for Development of Hydro Dams.

4.3 Design

This involves civil works, electromechanical equipment, power sub-transmission and distribution.

Following design criteria may be adopted for designing the SHP for a Power Project

No. of Houses	> N
Power allocation for a house (P)	> N Watts
Distribution loss (L)	< 10% of net generation
Allowance for future demand growth (G)	= 20% of present demand
Design capacity (C)	> [N*P]*(1+G)*(1+L) /1000 kW
Minimum power generation	> 25% of design capacity (0.25*C) kW
Overall Efficiency	> 60%
Design flow (F)	> [C*H*0.6]/ 1000 litre/s
Base flow	> Design flow (F)
Flow released to the natural stream	> 20% of design flow during lean season

4.3.1 Efficiency of SHP station and equipment

Efficiency of SHP = Efficiency of turbine x generator x gearbox

Turbine 88 – 94%

Generator 96 – 98%

Gearbox 98%

Weighted average efficiency 75%

4.4 Selection, Supply, Installation and Testing

Successful implementation of SHP Development programme depends upon the availability of specific equipment with required characteristics, duly tested and certified. This involves hydro-mechanical equipment like turbine and electro-mechanical equipment like alternator.

4.4.1 Hydraulic Turbines

• Quality of materials;
• Quality of manufacture (in accordance with modern practice);
• Runaway (speed and behaviour);
• Speed rise and pressure rise on load rejection;
• Leakage through the discharge regulating apparatus;

- Cavitation (the amount of material lost through cavitation/pitting on turbine components can form the basis of a guarantee with a guarantee period of the order of 8,000 h of operation, but not longer than two years);
- Output or discharge;
- Efficiency;
- Temperatures of guide and thrust bearings (which may be part of the generator).

4.4.2 Hydro-Electric Generators

The special requirements of the small hydro generators as per IEC 61116 are:

- Standardised or upgraded mass produced machines available off the shelf be used.
- The machine be designed for continuous operation at runaway conditions specially in the micro range and as induction generators.
- These machines are no readily available, thus affecting the shp development program.
- Synchronous generators excitation system should be designed for power factor control when in grid-connected mode.

4.4.3 Governing Systems

- For micro range SHP shunt load governors (electronic load controllers) are invariably used to control speed in an isolated system by varying load on a dump load system.
- Digitally controlled governors are cost effective and are replacing mechanical governors.
- International and American Standards indicating requirements of Governors and their testing are available.

4.4.4 Excitation Control System

- Excitation control system, as per ANSI/IEEE Standard 421A, includes the synchronous generator and its excitation system. The latter comprises the exciter and voltage regulator.
- The old type rotating exciter with brushes is more or less obsolete because of the difficult maintenance. The newer installations use either the static or the brushless excitation

system. The latter type is specially attractive for small units because of low maintenance requirement and low cost.

- In modern installations, both large and small, microprocessor-based digital voltage regulators are invariably used because of their versatility of functions and compatibility with other digital systems in the power station, like PLC or SCADA systems.
- The tests and test procedures given in IEEE standard 421A are extensive. There is a need to evolve another standard specifically for the excitation systems of small units specifying fewer and simpler tests only.

4.4.5 Electromechanical Standards and Codes

- IEC-61116(1992): Electro-mechanical Equipment Guide for Small Hydroelectric Installations.
- IS-12800 (Part-III) 1991: Guidelines for Selection of Turbine and Preliminary Dimensions of Surface Hydro Station – Small/Mini/Micro Hydropower Stations.
- IEC- 60545(1976): Guide for Commissioning, Operation and Maintenance of Hydraulic Turbines
- IS- 12824(1989): Type of Duty and Classes of Rating Assigned to Rotating Electrical Machines.
- IEEE/ANSI C50.12 (1982): Requirements for Salient Pole Synchronous Generators and Generator/Motors for Hydraulic Applications.
- ANSI/IEEE Standard 125 (1988) "IEEE Recommended Practice for Preparation of Equipment Specifications of Speed Governing of Hydraulic Turbines Intended to Drive Electric Generators".
- IEEE Standard 421(1972) "Criteria and Definitions for Excitation Systems for Synchronous Machines".
- ASME Power Test Code Number 29(1965), Speed Governing Systems for Hydraulic Turbine-Generator Units".
- IEC- 60041(1991): Field Acceptance Tests to Determine the Hydraulic Performance of Hydraulic Turbines, Storage Pumps and Pump Turbines.
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- IS- 4889(1968): Method of Determination of Efficiency of Rotating Electrical Machines.
- ASME PTC (18-2002): Hydraulic Turbines and Pump – Turbines: Performance Test Codes.
- IEEE Standard 421A(1978) "IEEE Guide for Identification, Testingand Evaluation of the Dynamic Performance of Excitation Systems".
- IEC Standard 308 (1970) "International Code for Testing of Speed of Governing Systems for Hydraulic Turbines".

4.5 Performance Testing and Evaluation of SHP Stations

Performance testing and evaluation of SHP stations before commissioning include:

- Generation as Designed and Planned.
- Part Load generation as guaranteed.
- Contractual discipline and Transparency.
- Made Mandatory by Ministry of Power or the proposed Hydropower Research Institute for all SHP stations for getting performance testing and evaluation done on their stations after commissioning their SHP projects for ensuring the projected generation and committed efficiency of generating equipment.
- Field measurement of flow in penstocks, channel.
- Efficiency measurement for hydro turbine-generator.
- Performance testing of control and protection equipments.

4.5.1 Testing and Evaluation Standards and Codes

- IEC-62006: Hydraulic Machines – Acceptance Tests of Small Hydroelectric Installations.

5. SUSTAINABLE DEVELOPMENT ISSUES

5.1 Government Policy

- Assist in exploiting SHP potential in Nigeria
- Assist in making SHP project commercially viable in Nigeria
- Assist in making the country a leader in the manufacturing of SHP system through continuous R & D
- Renovation and modernization of existing SHP stations
- Human resource development connected to small hydro and water mills.

5.2 State support for electricity production

- Simplifying the licensing procedures by possibly creating a single window,
- Simplifying procedures when refurbishing abandoned sites,
- Creating a stable regulatory framework to reduce uncertainty,
- Implementing a price system that takes into account the positive externalities of this energy source compared to fossil fuels.
- Investment subsidies
- Soft loans
- Energy Taxes
- Tax credits
- High feed in tariffs
- Supported price (green tariffs, green portfolios, tenders for specific electricity sources – NFFO)

6. CONCLUSION

1. Small hydro should be a state government subject in Nigeria and hence state government allots the sites.
2. Sites are allotted to private sector on MOU, advertisement based by state government through relevant agency/ministry. All SHPs are dealt and approved techno-economical at state level.
3. Implementation agreement, power purchase agreement is drawn between IPP and state utility. State electricity regulatory commission approves the price.
4. Observing quality standards in SHP will guarantee output; ensure reliable operation, safety and cost-effectiveness.
5. The use of high quality materials, construction techniques and standard guidelines will result in less maintenance and repair work throughout the life of the scheme, whereas low-cost construction will require considerable maintenance. Both approaches are acceptable, though the first approach is recommended for most schemes of larger capacity. The management plan must make provision for high maintenance activity and cost in cases of low-cost civil works.
6. UNIDO'S establishment of the Regional Centre for Small Hydropower Development in Africa at Abuja, Nigeria for providing technical assistance, training, awareness and information and consultancy services on

SHP development within the country and to countries in the West Africa Region is a welcome development. However, this centre should be adequately funded to meet most of its objectives.

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