Small Hydropower for Sustainable Development.

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ABSTRACT

The small hydropower system is one of the most effective renewable sources of energy for sustainable development. This paper presents the hydropower basic energy main elements in a small hydro scheme, site location, and flow duration curve in relation to assessing power and energy requirement in a small hydro system. The capital cost of small hydro plants compared to other options of power supply and the financial profitability of small hydro are also discussed.

Improving air quality and public health by reducing greenhouse emissions and increasing reliability of power supply with cheaper cost de-centralized or distributed generation are some of the outcomes achieved from small hydro system. Finally, strengthening national policy frameworks and the integration of hydro energy, enhancing national capacity for research and development and transfer and diffusion of small hydro energy technologies, establishing markets for small hydro, increasing access to finance and establishing enterprise for installing operating, and maintaining small hydro energy are some of the way forward to sustainable development using small hydro system.

(Keywords: sustainable development, hydropower, electricity demand)

INTRODUCTION

Small-scale hydropower is one of the most cost-effective and reliable energy technologies to be considered for providing clean electricity generation. In particular, two key advantages that small hydro has over wind, wave and solar power are high efficiency (70-90%), by far the best of all energy technologies, high capacity factor (typical > 50%), compared with 10% for solar and 30% for wind, high level of predictability, varying with annual rainfall patterns, slow rate of change; the output power varies only gradually from day to day (not from minute to minute), good correlation with demand, and long lasting and robust technology; system can readily be engineered to last for 50 years or more (British Hydropower Association, 2005). It is also environmentally benign. Small hydro is in most cases “run-of-river”; in other words any dam or barrage is quite small, usually just a weir, and little or no water is stored. Therefore run-of-river installation does not have the same kinds of adverse effect on the local environment as large-scale hydro.

Despite the growing expansion in the development and use of small hydro sources of energy in developed countries, the combined share of small hydro sources in the global primary energy supply remains small and limited some continent like Africa. Most developing countries have not benefited from such expansion. The international community should strengthen commitment to the scaling up of small hydropower development and use, especially in developing countries (National Development and Reform Commissions (NDRC), 2005).

The considerable benefits of small hydropower include the following:

- ‘Fuel-free’ source of power.
- Different to large hydro since environmental impacts of installation are negligible.
- Renewable energy source therefore helping to reduce greenhouse gas emissions and having a net positive impact on the environment.
- Constant generation over long periods unlike wind and solar power.
- Good correlation with demand (more hydro energy is available in rainy season).
- Long lifetime of systems, typically 25 years or more.
- Low maintenance requirements and running costs.
- Reasonable payback for grid -connected systems, often 10 years or less.

FEATURES OF SMALL - HYDRO

Head and Flow

Hydraulic power can be captured whenever a flow of water falls from a higher level to a lower level. This may occur where a stream runs down a hillside or a river passes over a water fall or man-made weir, or where a reservoir discharges water back into the main river. The vertical fall of the water, know as the "head" is essential for hydropower generation; fast-flowing water on its own does not contain sufficient energy for useful power production except on a very large scale, such as offshore marine currents(British hydropower Association, 2005). Hence two quantities are required: a flow rate of water Q, and a Head H. It is generally better to have more head than more flow, since this keeps the equipment smaller (Guide for Micro Hydropower Development, 2006).

The Gross Head (H) is the maximum available vertical fall in water, from the upstream level to the downstream level. The actual head seen by a turbine will be slightly less than the gross head due to losses incurred when transferring the water into and away from the machine. This reduced head is known as the Net head. (See Figure 1).

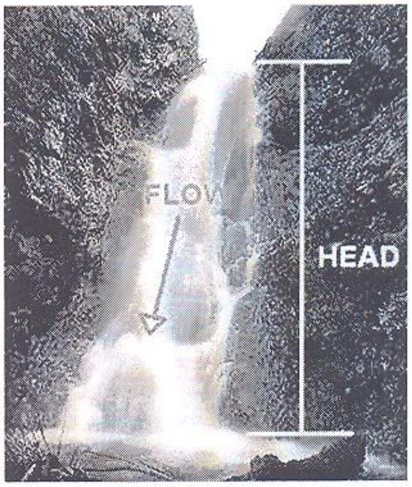

Figure 1: Head and Flow of Rate of Hydropower.

Sites where the gross head is less than 10m would normally be classed as "low head". From 10 – 50m would typically be called "medium head" and above 50m would be classed as "high head".

The Flow Rate (Q) in the river is the volume of water passing per second, measured in m^3/sec. For small schemes, the flow rate may also be expressed in liters/second where 1000 liters/sec is equal to $1m^3$/sec (see Figure 1).

Main Elements of a Small Hydro Scheme

A typical small hydro scheme on a medium or high head in shown in Figure 2. The scheme can be summarized as follows: water is taken from the river by diverting it through an intake at a weir, in medium or high head installations water may first be carried horizontally to the fore bay tank by a small canal or "leat", before descending to the turbine, the water passes through a setting tank or fore bay in which the water is slowed down sufficiently for suspended particles to settle out. The fore bay is usually protected by a rack of metal bars (a trash rack) which filters out water-borne debris. A pressure pipe or 'penstock' conveys the water from the fore bay to the turbine, which is enclosed in the power house together with the generator and control equipment. After leaving the turbine, the water discharges down a 'tailrace' canal back into the river.

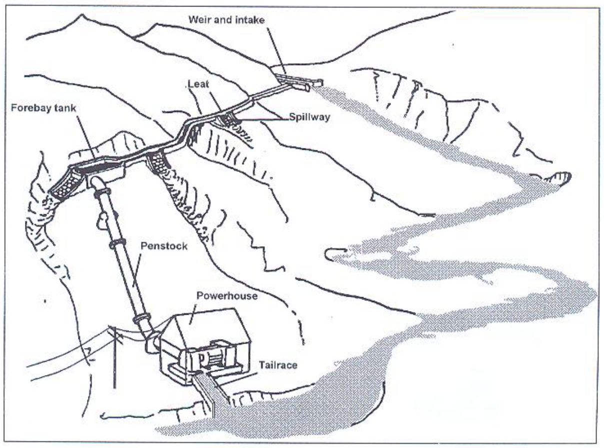

Figure 2: Hydro-Scheme Components.
(Source: British Hydropower Association, 2005)

In practice sites that are suitable for small-scale hydro scheme vary greatly. They include mountainous locations where there are fast-flowing mountain streams and lowland areas with wide rivers. The four most common layouts for a small hydro scheme is shown in Figure 3.

Power and Energy

The power available in a hydro scheme is proportional to the product of head and flow rate. The general formula for any hydro system power output is:

$$P = \eta \rho g Q H \quad \textbf{(1)}$$

where P, is the mechanical power produced at the turbine shaft in watts, η is the hydraulic efficiency of the turbine, ρ is the density of water (1000 Kg/m^3), g is the acceleration due to gravity ($9.81 m/s^2$), Q is the volume flow rate passing through the turbine (m^3/s) and H is the effective pressure head of water across the turbine (m).

The best turbines can have hydraulic efficiency in the range 80 to 90%, although this will reduce with size. Small and micro-hydro systems (<100kW) tend to be between 60 to 80% efficiency.

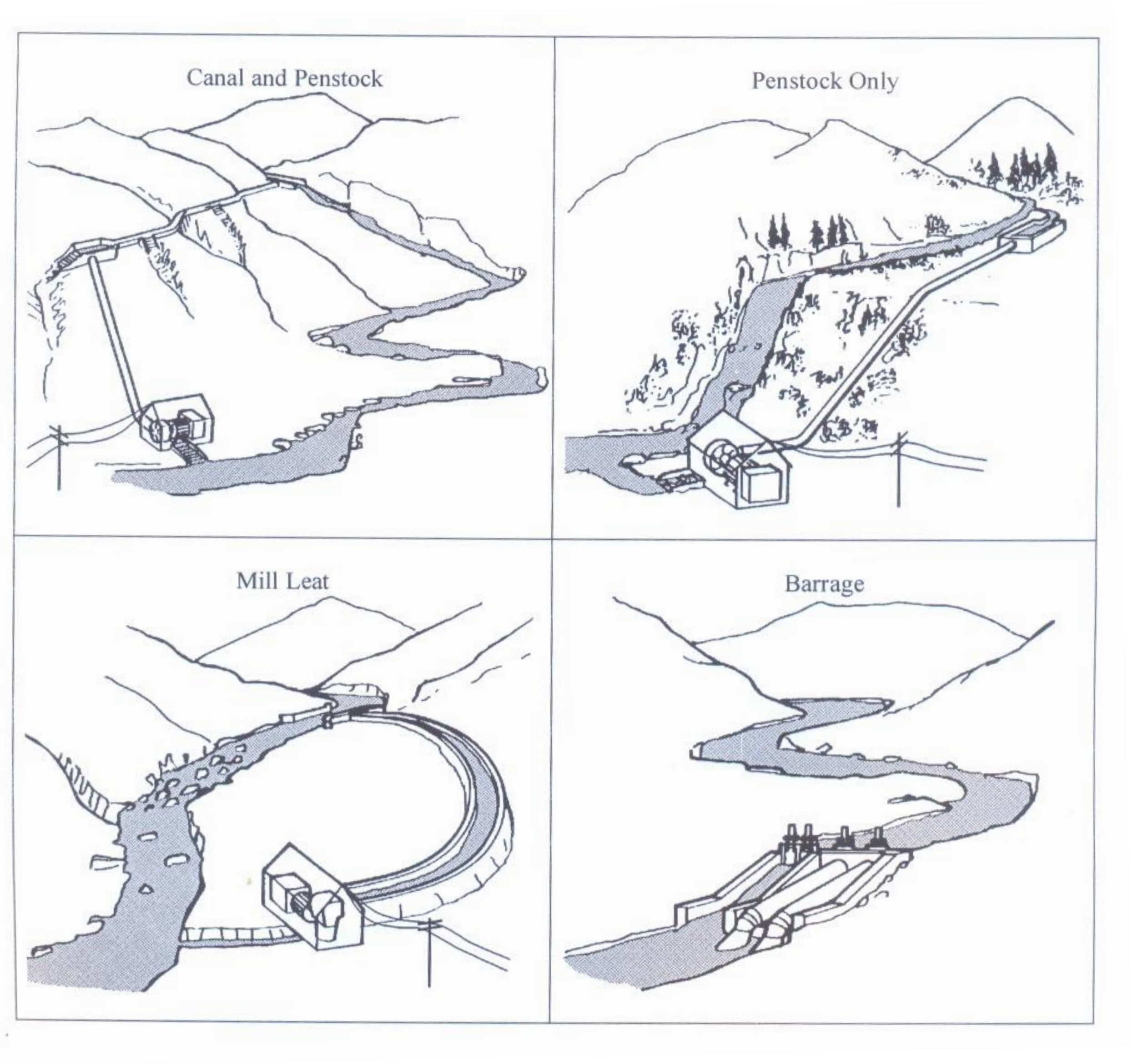

Figure 3: Layouts for a Small Hydro Scheme.

Small Hydro Site Location and Flow Duration Curve

The main issues that should be considered in a preliminary investigation of site are: the existence of a suitable water fall or weir and a turbine site, a consistent flow of water at a usable head, the likely acceptability of diverting water to a turbine, suitable site access for construction equipment, a nearby demand for electricity or the prospect of a grid connection at reasonable cost, the social and environmental impact on the local area, land ownership and/or the prospect of securing or leasing land for the scheme at a reasonable cost and an initial indication of design power and annual energy output.

There are few pieces of essential information that need to be obtained when a new site is being considered for small hydro scheme. First, one has to identify whether there is a significant energy resource. This involves estimating or measuring the flow and available head, and estimating what annual energy capture would result. If the potential output of a scheme is attractive then one need to be certain that permission will be granted by the federal and state government to use all the land required both develop the scheme and to have the necessary access to it. Finally, there needs to be a clear destination for the power (BHA, 2005).

The flow duration curve FDC, is used to assess the expected availability of flow over the time and the power and energy at a site and to decide on the “design flow” in order to select the turbine. Therefore, a stand-alone system such as a small hydropower system should be designed according to the flow that is available all year round; this is usually the flow during the dry and wet season. It is possible that some streams could dry up completely at that time. Ideally, minimum flow over the year should be taken to calculate the design flow to ensure that power is available year-round. Normally, only a fraction of the available flow in the stream is used for power generation. Therefore, FDC is less important as the size of system decreases. If the system’s generating capacity is less than 10kW or so, FDC may not be relevant at all (micro-hydropower systems, 2006).

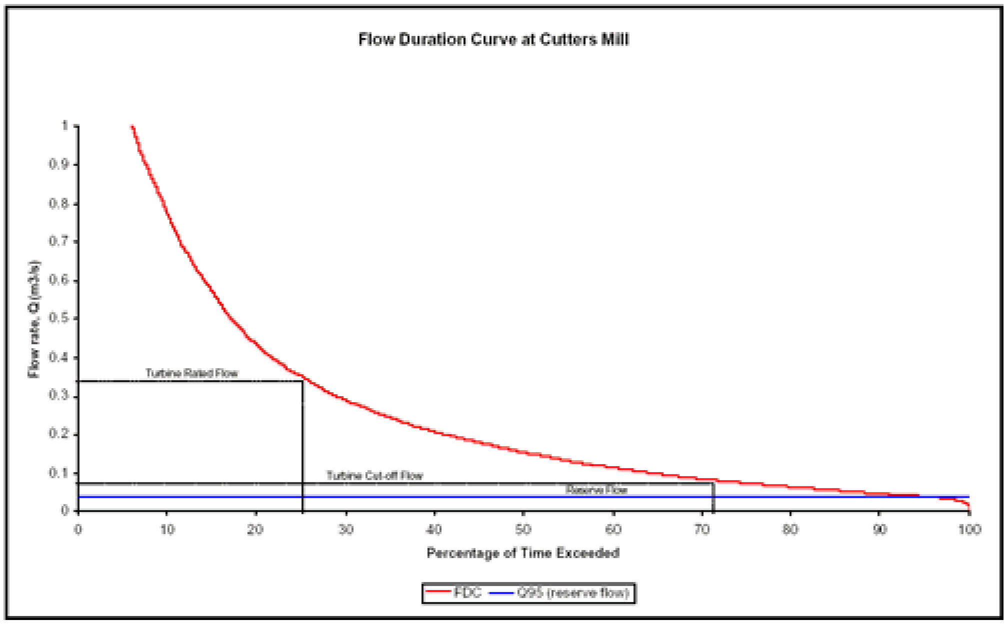

Figure 4: Flow Duration Curve.

ASSESSING POWER AND ENERGY REQUIREMENTS IN SMALL HYDRO-SYSTEM

In assessing the feasibility of developing a small hydropower system, one should carefully examine the power and energy requirements. The power one need is the instantaneous intensity of electricity required to power the appliances one use: this is measured in kilowatts.

The sizes of micro – turbines, small, and micro hydro are shown in Table 1.

Table 1: Various Types of Hydropower Schemes.

	Technology	**Typical available size P-module**
1	Micro-Turbines	35-KW-1MW
2	Small Hydro	1-100MW
3	Micro Hydro	25KW-1MW

(Source: Varlerijs Knazkins, 2004).

From Table 1, small hydro plants are in the range of 1-100MW. The amount of electricity generated is the result of the head and the flow rate at a specific site. The power generated also depends on the turbine generator efficiency and pressure losses at the intake and penstock. It is also important to note that available energy depends on the day to day and year to year variations of the flow. The formula to convert the water and the head into power is given by:

$$P = Q \times H \times 8 \qquad \textbf{(2)}$$

where P = Power (KW), Q = Water flow (m^3/s), H = Net head (m). Source: ESHA (1998), Layman's Handbook on How to Develop a Small Hydro Site. It is unlikely that schemes using significantly more than the mean river flow (Q_{mean}) will be either environmentally acceptable or economically attractive. Therefore, the turbine design flow for a run – of river scheme (a scheme operating with no appreciable water storage) will not normally be greater than Q_{mean} The greater the chosen value of the design flow, the smaller proportion of the year that the system will be operating on full power, ie it will have a lower 'capacity factor'. The capacity factor is the ratio summarizing how hard a turbine is working expressed as follows:

$$\text{Capacity factor (\%)} = \frac{\text{Energy generated per year (kWh/year)}}{\text{Installed capacity (kW) x 8760 hours/year}} \qquad \textbf{(3)}$$

A first estimate of how capacity factor varies with design flow is given as:

Design flow Qo (Q_{mean})	Capacity Factor
$0.75Q_{mean}$	40%
$0.5Q_{mean}$	50%
$0.33Q_{mean}$	70%

Source: Hydro web guide, 2006.

The peak power P can be estimated from the design flow Qo and the head H as follows:

$$P\ (KW) = 7.8 \times Qo\ (m3/s) \times H \qquad \textbf{(4)}$$

The annual energy output is then estimated using the capacity factor (CF) as follows:

$$\text{Energy (kWh/year)} = P\ (kW) \times CF \times 8760 \qquad \textbf{(5)}$$

There is clearly a balance to be struck between choosing a larger, more expensive turbine which takes a high flow but operates at low capacity factor and selecting a smaller turbine which will generate less energy over the year, but will be working flat out for more of the time ie a higher capacity factor.The capacity factor for most small hydro would normally fall within the range of 50% to 70% in order to give a satisfactory return on the investment. Table 2 show sample load analyses for some appliances.

Table 2: Sample Load Analyses.

Appliance	**Power Rating (watts)**	**Hours Per day**	**Hours Per mouth**	**Monthly (KWh)**	**Annual (KWh)**
Four Florescent lamps	200	8	240	48	576
Colour television	100	4	120	12	144
Refrigerator	300	10	300	90	1080
Water pump	1000	1.5	45	45	540
Computer	200	12	360	72	864
Total Energy consumption				267	3204

(Source: Energuide Canada, 2006)

It is important to work out total energy consumption and peak power consumption because a situation may arise in which the system could meet one need but not the other. It is good to compare the power needs with what is available from the scheme (calculate using the head and flow rate). If the monthly energy requirements are greater than the micro hydropower system can generate in a month, then the consumption need to be reduced so that it at least matches the available energy but in some cases, electronic load controller connected to the generator could be use to give the balance. In many small hydropower systems, the peak power demand is more likely to define the design capacity of the turbine rather than the system energy requirement.

When analyzing and optimizing a small hydropower system, it is imperative to remember that conservation is the most powerful factor, thus saving energy is always cheaper than producing more power.

THE COST OF SMALL HYDRO AND ITS FINANCIAL PROFITABILITY

Costs per Kilowatt Installed

The capital cost of small hydro plants, limited to shaft power, ranged from 99,960 naira (Nepal, Zimbabwe) to 172,620 naira (Mozambique). The average cost is 135,100 naira per installed KW which is in line with figures quoted in some studies (final synthesis report, BPSOHDC, 2000).

An important observation is that the cost per installed kilowatt is higher than the figures usually cited in the literature. This is partly due to the difficulty analysts have in establishing full cost on a genuinely comparative basis. A significant part of small hydro cost can be met with difficult to value labour provided by the local community as 'sweat equity'. Meaningful dollar values for local cost are difficult to establish when they are inflating and rapidly depreciating relative to hard currencies. In addition, there is little consistency in the definition of boundaries of the systems being compared, for instance, how much of the distribution cost, or house wiring, is included, how much of the cost of the civil works contribute to water management and irrigation and so forth.

It is of paramount importance to distinguish between schemes limited to mechanical power only and schemes which include electricity generation in order to produce estimates of the actual costs on a rigorously comparable basis. (Small Khennas, Andrew Barneth, 2000). A summary of financial returns on sampled micro hydro plants after financing is shown in Table 3.

The lowest cost per kilowatt installed were found in Gorkhe, originally built to supply mechanical power, Svinurai, Chifotu and Elias which supply power only.

Electricity generation schemes are expected to have a higher installed cost per kilowatt. There are also some differences between countries and even within the same country which might be explained by the following parameters: site characteristics, transport to site (in Nepal transport is said to constitute 25% total cost), labor content and wide variation between the cost of labor in the countries studied, standards, sizing (municipal plants in peru were often oversized) and transmission and distribution cost (World, Bank, 2000).

A major conclusion can be drawn from this: cost are highly site specific, are controllable with good management, proper sizing and appropriated standards. Furthermore, a major advantage of small hydro is that it can be built locally at considerably less cost than it can import and the costs of local manufacture can be reduced still further by developing local engineering capabilities and advisory services. For instance in Sri Lanka imported turbine generating sets up to 100kW cost approximately Rs.50,000 to Rs.150,000 (98,000 naira – 280,000 naira) per kW, while the local manufacturer are now capable of delivering them at RS. 10,000 to RS.15, 000 (19,600 naira – 28,000 naira) per kW with marginally reduced turbine efficiencies (Sri Lanka Report section 5.3).

Financial Probability of Small Hydro

At a more fundamental level, variations in financial performance of hydro project are due to variation in load factor. High load factors are achieved in schemes supplying power to motors rather than those installed primary for lightning. In Nepal, 90% of the hydro schemes are supplying mechanical power these schemes have a better profitability and can be financially sustainable in remote locations.

Table 3: Summary of Financial Returns on Sample Micro Hydro Plants After Financing.

	Year of Installation	Capacity kW	Cost per installed kW	IRR_{CI} %		IRR %		End-uses (main end use cited first)
Sri Lanka				cur	con*	cur	con	
Katepola	1994	35	$2,181	14.7	8	No return		Electricity for domestic end uses and services
Kandal Oya	1997	10	$3,115	15	9.3	10	6.9	Electricity for domestic end uses and services
Pathavita 2	1997	10	$2,203	32	16.3	6	3.1	Electricity for domestic end uses and services
Seetha Eliya	1983	60	$3,761	24	12.4	24	12.4	Tea factory. Electricity for domestic end uses
Nepal				cur	con	cur	con	
Barpak	1992	50	$2,345	33	27	22.8	17	Mechanical power (milling etc); Electricity for domestic end uses
Gorkhe (Rupatar)	1984-6	25	$714	42	32	17.4	4	Mechanical power (milling etc); Electricity for domestic end uses
Ghandruk	1985-8	50	$2,446	10.48	1	No return		Electricity for domestic end uses; Mechanical power (milling etc);
Gaura	1987	25	$2,277	13.2	3	7.39	NA	Mechanical power (milling etc); Electricity for domestic end uses
Peru				cur	con	cur	con	
Atahualpa	1992	35	$2,358	NA		17.5	14.5	Electricity for domestic end uses and services; Mechanical power
Yumahual	1998	11	$3,371	NA		17.6	14.6	Electricity for incubating plant
Pedro Ruiz	1980	200	$5,630	NA		No Return		Electricity for domestic end uses and services
Pucará	1986	2x200	$1,136	NA		7	3	Electricity for domestic end uses and services
Zimbabwe				cur	con	cur	con	
Nyafaru	1995	20	$3,307	Grant		8	NA	Electricity for domestic end uses and services
Svinurai	1993	13	$715	Grant		48	20	Mechanical power only (grain milling)
Mozambique				cur	con	cur	con	
Elias	1996	15	$1,200	NA		insufficient accurate data		Mechanical power only (grain milling)
Chitofu	1995	15	$1,233			insufficient accurate data		Mechanical power only (grain milling)

Source: *London Economics and Delucia Associates.*

The small hydro industry appears, therefore to be faced with a particular difficult paradox. Most of the financial viable installations provide mechanical power to productive enterprises, but the man demand from consumers in a number of countries appears to be fore electric lighting.

Small and micro hydro is therefore most likely to be profitable or at least finally self-sustaining, where there is: a high load factor (the actual consumption as a proportion of total possible generations).

CONCLUSION

Actions should be taken at the national, regional, and international levels to accelerate the market of small hydro energy technologies and increase investment in research development especially by developing countries, in order to enhance efficiency and reduce up-front costs. Significantly increasing the use of small hydro faces a number of challenges.

Government policies have a significant impact on attracting private sector investment and the pace of expansion of small hydro energy as demonstrated in several developed and developing countries. Experience has shown that successfully scaling up the use of small hydro-energy include: creating supportive policy, legal and institutional frameworks, securing public sector commitment including for Research and Development and Procurement policies, promoting private sector involvement and a stronger alignment between policy time frames and timelines for investment, supporting the establishment of small hydropower plants industries including small and medium enterprises and providing access to affordable finance including micro-finance and consumers-mechanism.

Finally, there is need to enhance international cooperation of capacity building in developing countries for strengthening national policy frameworks and the integration of hydro energy use into new sustainable development strategies for poverty reduction, health, education and agriculture; enhancing national capacity for research and development and transfer and diffusion of small hydro energy technologies; establishing markets for small hydro technology; increasing access to finance; enterprise development for sourcing; installing, operating and maintaining small hydro energy systems; and combining the increased use of small hydro energy efficiency and greater application of cleaner fossil fuel technologies.

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SUGGESTED CITATION

Uhunmwangho, R. and E.K. Okedu. 2009. "Small Hydropower for Sustainable Development". *Pacific Journal of Science and Technology.* 10(2):535-543.

Pacific Journal of Science and Technology