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Micro Hydro Energy Resources in Bangladesh: A Review

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Abstract: A reliable, affordable and secure supply of energy is important for economic development. This has been true for the past and present and will remain valid for the future. However, over time, changes have taken and will take place with regard to energy use, both with regard to the amount as well as with regard to the type of energy used. Many factors have played a role in bringing these changes. Availability, security of supplies, price, ease of handling and use, external factors like technological development, introduction of subsidies, environmental constraints and legislation are some of these factors. The following research paper is an in-depth scenario and analysis of the micro hydro energy in Bangladesh. We represent a look into a time tested, yet underused technology driven by water. Included within this document is an introduction to micro hydro system and how they apply specifically to power generation. Yet the source of micro hydro energy (lakes, rivers, and streams) remains untapped. The exploitable hydro capability in Bangladesh is one of the foremost primary energy resources but the current utilization of this potential is very low. The overall energy scenario will be ameliorated, if this exploitable source of energy could be harnessed using sustainable technology.

Key words: Energy, Micro hydro power, Bangladesh

INTRODUCTION

Water has been used as an energy source for thousands of years, with ancient civilizations using water to drive mills through the use of water wheels. Technology has grown over time, and the potential for water as a power source continues to be prominent. Large-scale examples such as the Hoover Dam and the Grand Coulee Dam are used to power large-scale projects (Rachel Beckett, 2006).

Modern times are calling for a clean, efficient renewable energy source. A possible solution for a number of instances is the implementation of micro hydro power systems. Micro hydro is the well-known principle of using water to drive a turbine and generate electricity; however micro hydro is implemented on a much smaller scale including private residences and businesses. Not only micro hydro is a non-polluting energy source, but also it is much more efficient than the burning of fossil fuels for electricity generation. In respect to coal burning, the most common energy source, micro hydro power is greatly more efficient. Efficiency of micro hydro units range 60% to 90% while modern coal burning units are 43% to 60% efficient (Rachel Beckett, 2006).

Micro hydro power systems are able to generate electricity by using the movement of water from small streams to rotate a wheel or turbine in order to spin a shaft. The shaft's motion is used to power an alternator or generator that converts the rotational energy to electricity. The most common type of current used in micro-hydro systems is a combination of AC and DC power. Following this, an inverter is used to convert the low voltage DC power produced by the system into 120 or 240 volts of AC power for the home. A regulator can also be used to control the electricity being sent to the home for use (Rachel Beckett, 2006; Energy efficiency and Renewable, accessed on July. 29, 2007).

The major advantage of hydroelectricity is elimination of the cost of fuel. Hydroelectric plants are immune to increases in the cost of fossil fuels such as oil, natural gas or coal, and do not require fuel to be imported. Hydroelectric plants tend to have longer lives than fuel-fired generation, with some plants now in service having been built 50 to 100 years ago. Operating labor cost is usually low since plants are automated and have few personnel on site during normal operation (Answers. com: Micro Hydro. accessed on July 29, 2007).

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Hydroelectricity eliminates the flue gas emissions from fossil fuel combustion, including pollutants such as sulfur dioxide, nitric oxide, carbon monoxide, dust, and mercury in the coal. Compared to the nuclear power plant, hydroelectricity generates no nuclear waste, nor nuclear leaks. Unlike uranium, hydroelectricity is also a renewable energy source. Hydroelectricity is also cheaper than nuclear power. Compared to wind farms, hydroelectricity is more reliable and more powerful, and can be regulated to suit variations in power demand. Hydroelectricity is also cheaper than electricity from wind farms (Answers. com: Micro Hydro. accessed on July 29, 2007). Fig. 1 shows a typical hydraulic turbine and electrical generator. In this study, a review of the country's primary resources and their use, electricity generation and consumption and the overall scenario of micro hydro as renewable energy source are presented.

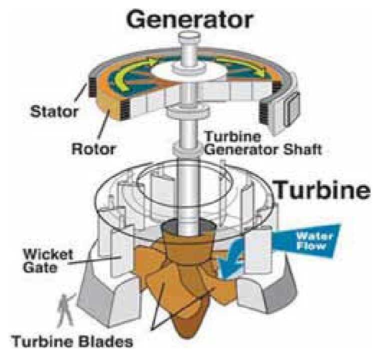

Fig. 1: Hydraulic turbine and electrical generator (Answers. com: Micro Hydro. accessed on July 29, 2007).

Bangladesh: Location, Topography and Economy:

The People's Republic of Bangladesh-a south-Asian country-is located between 23°34¢N and 26°38¢N latitudes and 88°01¢E and 92°41¢E longitudes. The Indian states west Bengal, Meghalaya, Assam and Tripura are on the west, the north and the east borders respectively (Hossain, A.K. and O. Badr, 2007; Bangladesh Bureau of Statistics. accessed on August 19, 2007), sharing 3715.18 km of common border (Rofiqul Islam, M. *et.al.* 2008). Bangladesh also shares its border with Myanmar on the southeast corner. In the south, the country has a long coast along the Bay of Bengal (Hossain, A.K. and O. Badr, 2007; Bangladesh Bureau of Statistics. accessed on August 19, 2007), The country is divided into 6 divisions (regions): Dhaka, Chittagong, Rajshahi, Barisal, Sylhet and Khulna. In these regions, there are 64 districts (Fig. 2) and more than 87,319 villages. The total area of the country is of 147,570 km^2 (Hossain, A.K. and O. Badr, 2007; Bangladesh Bureau of Statistics. accessed on August 19, 2007), The coastline of the Bay of Bengal is 66,400 km (Bangladesh Bureau of Statistics. accessed on August 19, 2007), In 2006-2007, the population of Bangladesh provisionally reached 140.6 million, making it the most densely populated country in the world. Of the total population, 80% resided in rural areas (Bangladesh Bureau of Statistics. accessed on August 19, 2007), The main rivers are Padma (Ganges), Jamuna, Meghna, Bramhaputra, Surma and Karnafuli. More than 90% of Bangladesh's rivers are originates outside the country. Three major types of landscapes are found in Bangladesh: floodplains (80%), terraces (8%), and hills (12%). Excepting the eastern hilly region, almost all of the country lies in the active delta of three of the world's major rivers: the Ganges, the Brahmaputra, and the Meghna (GBM). The Jamuna-Padma-Meghna river system divides Bangladesh into east and west (Fig. 2). 1.35 trillion m^3 of water flows through the country in an average water year. Numerous rivers flow across the country, which are mostly tributaries of these main rivers. Out of these, 57 rivers are Tran boundary, which originate from India and Myanmar. Apart from the south-eastern region, other parts of the country are mostly flat in nature. Major rivers of the country have high flow rate for about 5-6 months during monsoon season, which is substantially reduced during winter. More than 90% of Bangladesh's rivers originate outside the country (Rofiqul Islam, M. *et.al.* 2008).

The climate in the country follows a four-season cycle: winter (December-February), summer (March-May), monsoon (June-September) and autumn (October-November). In winter, the average maximum and minimum temperatures are 26.5 and 13.5°C, respectively, whereas the corresponding respective values in summer are 33.3 and 22.2°C (Hossain, A.K. and O. Badr, 2007; Sustainable Development Networking Programme.accessed on August 19, 2007). Average annual temperature is 26^0C and while rainfall is 2540 mm (Hossain, A.K. and O. Badr, 2007; Bangladesh Bureau of Statistics. accessed on August 19, 2007). The sectors of the country's economy are agriculture and forestry, fishing, mining and quarrying, manufacturing, construction, electricity and gas, transport and communication, wholesale and retail trade, financial services and other services (e.g.

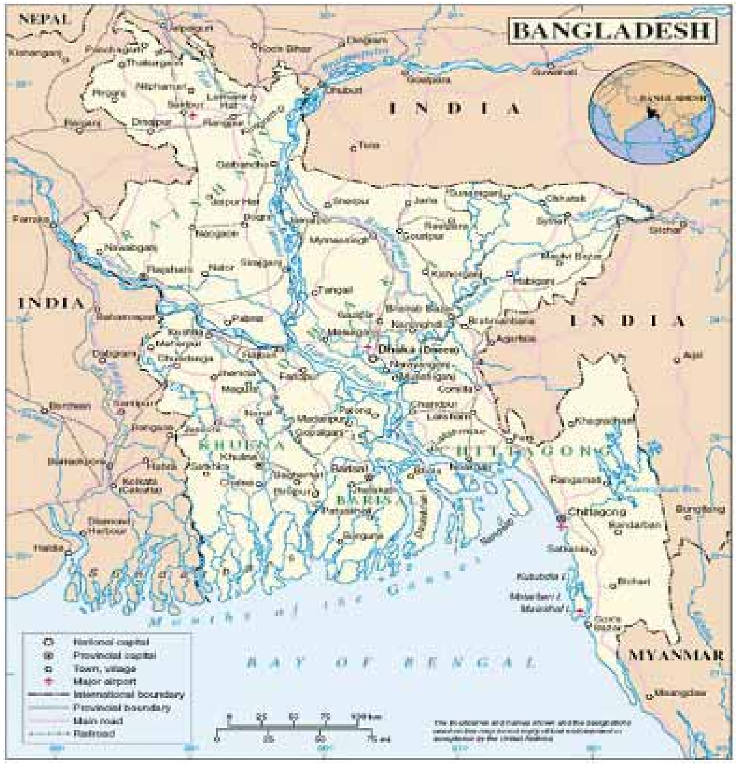

Fig. 2: Location, divisions and districts of the People's Republic of Bangladesh.

tourism, real state business). During the last 5 years, Bangladesh averaged over 5% growth in the GDP (Hossain, A.K. and O. Badr, 2007; Energy Information Administration. accessed on August, 2007. The national currency of the country is Taka, its exchange rate is US$1 = Taka 69.04 (as on 20/08/2007). Table 1 gives some of the national statistics of Bangladesh (Bangladesh Bureau of Statistics; Rofiqul Islam, M. *et.al.* 2008; World Bank. accessed on August. 22, 2007; Government of the People's Republic of Bangladesh, Bangladesh economic review 2007.

Table 1: National statistics of Bangladesh.

Indicators	1991	1995	2003	2005	2006
Population (million)	111.45	119.8	135	138.6	140.6
Urban population (%)	17.20	22.00	23.10	24.17	NR
Population in below poverty level (%)	47.00	45.80	44.30	40.00	NR
Land area (km^2)	147,570				
GDP (US$ in billion)	26.50	32.06	54.00	60.00	67.71
Industrial GDP (%)	22.14	24.18	27.80	27.2	27.91
Services GDP (%)	49.45	50.98	49.37	52.6	52.48
Agriculture GDP (%)	28.13	24.83	22.83	20.1	19.61
GDP per capita (US$)	241	336	363	463	476
Life expectancy at birth (years)	56	58	64.9	65.1	NR
Literacy rate (%)	38.8	43.2	48.8	50.0	NR

NR- Not reported

Commercial Primary Energy Resources and Use in Bangladesh:

Indigenous commercial primary energy resources of Bangladesh consist of the known reserves of natural gas and coal, and a limited hydroelectric capacity. The entire reserves of exploitable indigenous fossil fuels, with the exception of the coal reserve, are located in the eastern part of the country. This results in a gap of commercial energy supply between the east and the west.

Currently, the country has only one coalmine operation project at Barapukuria in Dinajpur district. The project has a target to provide 1.0 million tons of coal per annum from the Barapukuria coalfield. It is planned that 85% of its annual production will be utilized to produce electricity; the rest will be used as fuel for brick making. and other purposes. In the fiscal year 2004-2005, 74767.78 metric tons coal has been sold from the field for brick burning. The mining operations may continue up to 70 years from its inception. Bangladesh also has two other coalfields: 1000 million tons at Jamalganj and 450 million tons at Khalaspur. Early estimations suggest that it will not be techno-economically feasible to extract coal from Jamalganj reserve. The country has about 170 million tons of peat reserve in its southern regions. However, recoverable reserve is yet to be determined and the energy resources are not likely to be tapped in near future (Rofiqul Islam, M. *et.al.* 2008).

Natural gas is currently the only indigenous non-renewable energy resources of the country, which is being produced and consumed in significant quantities since 1970. Bangladesh is going to run out of gas in the next 25 years. Gas, the main sources of commercial energy, plays a vital role towards the growth of the economy of Bangladesh. The gas market is dominated by power and fertilizer (using gas as feedstock) sectors, which account for 55.18% and 17.91% of the demand in 2006 (Government of the People's Republic of Bangladesh, Bangladesh economic review 2007.). Table 2 shows the natural gas production and sector wise its consumption. Various marketing companies under the Bangladesh Petroleum Corporation (BPC) distribute kerosene and diesel throughout the country at a uniform tariff rate set by the government. Around 32% have access to electricity, while in rural areas the availability of electricity is only 22%. But the quality of power services in rural areas is very poor; there are reports of frequent voltage fluctuations, unreliable and erratic supply. Only 3-4% of the households have connection of natural gas for cooking purposes. Only about 2-3% households use kerosene for the same purpose and the rest (over 90%) of people depend on biomass for their energy needs (Rofiqul Islam, M. *et.al.* 2008; Islam, M.N. Energy security issues of Bangladesh,2000.

Table 2: Sector wise consumption of natural gas (Government of the People's Republic of Bangladesh, 2007).

Yea	Gas production (Billion ft^3)	Sector wise consumption (Billion ft^3)									
		Electricity generation	Captive power generation	Fertilizer production	Industrial use	Tea gardens	Brick fields	Commercial use	Cooking	CNG	Total
1990-91	172.84	82.60		54.20	13.20	0.70	0.00	2.90	10.50	0	164.10
1991-92	188.48	88.10		61.60	13.40	0.70	0.20	2.90	11.60	0	178.50
1992-93	210.98	93.30		69.20	15.20	0.70	0.20	2.40	13.50	0	194.50
1993-94	223.76	97.30		74.50	20.26	0.70	1.10	2.87	15.40	0	212.13
1994-95	247.38	107.40		80.50	24.24	0.60	1.10	2.88	18.86	0	235.58
1995-96	365.51	110.90		90.98	27.31	0.72	0.99	3.00	20.71	0	254.61
1996-97	260.99	110.82		77.83	28.62	0.71	0.48	4.49	22.84	0	245.79
1997-98	282.02	123.55		80.07	32.32	0.74	0.39	4.61	24.89	0	266.57
1998-99	307.48	140.82		82.71	35.79	0.71	0.35	4.71	27.02	0	292.11
1999-00	332.35	147.62		83.31	41.52	0.64	0.35	3.85	29.56	0	306.85
2000-01	372.16	175.27		88.43	47.99	0.65	0.44	4.06	31.85	0	348.69
2001-02	391.53	190.03		78.78	53.56	0.72	0.53	4.25	36.74	0	364.61
2002-03	421.16	190.54		95.89	63.76	0.74	0.52	4.56	44.80	0.23	401.04
2003-04	454.59	199.40	32.03	92.80	46.49	0.82	0.12	4.83	49.22	1.94	427.65
2004-05	486.75	211.02	37.87	93.97	51.68	0.80	0.0	4.85	52.49	3.62	456.30
2005-06	522.55	224.39	48.86	89.09	63.26	0.76	0.0	5.21	56.75	6.83	495.15

Total commercial primary energy consumption in Bangladesh increased per year between 1972 and 2005 (Fig. 3). The trend is mainly due the increased consumption of indigenous natural gas and imported oil. The contribution of hydropower to total commercial primary energy consumption is almost constant. In 2005, the shares of natural gas, oil, coal and hydroelectricity to total primary energy consumption were 73.6%, 23.0%, 2.3% and 1.7%, respectively (British Petroleum. B.P., 2006. plc). Per capita annual energy consumption of commercial primary energy (i.e. fossil fuels and hydroelectricity) in Bangladesh is one of the lowest in the world, compared with a world average of 1.556 toe/capita/year (Hossain, A.K. and O. Badr, 2007; World Bank; 2007; B.P Plc. 2006). The energy consumption (in million tonne of oil equivalent) in south-Asia is shown in Table 3. The per capita energy consumption in Bangladesh is 89 kgoe/y (The World Energy Book, 2005). far behind the other SAARRC countries like India, Pakistan, Bhutan, Sri Lanka etc.

Table 3: Energy consumption (in million toe) in South Asia (The World Energy Book, 2005)

	Bangladesh	Bhutan	India	Nepal	Pakistan	Sri Lanka
Biomass	16.64	0.29	139.30	7.40	23.36	3.58
Coal	0.00	0.01	166.90	0.17	3.30	0.00
Oil products	3.71	0.04	116.00	0.77	15.21	3.01
Natural gas	8.29	0.00	29.74	–	27.39	0.00
Hydro-electricity	0.23	0.12	17.69	0.14	6.47	0.83
Nuclear	0.00	0.00	5.33	0.00	0.42	0.00
Total energy consumption	28.87	0.46	474.95	8.48	76.15	7.42
Total commercial energy consumption	12.23	0.17	335.66	1.08	52.79	3.84
Per capita (kgoe/y)	89	243	315	44	355	200

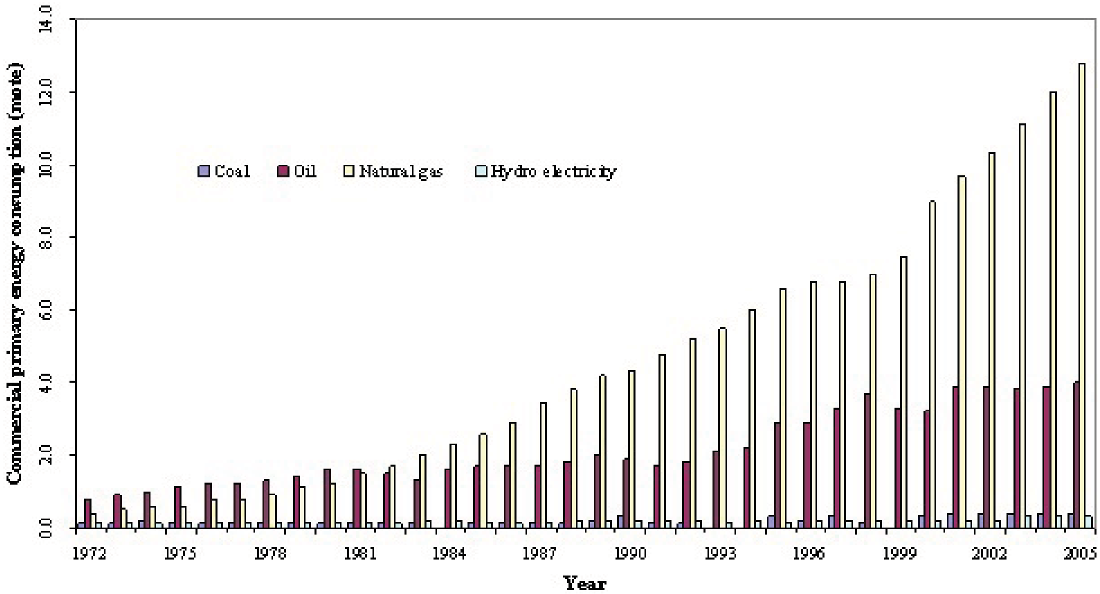

Fig. 3: Commercial primary energy consumption trends in Bangladesh (BP pic 2006).

Electricity Generation and Transmission in Bangladesh:

BPDB was established in 1972 as a public-sector organization with the responsibility for power generation, transmission and distribution of electricity throughout the country. Organizational changes were subsequently introduced to the transmission and distribution sectors. In 1977, the Rural Electrification Board (REB) was created and in 1991 the Government of Bangladesh (GOB) established the Dhaka Electric Supply Authority (DESA) to operate and develop the distribution system in and around Dhaka and bring about improvements in customer service, collection of revenue and lessen the administrative burden on BPDB. To increase the efficiency of the distribution system and for better customer service, the GOB implemented different reform programmes. As part of such programmes, two companies, the Power Grid Company of Bangladesh (PGCB) and the Dhaka Electric Supply Company (DESCO), were established in 1996 and 1997, respectively (Hossain, A.K. and O. Badr, 2007; Bangladesh Power Development Board. 2007). The distribution network area of DESA has been re-defined, with some area being allocated to DESCO for better management. In December 2002, all distribution networks were transferred to PGCB, which is now the sole authority for operation, maintenance and extension of the distribution network in the country (Hossain, A.K. and O. Badr, 2007; GPRB, 2007).

In order to develop the country's power sector, power generation and distribution were opened to both national and foreign private investments in 1996. This was followed by the formulation of 'Private Sector Power Generation Policy of Bangladesh' by the GOB. The involvement of Independent Power Producers (IPPs) was made effective after October 1996. The country's first private power plant (with a 110MW installed capacity) started feeding power to the national grid in October 1998 (Hossain, A.K. and O. Badr, 2007; GPRB, 2007;BP pic 2006). In summary, the utilities responsible for generation of electricity are: (i) Bangladesh Power Development Board (BPDB), which is the largest authority to generate electricity from the conventional sources (like indigenous gas, hydro, diesel, furnace oil) and (ii) Rural Electrification Board (REB), distributing electricity in the rural areas and generating electricity through Independent Power Producers (IPPs). Distribution of electricity to the consumer end is performed by BPDB, Dhaka Electric Supply Authority (DESA), Dhaka Electric Supply Company Ltd. (DESCO) and REB(Rofiqul Islam, M., *et al* 2008).

As on June 2006, in FY 2006, BPDB has total installed capacity of 5245 MW at 103 units (BPDB 3985 MW at 66 Unit and IPP (mixed) 1260 MW at 37 units) of Power Plants located at different parts of the country. The main fuel used for power generation is indigenous gas. The gross energy generated in the public sector under BPDB was l 15,417 Gwh. In addition, 8286 Gwh of energy was purchased by BPDB from Independent Power Producers (IPP) in the private sector. The maximum demand served during peak hours is 3782.1 MW in October, 30, 2005. The transmission network of BPDB (now PGCB) is 3919 route km long comprising 230, 132 and 66 KV lines. The total numbers of grid sub-stations are 93 (7 BPDB, 74 PGCB &

Others 12) and the total capacity is 13,309 MVA(BPDB, 2007) . In the fiscal year 2005 -06, the per capita electricity generation is 165 kWh and it is expecting to be 170 kWh in FY 2006-07(BBS, 2007 . Different types of power plants generate electricity and synchronize it with the national grid. In addition to grid-connected power plants, there are some isolated diesel engine power stations at remote areas and islands. The electricity generation in Bangladesh between 1990 and 2005 is shown in Fig. 4. The classification of the total installed capacity of both BPDB and IPP according to plant and fuel type and sector of production are shown in Fig.5.

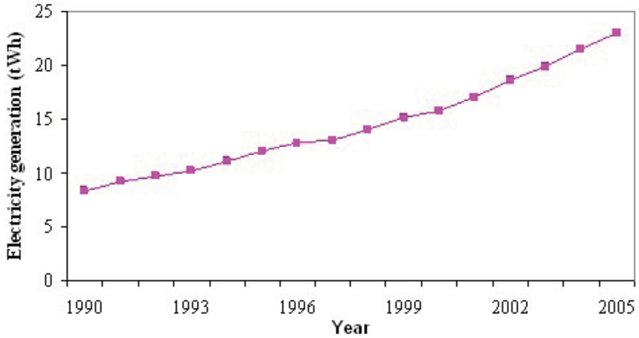

Fig.4: Electricity generation (Terra watt-hour) in Bangladesh(BP Plc, 2006).

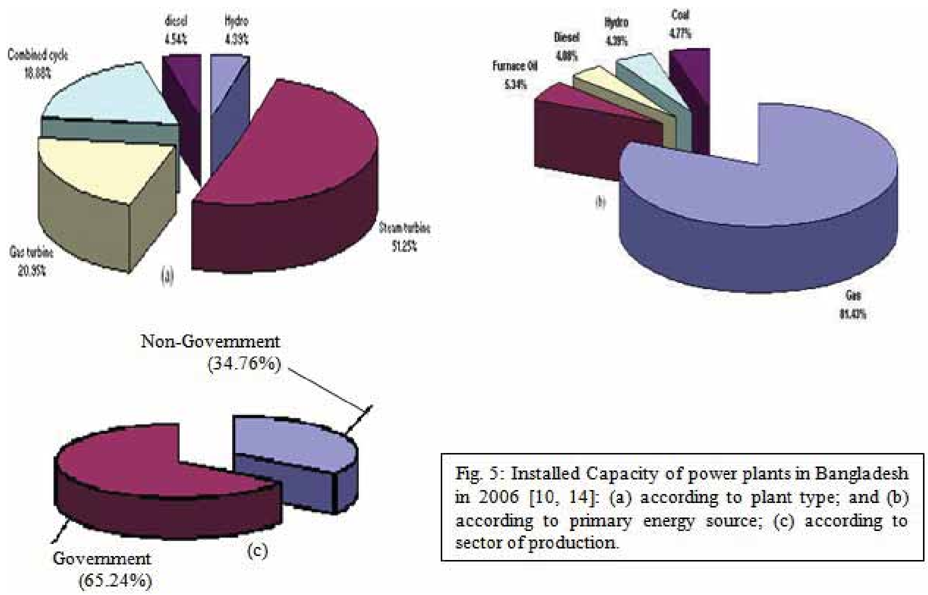

Fig. 5: Installed Capacity of power plants in Bangladesh in 2006 [10, 14]: (a) according to plant type; and (b) according to primary energy source; (c) according to sector of production.

All natural gas fields are situated in the eastern part of the country. In this part, electricity is generated in gas-fired thermal power stations and a small percentage through hydropower. In the western part, imported oil is used for the generation of electricity. The fuel cost per kWh of the electricity generated in the western part is much higher than that in the eastern part. Low-cost electricity, generated in the eastern part, is transferred to the western part through the 230kV East-West Inter connector transmission line. BPDB owns and operate the high-voltage transmission network throughout Bangladesh(Hossain, A.K. and O. Badr, 2007; Bangladesh Power Development Board. 2007). Electricity has been generating from natural gas since 1970 and from the last two decades it's share being dominating. Generation of electricity from natural gas was 81.43% of total generation in 2006(GPRB, 2007). Table 4 shows the total electricity generation (In millions of kilowatt hours) and electricity generated using natural gas(BANGLADESH, 2007).

Table 4: The total electricity generation and electricity generated using natural gas (In millions of kilowatt hours) (Bangladesh, 2007).

Year	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06
Electricity Generation	14,450	15,563	17,021	12,881	13,342	14,067	15,542
Based on natural gas	12,603	13,266	13,302	11,331	11,548	12,171	13,384

Electricity Consumption in Bangladesh:

Industrial and domestic sectors are the main consumers of the electricity (Hossain, A.K. and O. Badr, 2007; Bangladesh Power Development Board. 2007). Only 20% of the population (25% in urban areas and 10% in rural areas) are connected to grid electricity, with the vast majority (80%) being deprived of conventional supplies (Hossain, A.K. and O. Badr, 2007; eia, 2007) . REB has been supplying electricity to rural areas through a number of Rural Electrification Societies, known as 'Polly Biddut Samity' (PBS). As of December 2006, 70 of these were operating commercially in the country. There are 71,41,324 customers (residential 60,56,150; pump for irrigation 1,99,948; commercial 7,53,727; industrial 1,17,586, others 13,913) in 46,523 villages. This required the installation of distribution lines with a total length of 210,328-km and 328, 33/11 kV grid sub-stations(GPRB, 2007). The consumption pattern of BPDB's electricity for fiscal year 2006 is shown in Fig. 6(bpdb, 2007).

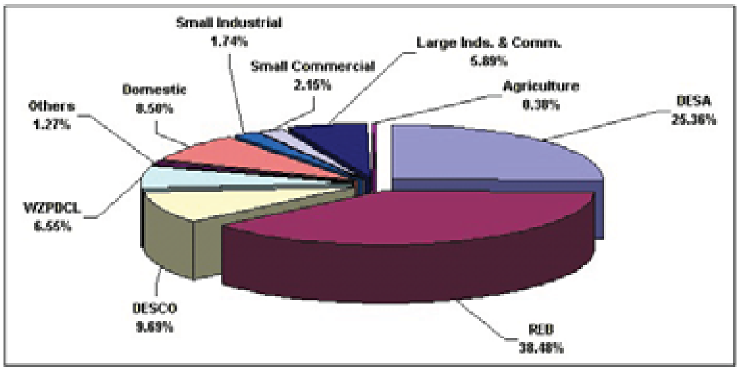

Fig.6: Consumption pattern of electricity under BPDB in FY 2006

Hydropower Background:

Hydro power is the generation of electrical energy by harnessing water's kinetic energy created by gravity. Hydro power is centered on the efficiency of the water's kinetic energy converting to electrical energy. In hydro power, the kinetic energy of the water depends on two aspects, head and flow. The head refers to the vertical distance the water travels and the flow refers to the volume of the water that passes through the turbine in a given amount of time(Rachel Beckett, *et al,*2006) . The head of a site is the vertical distance from the source, the surface, to the point of the water's outflow (Micro-hydro power, 1989). When evaluating a potential site, head is usually measured in feet, meters, or units of pressure. Head also is a function of the characteristics of the channel or pipe through which it flows(eere, 2007) . The flow of the site is a volume of fluid that passes through a given area per unit of time (Micro-hydro power, 1989). The flowing water moves through the system and pushes the turbine to make it spin. The spinning of the turbine is turned into electricity by means of a generator. The electrical energy created is usually stored in a battery which can then power electrical objects in house, such as appliances and lights. When looking at the full process of micro hydro power and the transference of energy from one form to another, one must also take into account that there are no toxic emissions because micro hydro is a very environmentally friendly source of power (Rachel Beckett, *et al,*2006).

As with any other type of renewable energy source, there are many types of hydro power. This includes impoundment, diversion, and pumped storage. Impoundment describes a certain hydro facility where a dam is used to store water. The water is used to run the turbine to create the electrical energy. These are the most widely recognized styles although they are actually not very common and are quite infeasible for most residential areas due to their costs and complexities. Diversion is almost the same except it channels a portion of the river through a canal or penstock. Diversion is also called a "run-off-river," in some cases. Pumped storage, another type of micro hydro utility, needs its own facility. In pumped storage, water is pumped from a lower reservoir to an upper reservoir. When water is released from the top, energy is created. Of these methods, diversion is mostly used in real-world examples (Rachel Beckett, *et al,*2006; Answers. com, 2007).

There are many sizes of hydro power that have been used in the past. Large hydropower, as defined by the United States Department of Energy, has capacities greater than 30 megawatts (MW). Small hydropower, the medium segment of hydro power usage, describes capacities between .1 and 30 MW. Table 5 outlines the categories used to define the power output from hydropower. Micro hydro power is more appropriate for the residential use. One Hundred Kilowatts of power is sufficient for a residential household. Anything greater would be simply wasteful (Micro-hydro power, 1989).

Table 5: Classification of hydropower by size (Micro Hydro Systems, 2007; Fraenkel P., O. Paish, 1991).

Large- hydro	More than 100 MW and usually feeding into a large electricity grid
Medium-hydro	15 - 100 MW - usually feeding a grid
Small-hydro	1 - 15 MW - usually feeding into a grid
Mini-hydro	Above 100 kW, but below 1 MW; either stand alone schemes or more often feeding into the grid
Micro-hydro	From 5kW up to 100 kW; usually provided power for a small community or rural industry in remote areas away from the grid.
Pico-hydro	From a few hundred watts up to 5kW

Micro hydro power is a site-specific type of renewable energy. Each different site requires a separate evaluation in order to determine the energy output. A micro hydro application is generally installed in home areas or any place where a small stream can be harnessed for power. This means that each individual site will most likely, but not necessarily, have a low head and a low flow. The higher head a site has, the higher the final energy output will be. Higher heads require less water to produce a given amount of power. The flow of a site can be measured in many ways, some are more precise than others. In some instances, the flow rate of a stream can be determined through the access of government records of stream flow. Once both the head and flow data are measured, the potential power of an application can be obtained using Eq. (1) (Micro-hydro power, 1989; Anderson, T., *et al*, 1999).

$$P = 9.81 \times Q \times H \qquad (1)$$

Where "P" equals the potential power in kilowatts, "Q" is the flow in m^3/s and "H" is the head in m. Energy is lost as it is converted from one form to another, so this lowers the actual power that one site can put out. After the micro hydro system is in place and has been in operation for a decent length of time, the actual output can be determined. The system must be able to output the amount of energy required to sustain the household or factory in order for the application to have worth.

***Measurement of Flow*:**

The quantity of water falling from a potential micro hydropower site is called flow. It is measured in gallons per minute, cubic feet per second, or liters per second. One can measure flow using the bucket or weighted-float method (eere, 2007) . The bucket method involves damming the stream with logs or boards to divert its flow into a bucket or container. The rate at which the container fills is the flow rate. Knowing the true, minimum flow of water is critical to accurately determining the size and output of the turbine. It is best to conduct these measurements during low season for conservative estimation (Micro Hydro Systems, 2007) Stream flows are quite variable over a year, so the season during which flow rate is measurements are important. Unless considering building a storage reservoir, the lowest average flow of the year should be used as the basis for system's design. However, if there are legally restricted on the amount of water to divert from the stream at certain times of the year, then the average flow during the period of the highest expected electricity demand should be used (Micro Hydro Systems, 2007).

Weighted-Float Method:

This method involves measuring stream depths across the width of the stream and releasing a weighted-float upstream from the measurements. Due to water safety concerns, this method isn't recommended if the stream is fast-flowing and/or over the calves. An assistant, a measuring tape, a yardstick or measuring rod, a weighted-float, such as a plastic bottle filled halfway with water, a stopwatch and some graph paper are needed. With this equipment one can calculate flow for a cross section of the streambed at its lowest water level. The flow rate measurement process is discussed in the succeeding section and is shown in the Fig. 7.

Flow Rate Measurement Process:

First, select a stretch of stream with the straightest channel, and the most uniform depth and width possible. Measure the width of the stream at the narrowest point. Holding the yardstick vertically, walk across the stream and measure the water depth at one increment. To help with the process, stretch a string or rope upon which the increments are marked across the stream width. Then plot the depths on graph paper to give a cross-sectional profile of the stream and determine the area of each section by calculating the areas of the rectangles (area = length × width) and right triangles (area = ½ base × height) in each section.

Secondly, Mark a point L-m (at least 6-m) upstream from the same point where the stream's width is measured. Release the weighted-float in the middle of the stream and record the time it takes for the float to travel to original point downstream. Dividing the distance between the two points by the float time in seconds the flow velocity in meter (m) per second is calculated. Then, multiplying the average velocity by the cross-sectional area of the stream with appropriate correction factor (Table 6) the flow rate is calculated (Eq. (2)Fraenkel P. *et al*, 1991), where the flow rate (in m3/s) is Q, A_{ave} is the average cross-sectional area (m^2) and $V_{surface}$ is the surface velocity (m/s).

$$Q = A_{ave} \times V_{surface} \times Correction\ Factor \quad (2)$$

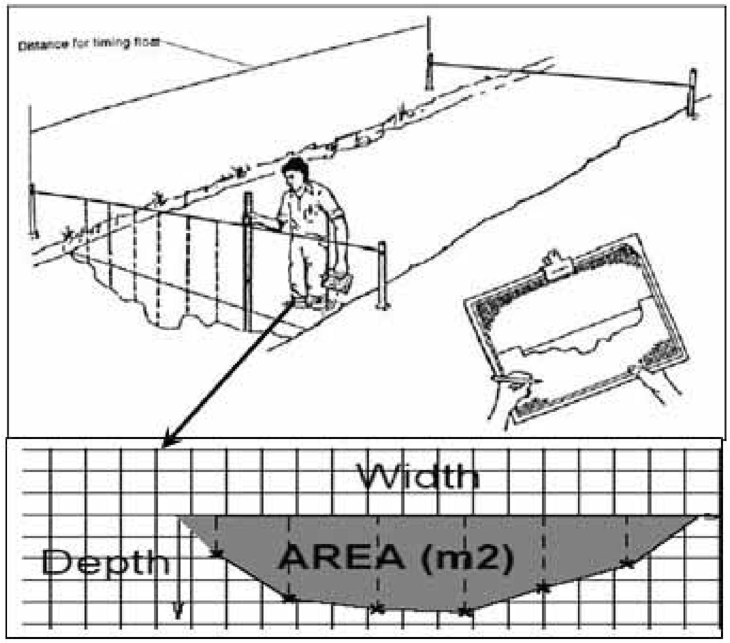

Fig. 7: Charting the cross-sectional area of a stream (Fraenkel P. *et al*, 1991; Phillip Maher., and Nigel Smith, 2001).

Table 6: Velocity correction factor for different types of streams (Fraenkel P., O. Paish, 1991).

Type of stream	Velocity correction factor	Accuracy
A rectangular channel with smooth sides and bed	0.85	Good
A deep, slow moving stream	0.75	Reasonable
A small stream with a smooth bed	0.65	Poor
A quick, turbulent stream	0.45	Very poor
A very shallow, rocky stream	0.25	Very poor

Hydro Energy Scenario in Bangladesh:

Hydropower generation is an eco-friendly clean power generation method. It is an established source of electricity and currently accounts for about 20% of electricity generation worldwide (Rofiqul Islam, M., *et al* 2008). Renewable energy exploitation in Bangladesh is not new. People are using renewable energy sources like solar, wind, hydro power for different purposes from primordial time.

The only hydro power station of the country, the Karnafuly Hydro Power Station with a generating capacity of 230 MW (eere, 2007) by 5 units $(3\times 50\,MW + 2\times 40\,MW = 230\,MW)$ across the river Karnafuly (Rofiqul Islam, M., *et al* 2008). This plant is the only hydroelectric power plant operated by (2 x 50MW = 100MW) BPDB. BPDB is considering extension of Karnafuli hydro station to add another 100MW capacity. The additional energy will be generated during the rainy season when most of the year water is spilled. Apart from Kaptai, two other prospective sites, for hydropower generation at Sangu and Matamuhuri River, are identified by BPDB. The first micro hydropower unit of 10 kW has been installed in a village of Bandarban through private initiatives. The project is providing electricity to 140 families in the village and to a Buddhist Temple (Rofiqul Islam, M., *et al* 2008).

Sangu Project would be a new project with estimated annual energy of about 300 GWh/yr. For an installed capacity of 140 MW, the annual plant factor is 23 % and it is assumed that the plant would operate in a peaking mode (Rofiqul Islam, M., *et al* 2008; Micro Hydro Energy Potential in Bangladesh, 2007). However, this project needs a detailed environmental, social and economic study in the present context (Rofiqul Islam, M., *et al* 2008). Matamuhari hydroelectric Project would be a potential project of capacity 75 MW and approximate average annual energy 200 GWh/yr (Rofiqul Islam, M., *et al* 2008; Micro Hydro Energy Potential in Bangladesh, 2007).

Barkal is one of the remote and unelectrified Upazila (sub-district) in the Chittagong Hill Tracts region (ranging 300-500 m in height). Engineers of Bangladesh Power Development Board (BPDB) have conducted reconnaissance survey in the Upazila and identified availability of water sources for Micro-Hydro Power Plant. Based on the electrical load demand of the adjacent area, they have been designed a 20 kW Micro-Hydro Power Plant with the help of RETScreen, developed by CANMET Energy Diversification Research Laboratory of Canada (CEDRL). The project will be funded by the Ministry of Chittagong Hill Tracts Affairs (Rofiqul Islam, M., *et al* 2008; Micro Hydro Energy Potential in Bangladesh, 2007). At Barkal area of Rangamati district a 50 KW generator has been installed. No fund has yet been allocated from the government for this purpose. BPDB has completed a pilot project for installing 1x 50 KW mini hydro plant at Barkal water fall from its own revenue fund (bpdb, 2007).

In February 1981 the Water Development Board and Power Development Board (Rofiqul Islam, M., *et al* 2008; Mini Hydro, 1981; Local Government, 2007) jointly carried out a study on the assessment of Small/Mini Hydropower Potential in the country. The committee explored 19 prospective sites for possible installation of small hydropower plants. The finding of the committee is summarized in Table 7. Later in the month of April 1984, Six Chinese experts visited Bangladesh and identified 12 potential sites for development of mini hydro power plant. Out of these sites, only Mahamaya Chara, near Mirersharai, close to Dhaka-Chittagong highway was identified as the best site for development of small hydro (Rofiqul Islam, M., *et al* 2008; Mini Hydro, 1981; Local Government, 2007). Accordingly, it has been taken up for development of an integrated project for flood control, irrigation and power generation. A working group has been formed by the engineers of Bangladesh Power Development Board (BPDB) and Bangladesh Water Development Board (BWDB) to carryout groundwork of the project. A dam is proposed to be constructed on the Mahamaya Chara for the retention of monsoon run-off from a drainage area of about 10.5 km^2 and to provide irrigation facilities from the reservoir behind the dam. It is also planned to utilize the reservoir water for the generation of hydroelectricity. A mini hydro power plant will be installed at the foot of the dam (Local Government, 2007). It has been found out from the feasibility study that generation of electricity is possible throughout the air except in the month of April and May (Rofiqul Islam, M., *et al* 2008).

Table 7: Summery of findings of BPDB/BWDP joint study and Flood Action Plan.

Findings of BPDB/BWDB study		Findings Flood Action Plan			
Name of river/ chara/stream	Potential Energy (kW)	Name of river and site	Average yea		
			Min	Mean	Max
Chittagong		Meghalaya Group			
Fiaz lake	4	Kangsha at Jariajanjail	16.7	274.3	738.5
Chota Kumira	15	Sari-gowain at Sarighat	6.4	128.2	381.9
Hinguli Chara	12				
Sealock	81	Barak Group	6.4	524.4	1429.3
Lungi Chara	10	Surma at Kanairghat	7.8	545.0	1470.1
Budia Chara	10	Surma at Sylhet	80.8	660.0	1610.0
		Kushiyara at Sheola	7.2	138.8	331.6
Sylhet		Sonai-Bardal at Jaldhup			
Nikharai Chara	26				
Madhb Chara 1500-ft from fall	78	Tripura Group			
Ranga pani Gung		Manu at Manu River Barage	10.4	83.7	182.2
	616				
Jamalpur		Brahmaputra Group			
Bhugai-Kongsa	65.5	Old Brahmaputra at Mymensingh	19.4	704.9	2055.5
Marisi	32.5	Lakhya at Demra	38.8	692.3	1750.9
		Old Brahmaputra at Bhairab Bazar	4.3	123.3	452.5
Dinajpur					
Dahuk	24				
Chawai	32				
Talam	24				
Pathraj	32				
Tangon	48				
Punarbhaba	11				
Rangpur					
Chikli	32				
Fulkumar	48				

In 1992, under the Flood Action Plan (FAP), Northeast Regional Water Management Project (FAP-6) conducted a preliminary assessment of selected rivers in the Northeast Region. The finding for the most promising rivers and sites shows that they are suitable for development of run-off-river low head schemes. However, to obtain the required head for generating power a weir or barrage need to be constructed across the river channel. The identified site along with the flow data are listed in Table 7 (Rofiqul Islam, M., *et al* 2008; Local Government, 2007). Based on mean monthly discharges and an assumed 5m head the hydro potential of the 10 major and medium perennial rivers of the Northeast Region is estimated as 161MW, with an annual energy production of about 1410 GWh. These are perennial rivers with sufficient flow for power generation throughout the year (Rofiqul Islam, M., *et al* 2008; Local Government, 2007).

There are also rivers which carry high discharges during the monsoon season and very small during the dry season. They have relatively high longitudinal slope across alluvial fans close to the Indian border. Most of the rivers have little flow in the winter months and sometimes they dry out completely. The suitable scheme would include diversion structure across the river channel, diversion channel along the bridge and the powerhouse at a suitable location that offers sufficient head. Nine rivers were identified in the study. The mean monthly power distribution from these rivers is given in Table 8 (Rofiqul Islam, M., *et al* 2008; Local Government, 2007). The potential annual power output of these rivers is estimated at 35MW and the annual energy production at 307 GWh.

Table 8: Hydropower Potential in Meghalaya Rivers of Northeast Region.

River	Site	Catchment Area (km^2)	Estimated Annual Output	
			MW	GWH
Someswari	Dugapur	2134	5	43
Jadukata	Saktiakhola	2513	13	115
Jhalukhali	Dalura	448	5	45
Sarigoyain	Lalakhal TG	802	3	30
Lubha	Mugulgul	724	3	27
Dhalai	Khalasadaq	342	2	15
Umium	Chalelhnapur	518	2	20
Bhugai	Hatipagar	453	1	6
Darang	Ghosegaon	381	1	6
	Total		35	307

Teesta barrage is located in the North-Western part of the country. It is the largest irrigation project of the country. There are at least 19 potential sites of hydropower generation in the Teesta barrage project having 10 sites with more than 2m head. The constructions of these regulating structures have been completed and most of them are in operation. These sites can be investigated for development of small hydro projects. The prospective sites at Teesta barrage is shown in Table 9 (Rofiqul Islam, M., *et al* 2008; Local Government, 2007).

Table 9: Potential sites in the Teesta Barrage for small hydro power generation.

Sl	Regulating Structure (number)	Discharge (m^3 /sec.)	Water level		Head (meter)
			Upstream (m)	*Downstream (m)*	
Teesta Canal					
1.	R3T	154.6	47.9	45.8	2.1
Rangpur Canal					
1.	R2R	73.1	43.1	40.9	2.2
2.	R4R	53.5	38.9	36.8	2.1
3.	R5R	45.2	36.2	34.1	
Bogra Canal					
1.	S1B (L)	1.4	43.3	40.5	2.7
2.	R1S2B	0.7	41.9	39.3	2.6
3.	R1S3B	4.0	41.6	38.6	3.0
4.	R1S4B	1.0	41.5	38.3	3.3
5.	R1S5B	2.1	41.5	37.5	4.1
6.	R3B	73.6	41.3	38.7	2.6

There are lots of canals, tributaries of main river Karnafuli, Shangu, Matamuhuri as well as tiny waterfalls in the sites in Chittagong hill tracks (CHT). The opportunities that exist in the CHT areas include the potential for the utilization of hydropower along with indigenous technical knowledge systems to operate local institutions. This study being carried out to harness of micro-hydro resources and find the potentials of setting up decentralized micro-hydropower unit with local implementation and management, thereby making remote tribal rural development possible through self-reliance and the use of local natural resources. Example could be given from Mr. Aung Thui Khoin innovation of indigenous micro hydropower unit that draws attention of LGED and UNDP by wider coverage's press and electronic media. The unit is constructed with wooden turbine and making an earthen dam on the flowing Hara Khal at remote hilly region of Monjaipara, Bandarban. As observation, about 10kW electricity is being generated by this indigenous micro hydropower unit that illuminated 40 households of that village. Focusing on that innovation, it is encouraging that such micro-hydro unit may be undertaken to set up on potential sites in the off grid CHT region to bring up sustainability in socioeconomic uplift of the local backward tribal community. On primary discussion, LGED and UNDP come to the points that:

- The most temporary nature Mojaipara micro-hydro unit should be improved in order to make it sustainable.
- Such power unit should be replicated in the whole off-grid CHT region that are crisscrossed by numerous canals, tributaries that holds potential sites.
- On Bamer-chara, such micro-hydropower unit may be set up for improvement of tourism, irrigation, and provide power to local inhabitants.

On the above-mentioned ground, an agreement has been signed between LGED and innovator Mr. Aung Thui Khoin for a month long study. The objectives (LGED, 2007) of the study include

- To identify micro-hydropower potential sites within the hilly regions and promotion of indigenous technologies for development of hydropower.
- A possible integration with power generation and irrigation schemes can also be considered.
- Implementation of a micro-hydro system at Bamerchara, Chittagong district can be taken as a pilot project.
- Study and development (if possible) of the Mr. Aung Thui Khoin's micro-hydropower unit.

From the study some prospective sites for micro hydropower development in three districts of CHT region has been identified with the help of LGED officials, local communities and head man, which are described in Table 10 (Rofiqul Islam, M., *et al* 2008; LGED, 2007) . LGED has been exploring the potential of mini and micro hydro power as eco-friendly sources of energy in the hilly region to meet the different energy needs of the remote inaccessible, underdeveloped and sparsely populated mountain areas. Several studies carried out in Bangladesh recommended that mini and micro-hydro alone might not be a feasible option in this country. However its integration with irrigation and flood control projects can be made economically viable. In this regard, LGED has implemented Bamer Chara Irrigation Project in Banskhali Thana under Chittagong district with an intention to provide irrigation facilities to 355 ha land. A large reservoir has been built in this project for dry season irrigation. Water enters the project area through a gated spill way and flow is controlled at the downstream by a conventional regulator. Currently LGED is examining the flow rate in the spillway and exploring the scope for installing a Micro-hydro power plant at the site (Rofiqul Islam, M., *et al* 2008; Mini Hydro Power Generation in Bangladesh, 1981; Reba Paul,1999.

Table 10: Prospective sites for micro hydropower development in CHT.

Name of the canal with location	Sectional area (m^2)	Lowest flood level (m)	Highest flood level (m)	Power potential (kW)
Nunchari Tholi Khal in Khagrachari	11	0.06 (May)	3	5
Sealock Khal in Bandarban	25	0.15 (April)	4	30
Taracha Khal in Bandarban	35	0.1 (April)	6	20
Rowangchari Khal in Bandarban	30	0.1 (April)	5	10
Hnara Khal in Kamal Chari, Rangamati	20	0.15 (May)	4.20	10
Hnara Khal in, Hang Khrue Chara Mukh, Rangamati	25	0.12 (May)	4	30
Monjaipara microhydropower Unit	15	0.50	1	10
Bamer Chara irrigation Project				10

Feasibility study on R&D of Renewable Energy (Solar, Wind, Micro-Mini Hydro)'' has been undertaken by the Institute of Fuel Research Development (IFRD) and Bangladesh Council of Scientific and Industrial Research (BCSIR). They have collected data through the related instruments regarding the micro-mini hydro study at two selected places of Shailopropat in Banderban and Madhobkundu in Moulibhibazar (Rofiqul Islam, M., *et al* 2008; Reba Paul,1999; LGED, 2007; Hasanuzzaman, M., J.K. Saha,2002). The collected data and information are analyzed on various aspects at RET laboratory of IFRD. On the basis of analysis of collected data up to June 2001, it is expected that 5-10kW and 10-20kW capacity micro-hydropower plant can be installed for electricity generation at Sailipropat and Madhobkundu sites, respectively. Summary of different measurements and calculations for small hydropower generation are shown in Table 11.

Table 11: Summary on Micro Hydro Power Generation in Hilly Districts.

Name of Water Falls	Average Discharge (l/s)	Approximate Duration of Flow (months)	Probable Fall for Hydropower Generation (meter)	Electrical Power (KW)	Annual Energy Production (kWh)
Sailopropat, Banderban	100	12	6	5	43,800
Madhobkundu, Moulvibazar	150	12	10	15	131,400

Some researchers have studied a channel in Halda River near Madhunaghat Bridge on the Chittagong - Kaptai road in the Chittagong district as prospective site for micro-hydro (Wazed, *et al.,* 2004). The average flow velocity is 0.75 m/s, average flow rate is 7.87m^3/s and average available water head is 3.28 m. The monthly average flow rate and available head in Mohamaya chara (Reba Paul,1999), Bamerchara (Mini Hydro Power Generation in Bangladesh, 1981), and flow rate in Sailopropat, Bandarban (Reba Paul,1999) has been reported.

Recently BPDB has submitted a proposal to the GOB for the installation of the following two small hydropower projects: a 10kW plant at Barkal in the Rangamati district and a 25 kW plant at the Teesta Barrage (Hossain, A.K. and O. Badr, 2007). The SRE project of Local Government Engineering Department (LGED) has a plan to consider the development framework for micro-hydropower program at potential sites in Bangladesh (Rofiqul Islam, M., *et al* 2008).

The REREDP project has also taken a program for development framework for hydropower. The project will provide support for assessment for run-of the-river mini-hydro in the hilly regions. If assessments indicate positive potential, IDA would support development and implementation of pilots to confirm commercial feasibility. Support will in that case be extended to formulate a policy framework for commercial development of these resources, including development of Small Power Purchase Agreement (SPPA) and incentives (Rofiqul Islam, M., *et al* 2008).

RESUIT AND DISCUSSIONS

Micro hydro is a major primary source of energy in Bangladesh especially in the north-eastern hilly regions. Promoting renewable energy sources for energy requirements in conjunction with alleviation of rural poverty, diversification of energy resources and reduction of oil imports are needed to shift the economical growth towards greater sustainability, as well as environmental and social stability. Information on the socio-economic aspects is limited. The available data are scattered and least quantified. So, it is difficult to assess full impact of micro hydro energy in the country both socio-economically and environmentally.

There are more than 87,319 villages in Bangladesh, and most of them are unconnected to the national grid. It is only 10% of our rural householders are hooked on the grid. The electrification by grid extension or secondary power station can only reach a small minority of the population in rural areas. In view of the dispersion of localities and the low demand, the cost of production, transmission and especially distribution of electricity would be prohibitively expensive. Decentralized and standalone systems could effectively become a viable option in these areas.

There are lots of canals, tributaries of main river Karnafuli, Shangu, Matamuhuri as well as tiny waterfalls having potentials for setting up mini/micro hydropower unit in Chittagong Hill Track (CHT) region. CHT is being almost isolated from governmental and non-governmental development initiatives for many years because of remoteness and terrain landscape, scattered settlement pattern, lack of infrastructural development and diversification of economies. Confronting sustainable development issues in CHT and seeking local solutions, considering natural resources and ecosystem, development of affordable indigenous and sustainable technologies is viable options to promote livelihood at CHT. Since power is key indicator in all development strategies, harnessing micro-hydro resources and setting up decentralized small-scale water power or micro-hydro schemes are a particularly attractive option in terrain areas without hampering ecosystem. Extension of grid electricity is not economically feasible at the remote mountain areas like CHT because of scattered settlement and lack of infrastructural development.

Concluding Remarks:

Dissemination of micro hydro energy throughout the country should be given priority in solving the energy crisis. There is no way other than taking renewable energy for reducing environmental degradation. Scientists of the world are now seeking energy solution from the renewable sources. By generating micro hydro energy from the abundance sources Bangladesh can solve a big portion of energy deficiency.

The energy sector of Bangladesh is evolving remarkably. It is facing an accelerating compound crisis of the globally established fossil (oil) and atomic energy system; therefore, immediate different breakthroughs for energy are necessary to reach electricity goal of the country. Bangladesh is going to run out of gas in the next 25 years. Frequently escalating oil prices indicate the depletion of fossil resources and the urgent need to replace the current mix of fossil transport fuels.

Market survey for wind, small-hydro, modern biomass or other types of RET applications are not yet been done properly. From the previous resource potentials it can be implied that micro hydropower plants can be installed in the north-eastern hilly regions and in the existing irrigational canal system with sufficient head.

More than 90% of Bangladesh's rivers are originates outside the country, due to which proper planning of water resource s is difficult without neighboring countries cooperation. Downstream water sharing with neighbors is a highly contentious issue in Bangladesh.

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