THE SUSTAINABLE MANAGEMENT OF MICRO HYDROPOWER SYSTEMS FOR RURAL ELECTRIFICATION: THE CASE OF BHUTAN

by

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ABSTRACT

THE SUSTAINABLE MANAGEMENT OF MICRO HYDROPOWER SYSTEMS FOR RURAL ELECTRIFICATION: THE CASE OF BHUTAN

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In this study I explore the challenges and opportunities associated with the development of sustainable mini-grid hydropower systems by evaluating two systems with different management models in the Ura and Chendebji communities in Bhutan. This research is based on field surveys and key informant interviews, complimented by a review of the literature. The findings reveal that access to electricity has improved the quality of life but has not triggered any substantial increase in income.

Although there is evidence of surplus electricity generation, daily peak loads overshoot the installed capacity of the micro hydropower plants. The main reasons for high peaks include increased use of electrical appliances (lights and rice cookers) as a result of population growth. Promotion of energy efficient appliances and load shifting could address some of the peak demand and supply issues. However, without a grid connection, peak loads are unlikely to be met.

Additionally, the financial analysis in this study shows that revenues from the current tariff do not meet the combined costs of annual operation and maintenance, and levelized repair and replacement costs per annum of the systems. There is a need for an annual subsidy of US$ 2,281 for Chendebji and US$ 1,576 for Ura micro hydropower systems.

My key policy recommendation is that the development of micro hydropower should be coupled with the development of income generating opportunities in order to enhance the economic self-reliance of rural communities. Furthermore, by integrating micro hydropower with the grid at higher feed-in tariffs, the sale of surplus power could improve load management and displace the need for government to provide a subsidy. Finally, an education and training program should be provided in order to continuously maintain the skills of the local plant operators and increase consumer awareness about energy conservation.

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ACRONYMS AND ABBREVIATIONS

ADB	Asian Development Bank
BPC	Bhutan Power Corporation
BEA	Bhutan Electricity Authority
CMHMC	Chendebji Micro Hydropower Management Committee
DoE	Department of Energy
Dzongdhag	District Commissioner
Dzongkhag	District
DYT	Dzongkhag Yargay Tshogdu
FYP	Five Year Plan
GDP	Gross National Product
Gewog	Block
GEF	Global Environment Facility
Gomchen	Semi-monk
Gup	Village Head
GYT	Gewog Yargay Tshogchung
JBIC	Japan Bank for International Development
JICA	Japan International Cooperation Agency
kV	kilo Volt (1000 Volts)
kWh	kilowatt-hour
LPG	Liquid Petroleum Gas
MW	Megawatts (1,000,000 Watts)
Nu	Ngultrum (Bhutanese currency)
O&M	Operation and Maintenance
RED	Renewable Energy Division
RE	Rural Electrification
REMP	Rural Electrification Master Plan
RGoB	Royal Government of Bhutan
UNDP	United Nation Development Programme
W	Watts

Currency Conversion Assumption

US$ 1.00 = 45 Nu (Bhutanese Ngultrum)

CHAPTER 1. INTRODUCTION

Bhutan is fortunate to be blessed with abundant natural renewable resources that can be tapped to meet its growing energy needs, despite being landlocked and one of the least developed countries. Energy is recognized as a priority sector in Bhutan for poverty reduction and sustainable development. In its “Bhutan: 2020” policy paper, the Royal Government of Bhutan (RGoB) envisages that the entire country will have access to electricity by year 2020. Although the country has surplus power generation, the rugged terrain, sparsely populated demography, and the high cost of grid extensions to remote areas have prevented a large percentage of the rural population from receiving power from the national grid. As part of the efforts to achieve the target, the RGoB has been striving to promote distributed renewable energy systems. This includes installations of solar photovoltaic (PV) and micro hydropower systems in remote villages where extension of grid electricity is techno-economically unfeasible.

Since the 1980s, the RGoB has conducted a number of technology demonstration projects and rural electrification delivery schemes for micro hydropower systems. The need for a comprehensive management strategy and action plan became more obvious recently in view of the development of the RGoB’s future plan for rural electrification (ADB, 2006). With reformation of the power sector following passage of the Electricity Act 2001 in July 2002, the corporatized utility company is now responsible for overall management of all the micro hydro systems in Bhutan. The utility company has not been eager to take over the management of new micro hydros because of the financial burden imposed by micro hydropower. Realizing the practicality and resource requirements

RGoB is encouraging more participation by local governments, communities, and the private sector rather than imposing the management of the micro hydros on utility company. Under the RGoB's decentralization policy, these groups would assume responsibilities for the management of energy infrastructure currently held by the central government. The role of the central government is now seen as progressively moving towards regulations rather than administration of decentralized energy projects. The communities are expected to play a more proactive role in their own development.

Most rural communities in Bhutan have limited access to the resources and income required to manage these projects. Agriculture integrated with livestock farming is the economic mainstay of a majority of the rural communities in Bhutan, many of which face challenges in enhancing and diversifying agricultural production for improving their livelihood and subsequently their income. The additional responsibility to manage and operate a micro hydro system poses major challenges. At the same time, it also provides income generating opportunities. Thus, there are many challenges and opportunities associated with developing a sustainable micro hydropower system in Bhutan.

This study will attempt to identify some of these challenges and opportunities by evaluating two micro hydro systems managed with different models in the Ura and Chendebji communities in Bhutan. These two sites provide a set of comparative cases for determining the impacts of institutional arrangement, local capacity and economics on managing, operating and maintaining the systems. These cases will also allow for an examination of the role that the social dynamics of particular places play in shaping the ways that electricity is used in the respective localities.

The output of this study is expected to address some of the underlying issues that impede the community from realizing its goals and to serve to provide timely, useful input to the RGoB for refining its ongoing efforts on decentralized micro hydro projects.

1.1 Research Question:

From a management perspective, what are the best institutional mechanisms that will ensure equitable, economically efficient and sustainable micro-hydroelectric schemes for rural communities in Bhutan?

1.1.1 Sub research questions:

1 What are the goals, criteria, and barriers of and to the development of a viable micro hydropower based rural electrification in Bhutan, given the current institutional structure?

2 With increasing demand for electricity in communities with existing micro-hydropower, where demand for energy is outstripping supply, what institutional measures can be taken to ensure equitable distribution?

3 What kind of electricity pricing should be applied to micro hydropower based rural electrification, taking into account the local economy and affordability?

4 What is the most cost-effective and efficient institutional delivery mechanism appropriate for operating and managing micro hydropower based rural electrification

in Bhutan, taking into account accessibility, local resource endowments and institutional capacity?

1.2 Thesis Outline:

The Thesis statement, research issue and questions are introduced in Chapter 1. The summary of background information on various existing RGoB policies and programs pertaining to rural electrification and institutional arrangements are discussed and analyzed in Chapter 2. Chapter 3 explores the literature related to micro hydro development and institutional arrangements based on experiences in developing countries. A research methodology and framework for data analysis are discussed in Chapter 4. The results of data analysis and a synthesis of various factors for development of interventions to achieve sustainable management of micro hydropower are discussed in Chapter 5. Conclusions are set forth and specific institutional measures are recommended in chapter 6.

CHAPTER 2. BACKGROUND: SITUATION ANALYSIS

Bhutan is a small country located in the eastern Himalayas with a total area of 38,394 square kilometers. It is surrounded by steep mountains and 72% is covered with dense forest (DoE, 2005). The country is bordered by Tibet (China) in the north and northeast, Sikkim (India) in the west, West Bengal (India) in the southwest, Assam (India) in the south and Arunachal Pradesh (India) in the east as shown in Figure 2.1. The country has a population of 634,982 as per the national census carried out in May 2005.

This chapter provides a brief overview of the electricity sector, institutional arrangements, laws and regulations pertaining to rural electrification, rural electrification efforts and current status of micro hydropower schemes in Bhutan.

Figure 2.1: Bhutan on an Atlas. Source: REMP (2005).

2.1 The Electricity Sector in Bhutan

The development of a hydropower industry has been recognized as the primary driving force for the economic development for the country (Tshering and Tamang, 2005). Accordingly, the Vision 2020 document has set targets of adding 2000 MW of hydropower by 2012, and 3000 MW by 2017.

According to the Power System Master Plan (PSMP, 2004), Bhutan has techno-economically feasible and identified potential hydropower sites totaling 23,760 MW. The current total installed electrical generation capacity is 1,505 MW including recently commissioned Tala hydropower project, out of which 1,489 MW (89%) is hydropower. In 2005-06, the total electricity production was 2,560 GWh. All the hydropower plants are run-of-the-river type, and electricity from India is imported during the dry season. In 2005-06, about 23 GWh were imported (DoE, 2007a). Since the annual peak load in Bhutan occurs in the winter, the dominance of run-of-the-river type hydropower plants may be a problem in the future. However, imports from India are expected to meet any shortfalls in power, albeit at higher cost.

A majority of the electricity generated in Bhutan is exported to India. The current export tariff is about 4.5 cents per kWh and is determined bilaterally between the two governments. In 2005-06, the net export was about 1,786 GWh, constituting 70% of the total production (DoE, 2007a). With the recent commissioning of the 1020 MW Tala hydropower project, it is expected that by end of 2007 hydropower revenue will account for 60% of the government's annual revenue and about 30% of Gross Domestic Product (DoE, 2007b).

Contrasting the large-scale hydroelectric market in Bhutan, domestic consumption of energy is dominated by traditional biomass fuel (66%) and imported fossil fuels (diesel, petrol, LPG, coal, kerosene etc.). The demand for fossil fuels is increasing at an alarming rate (DoE, 2005), and Bhutan does not have any domestic petroleum resources. Presently, Bhutan imports about 70,047 metric tons of oil equivalent (toe) at a cost of about USD 47 million per annum (DoE, 2005). Thus the import of petroleum products consumes a substantial percentage of foreign export earnings. Increasing demand coupled with rising oil prices in the global market are a concern to the Bhutanese economy, leading to inflation. Consequently, rising prices for goods and services leads to an increase in the cost of development activities. In addition to economic concerns, fossil fuels are polluting in nature and contribute to climate change. Overall, their continued heavy use is not sustainable in the long run.

According to the Population and Housing Census conducted in 2005, the major sources of cooking fuel are electricity (30.6%), firewood (37.2%), LPG (25.5%) and other sources (6.7%). Electricity (57%) is the main source of lighting, followed by kerosene (36.5%) and other sources (6.4%). In 2005-06, the domestic peak power demand was 120 MW and the total energy demand was 622 million kWh. Over the past year, there was a domestic demand growth of about 9% (MOHCA, 2005).

2.2 Energy Sector Organization and Governance

The Department of Energy (DoE) which was previously known as the Department of Power, was established in 1965 (MTI, 2007). After the Electricity Act was passed in 2001, the Power Sector underwent major reforms and the erstwhile Department of Power was split up into three agencies: 1) the Department of Energy (DoE), 2) the Bhutan Electricity Authority (BEA), and 3) the Bhutan Power Corporation (BPC).

The DoE is responsible for developing the long term policies and plans for the energy sector. It is also responsible for providing technical input for mobilization of resources and funds, and implementation of activities in the Energy sector. For off-grid electrification, the DoE is generally responsible for the provision of systems through mini/micro hydros and solar PV home systems. However, there are other agencies that are involved. A number of solar electrification projects have also been independently implemented by the departments of Education, Home Affairs and Health and the Ministry of Agriculture.

The Bhutan Electricity Authority (BEA) is in charge of regulations in the energy sector. The BPC got spun off as the entity to take over the transmission, distribution and supply utility functions. As a corporate entity, the BPC was expected to generate enough revenues to cover its costs. However, it was observed from the abridged Profit and Loss Statement of BPC in 2004-2005, the BPC has been running on a loss since it was incorporated in 2002. This was due to several factors including low tariff rates for electricity (i.e. high subsidies) and writing off of some mini hydros assets due to flood damage (DoP, 2002).

At present, there are four hydroelectric generating companies in Bhutan providing grid-power: the Chukha Hydro Power Corporation (336MW), the Kurichu Hydro Power Corporation (60MW), the Basochu Hydro Power Corporation (62 MW) and the Tala Hydro Power Project (1020 MW).

2.3 Government Plans and Policies for Rural Electrification

In this section, I present the policies and plans of Royal Government of Bhutan (RGoB) pertaining to rural electrification.

2.3.1 Bhutan 2020: A Vision for Peace, Prosperity and Happiness

Royal Government of Bhutan's (RGoB) rural electrification (RE) efforts are guided by the 'Bhutan 2020' policy document. This document sets a target of providing electricity to 50% of the rural population by 2012, and to all the households by 2020 (RGoB, 1999). The Vision document also seeks to transform the role of the state from that of a "provider" to an "enabler". To quote the document:

"*We must continue with the progressive redefinition of the role of the Royal Government from that of 'provider' to that of 'enabler' of development, with a continued emphasis on the creation of conditions that mobilize the energies and imagination of people, enable entrepreneurship to flourish, and make it possible for the private sector to become a more active partner in the nation's future development*".

2.3.2 The Draft Constitution of the Kingdom of Bhutan

The draft Constitution lays stress on decentralization as a means to facilitate direct participation of the people in their social, economic and environmental well-being. It also sets a role for local government bodies to ensure provision of sustainable services to the community and states that government will support the capacity building of local governments (Draft Constitution, 2007).

2.3.3 Electricity Act 2001

The Electricity Act of 2001 (EA) deals with restructuring the electricity sector through the establishment of the Bhutan Electricity Authority (BEA) as well as laying out the licensing procedures of generation, transmission and distribution. The Act establishes BEA as an autonomous regulator of the electricity sector. The main functions of BEA in RE are to set technical and safety standards for construction, operation and maintenance, set tariffs, and set subsidies for 'non-economic viable electricity supply'. According to the Act, BEA may exempt the requirement for a license for generation projects below 500 kW.

Regarding RE, the Electricity Act states that the government will promote public and private sector participation to achieve equitable distribution of electricity and maximize socio-economic and environmental benefits, and that it will promote extension of grid and off-grid electrification. Further, the Act states that the government can prescribe levies to recover the cost of delivering electricity to rural and remote customers (Electricity Act, 2001).

2.3.4 Dzongkhag Yargay Tshogdu (DYT) and Geog Yargay Tshogchung (GYT) Acts of 2002

The DYT and GYT Acts of 2002 aim to promote local socio-economic development by empowering people through their role government bodies, the DYT and

GYT, to decide on their plans and programs and also to implement activities based on local needs and conditions.

The DYT is the district level local government that functions according to the DYT Act of 2002. The Act has provided DYT with regulatory, financial and coordination functions and powers so that such decentralization of power and responsibilities will promote people’s participation in the decision making process. The DYT has the responsibility to prepare the Dzongkhag’s and Geog’s (Block’s) five-year and annual plans in line with national plans and policies. It can also submit motions arising from Geogs and Dzongkhag to the National Assembly. DYT also monitors and evaluates all activities in the Dzongkhag. The DYT administration, headed by the Dzongdhag (District Commissioner), assists the DYT to carry out its responsibilities.

According to the Act, the DYT has the power to give direction and approval of RE schemes in accordance with the EA. The DYT administration has the responsibility to implement RE schemes in the Dzongkhag (DYT and GYT, 2002).

The GYT is the block level local government. Each district is subdivided into blocks, which has a number of villages under its jurisdiction. The GYT is also vested with certain administrative, regulatory and financial powers. According to the Act, the GYT can administer, monitor and review all activities that are part of the Geog’s plans. Specifically mentioned in the Act is micro hydro. The GYT also has the power to approve rates of local utilities that produce power locally.

2.3.5 9th Five Year Plan (2002-07)

The 9th Five-Year Plan (FYP), which is currently under implementation, has objectives for electricity generation, transmission and distribution. The generation objective is to develop large hydropower projects mainly for export, but after meeting domestic needs, and to supply electricity to remote communities through decentralized hydropower projects. The transmission objective is to extend transmission lines and interconnection of grid networks, establish a load dispatch center, and extend the grid to feasible unelectrified Dzongkhags (Districts). The distribution objective is to carry out extensive electrification, including rural electrification, from grid or off-grid sources. The 9th FYP target for rural electrification of 15,000 households is a 300% increase from that of the 8th FYP. The budget outlay for this is Nu. 1.5 billion (USD 33 million). The 9th plan has now been extended for a year to include 2008.

2.3.6 The Rural Electrification Master Plan

At the request of Royal Government of Bhutan (RGoB), the government of Japan conducted an Integrated Master Plan Study for Dzongkhag-wise Electrification in Bhutan. The study was completed in November 2005, presented a technical plan to achieve 100% electrification of rural households by 2020, and assessed the finances required to achieve the target. According to the study, 88% of the rural households will be connected to the grid, and 12% will be provided electricity through off-grid options. This report is guiding the RGoB in RE planning.

2.3.7 10th Five Year Plan

The 10th FYP covers the period from 2008-2013, and is currently under preparation. According to the draft plan, 20,000 households will be electrified and 4 micro hydropower in remote villages will be constructed. The plan has estimated a total budget outlay of USD 150 million for Department of Energy alone.

2.3.8 National Renewable Energy Policy and Program for Sustainable Development (Draft)

The project study is funded by United Nation Development Programme (UNDP) under its Thematic Trust Fund (TTF) for Energy focusing on developing the RE Policy and Program for RGoB. The report provides institutional, financial plans and guidelines for implementation of the Renewable Energy Policy and Program for Bhutan in the 10th Five Year Plan. It focuses on institutional capacity building of the Renewable Energy Division under the Department of Energy to take up a lead role on development of renewable energy such as solar photovoltaic systems and micro hydropower for off-grid energy services.

Regarding micro hydro, the study suggested a public-private partnership in development of micro hydropower and establishment of the Rural Energy Service Concessionaire (RESCON) system to facilitate such public-private partnership. The RESCON concept is based on Rural Energy Supply model (RESuM) guidelines developed by the International Solar Energy Society. The report also recommended the creation of a rural electrification fund and using this fund for development of micro hydro where investments are not forthcoming. Further it recommends that micro hydros constructed through the Government managed funds should remain the property of the Government, but could be managed by the Community (RED, 2006).

2.4 Rural Electrification Efforts in Bhutan

In this section, I present the summary of both on-grid and off-grid rural electrification efforts made by RGoB followed by discussions on micro hydropower schemes in Bhutan.

2.4.1 On-grid Rural Electrification

The high cost of grid extension has kept a large percentage of the rural population off of the national power grid. Based on past rural electrification projects, it is estimated that the cost for electrifying one rural household is about US$1,800. In those projects, no capital contributions were made by the beneficiaries of the grid connections. Based on BPC figures, the average rural consumer utilizes less than 50 kWh per month and falls in the lowest tariff category of US$0.013 per kWh. However, the estimated cost for supplying rural electricity is about US$0.10 per kWh; the on-grid rural consumer receives substantial operational subsidy (BPC, 2006b).

The Bhutan Vision 2020 document envisages providing electricity to 50% of the rural population by 2012, and to all the households by 2020 (RGoB, 1999). In 2005, a Rural Electrification Master Plan was formulated, which aims at electrification of 100% of rural households by 2020. Out of the 1,716 villages that were analyzed in the study, it was found that grid extension was more economically beneficial for 1,267 villages. It was determined that 88% of the rural households will be connected to the grid, and 12% of the rural households will be provided off-grid access by 2020. The on-grid electrification program for the 29,338 households is expected to cost US$ 71.3 million. The on/off evaluation in the study was calculated using an economic evaluation based on a consumer surplus model that compares the cost-benefit thresholds between grid extension and small scale solar home systems. For off-grid electrification, only small solar home systems were used for determining the viability of the households (REMP, 2005).

Up to the mid-1990s rural electrification progressed slowly due to the unavailability of funds. After 1997, the rural electrification program rapidly increased due to focused efforts on rural electrification and increased support from multilateral and bilateral sources. By the end of the 6th FYP (1987-1992), around 7,360 households were electrified. Around 5,476 households were electrified in the 7th FYP, some 8,556 households were electrified in the 8th FYP, and 15,024 households are expected to be electrified in the 9th FYP. By the end of the 9th FYP, 52.2% of the rural households are expected to be electrified (DoE, 2007b, BPC, 2006a). Currently, the 10th FYP plans have been formulated, and a very ambitious target of electrifying over 20,000 households is being finalized (Draft 10th FYP, 2007). This will increase the percentage of rural households electrified to about 85%. The remaining 15% will be electrified in the 11th FYP and will complete the electrification of the 70,273 rural households (REMP, 2005). The plan to complete the electrification by 2017 will provide some cushion for delays in the implementation of the RE works, and should ensure that the Vision of Electricity for

All is achieved by 2020. Figure 2.2, below shows the achievements in the rural electrification on a five year plan basis and also from a cumulative basis.

The DoE is the central agency responsible for developing the plans and policies for rural electrification. The Ministry of Finance (MoF) also plays a central role, coordinating and mobilization funds with the DoE providing technical support for the mobilization of funds. The Asian Development Bank (ADB) has been the largest donor active in rural electrification so far. It has provided soft loans for three rural electrification projects in Bhutan so far, and it is expected to continue to provide loans for future rural electrification activities (DoE, 2007b).

So far the financing practice followed has been for the MoF to take the loan from the ADB at concessional rates of 1%. The loan repayment by the MoF is in ADB denominated currency. The MoF on-lend this loan to the BPC at a much higher rate (6%) to cover for currency fluctuation risks. The BPC is the central implementing agency for on-grid network expansion while off-grid supply network expansion activities are implemented by the DoE.

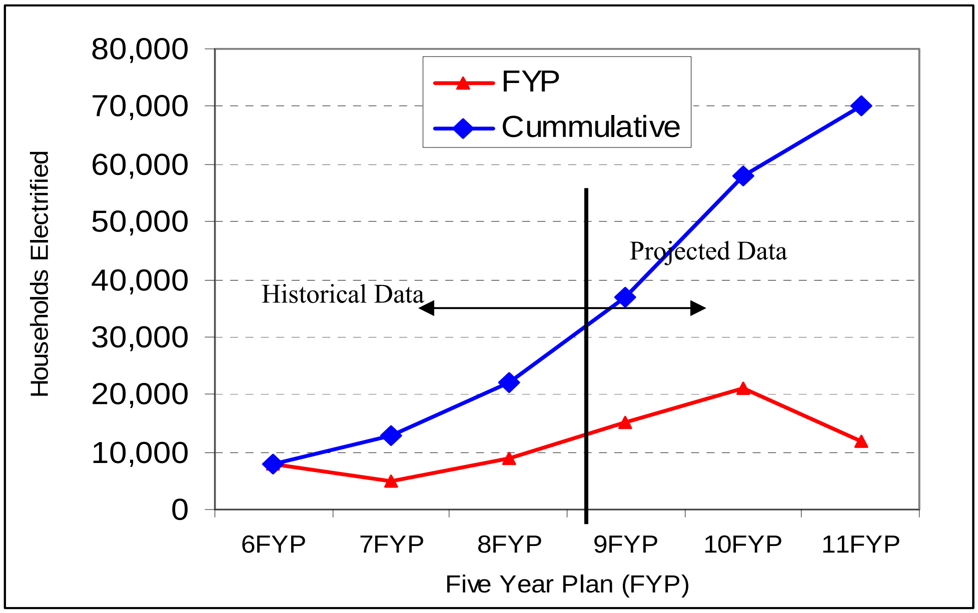

Figure 2.2: Rural Electrification Achievements: 5FYP and Projected.
Source: DoE, 2007b and BPC, 2006b.

There are several agencies involved in the rural electrification programs in the country which are supported by ADB: the Austrian Coordination Office, Stichting Nederlandse Virijwilligers (SNV), UNDP/GEF, and the Government of India (GoI). The Japan Bank for International Cooperation (JBIC) has also indicated a willingness to finance some of the rural electrification activities (DoE, 2007b). These programs have supplemented the DoE-led national electrification efforts in rural areas.

2.4.2 Off-Grid Rural Electrification

Distributed generation options such as solar photovoltaic, micro hydro, and diesel engine generators provide rural electrification in several parts of Bhutan which are off the national grid.

Solar electrification programs have been implemented in Bhutan since the early 1980s, primarily through international initiatives. Department of Power (DoP) programs in solar energy began in 1988. Since then, a number of solar electrification projects have been independently implemented by the Department of Education and the Ministry of Agriculture (MoA). Development assistance agencies such as UNICEF, UNCDF, Government of India, Royal Society for Protection of Nature (RSPN), Danida and SNV have also supported these initiatives. Unfortunately, records for solar installations in the period prior to 2000 do not exist and it is difficult to track the number and location of the solar projects installed up to this period. It is estimated that after the year 2000, about 4,350 solar PV systems have been installed in Bhutan by various agencies (RED, 2006).

At present, there are two models for the management of off-grid micro hydro systems. In the predominant model of the past, the BPC owns, manages, operates and maintains the micro-hydros. However, due to a lack of financial viability for micro-hydros, the BPC has shown a reluctance to take over the management of the new micro-hydros being built. Therefore, when the Chendebji micro-hydro was recently commissioned in October 2005, an alternative model involving the community had to be developed. This community-based management model is being piloted in Chendebji and is expected to be refined and used for future micro-hydro projects.

According to the RE Master Plan, 12% of rural households (i.e. 3,918 households) will be electrified through off-grid means. If all of them were electrified with small solar home systems, the estimated off-grid electrification cost is US$ 2.5 million (REMP, 2005).

2.5 Micro Hydropower Schemes in Bhutan

The first micro-hydros were built with financial assistance from the Japanese Government in the late 1980s. Nine systems ranging in size from 20-70 kW were commissioned in 1987 and four 200 kW systems were commissioned in 1991-1992. This was followed by the construction of micro-hydros funded by the Government of Bhutan, Government of India, the EU and the e7 (DoE, 2007b). At present there are 16 operational micro-hydros in Bhutan and though many of them are over 15 years old, most of them have been functioning without serious problems. The current installed micro hydro capacity is 1,350 kW and about 1,795 households are exclusively connected to micro hydropower systems (DoE, 2007a). The Thinleygang and Yadi plants were decommissioned after their penstocks were washed away in land slides. Besides these, the micro hydros at the other locations are still functioning (BPC, 2006a). Table 2.1, below shows the list of micro-hydro plants existing in Bhutan.

Table 2.1: Details of existing off-grid micro hydro plants.

Sl.#	Dzongkhag	Plant Name	Donor	Installed Capacity (kW)	HH Electrified (2007)	Const. Cost (US$)	Start Date
1	Bumthang	Tamshing	Japan	30	38	303,158	Feb-87
2	Bumthang	Ura	Japan	50	158	505,263	Mar-87
3	Chirang	Chachey	Japan	200	293	3,791,538	Jun-91
4	Dagana	Darachu	Japan	200	377	4,276,538	Apr-92
5	Lhuntse	Rongchu	Bhutan	200	249	760,000	1-Dec
6	Lhuntse	Gangzur	India	120	cg	167,667	Mar-00
7	Mongar	Sengor	UNDP	100	uc	453,000	
8	Mongar*	Yadi	Japan	30	cg	303,158	Apr-87
9	Sarbhang	Surey	Japan	70	53	707,368	Apr-87
10	Zhemgang	Kekhar	Japan	20	37	202,105	Mar-87
11	Zhemgang	Tintibi	Japan	200	248	4,018,462	Apr-92
12	Zhimphu	Lingshi	EU	10	ni	ni	1999
13	Thimphu*	Thinleygang	Japan	30	cg	ni	Mar-87
13	Trongsa	Tangsibji	Japan	30	126	303,158	Mar-87
14	Trongsa	Trongsa	Japan	50	cg	505,263	Mar-87
15	Trongsa	Bubja	Japan	30	114	303,158	Mar-87
16	Trongsa	Chendebji	E7	70	50	563,198	5-Oct
17	Wangdue	Rukubji	Japan	40	62	404,211	Feb-87
	TOTAL			1,480	1,805	17,567,245	

* decommissioned, cg = connected to grid, uc = under construction, ni = no information
Source: DoE and BPC, 2007

2.6 Existing Micro Hydro Policies and Plans

Currently, no integrated policy exists for the development of micro-hydros in Bhutan. Since their development is expensive, most of the projects have been implemented on an ad-hoc basis based on the availability of external donor funding. The various donors in the micro hydro sector and the RGoB have different objectives and different approaches to micro hydro development. These factors have led to differences in the way the micro-hydros are constructed and later executed.

The selection of areas for development of micro-hydros has been based on the availability of suitable sites and accessibility to the road. In the past, not much consideration was given to whether the site would be getting grid electricity in the future since no comprehensive plan for national electrification existed (ADB, 2006).

As mentioned in previous sections, according to the Rural Electrification Master Plan (REMP), by 2020 it is planned that about 88% of the households will be connected to the grid and about 12% will be connected through off-grid means. The selection of on-grid and off-grid electrification has been based primarily on economic considerations. Wherever economically viable, grid extension has been considered. For the off-grid areas, solar PV has been considered as a viable option, with micro-hydro development being considered too costly. According to the RE Master Plan (REMP, 2005), micro hydros are to be considered only if grant financing is available. In case grants are available in the future, the Master Plan provides some guidelines on selection of micro-hydro sites.

At some potential micro-hydro sites, the REMP Study Team conducted field surveys on hydropower potential. Discharge measurements and simple topographic surveys using a hand level were conducted at seven (7) sites. The survey sites were selected from a group of candidate sites from a UNDP/GEF pre-feasibility study for 31 small hydropower candidate sites selected by DoE in 1999 and surveys conducted by India in the 1980's for proposed hydropower projects. The locations of the seven surveyed sites are listed in Table 2.2 below.

Table 2.2: REMP Field Survey Results Micro Hydropower Project Sites

No.	Dzongkhag	Village	River	Gross Head (meters)	Potential (kW)	Notes
1	Lhuentse	Khoma	Yongla	80	940	Grid in 2002
2	Lhuentse	Autsho	Phawan	43	220	Swedes
3	Mongar	Sengor	Manshing	101	90	UNDP/GEF
4	Bumthang	Tang	Selgang	106	820	Swedes
5	Bumthang	Tang	Tendeygang	55	140	UNDP/GEF
6	Wangdue	Lumuzu	Chuba lung	59	270	REMP
7	Wangdue	Tara	Ramichu	91	3100	REMP

Source: REMP, 2005

In the past the Department of Power managed, operated and ran all the micro-hydros. All of these micro hydropower systems were handed over to the Bhutan Power Corporation (BPC) when it was corporatized in 2002. The BPC is now responsible for the operations, maintenance and overall management of almost all the systems. While BPC has been managing the micro-hydros, it has not been eager to take over the management of new systems because of the financial burden imposed by them. Due to BPC's reluctance to take over new projects, when the Chendebji micro hydro was completed in 2005, an alternative model was sought. As a pilot scheme the DoE ventured ahead with a community based management model for the Chendebji project. Currently, the UNDP is funding the construction of a 50 kW (expandable to 100 kW) demonstration micro hydropower project at Sengor. GEF will provide $520,000 while UNDP will provide $335,000 of the project funds. Once the Sengor plant is commissioned, the DoE is planning to use the Chendebji community management model as well.

Thus, there are two models for management of micro hydropower systems in Bhutan: i) The BPC managed model, and ii) The Chendebji Community managed model.

2.6.1 The BPC Managed Model (Ura 50 kW Micro Hydro)

As mentioned in previous section the Bhutan Power Corporation (BPC) operates, maintains, and manages all of the micro hydropower systems that were handed over from the Department of Power when it was divided up in 2002. The DoE's role is to assist BPC with sourcing spare parts for the micro hydropower systems built with Japanese assistance. The communities do not have any role in the operation and maintenance (O&M) of the micro hydropower systems. In case of issues with the systems, any requests or feedback from the beneficiaries has to be routed through either block committees or through the Dzongkhag administration (District administration). The Dzongkhag may choose to contact BPC's electricity service division or the DoE directly. BPC either appoints a regular staff person or in some cases employs local personnel for daily O&M. For instance, in Ura, a local operator is employed and paid a minimum wage of US$ 2.50 per day. Beside O&M tasks, the operator also bills and collects energy sales. A preventive maintenance team from the Begana maintenance unit in Thimphu visits bi-annually or on request of the Electricity Supply Division during unforced breakdowns of the systems. Figure 2.3 below shows the BPC managed institutional model for Ura Micro Hydropower Project.

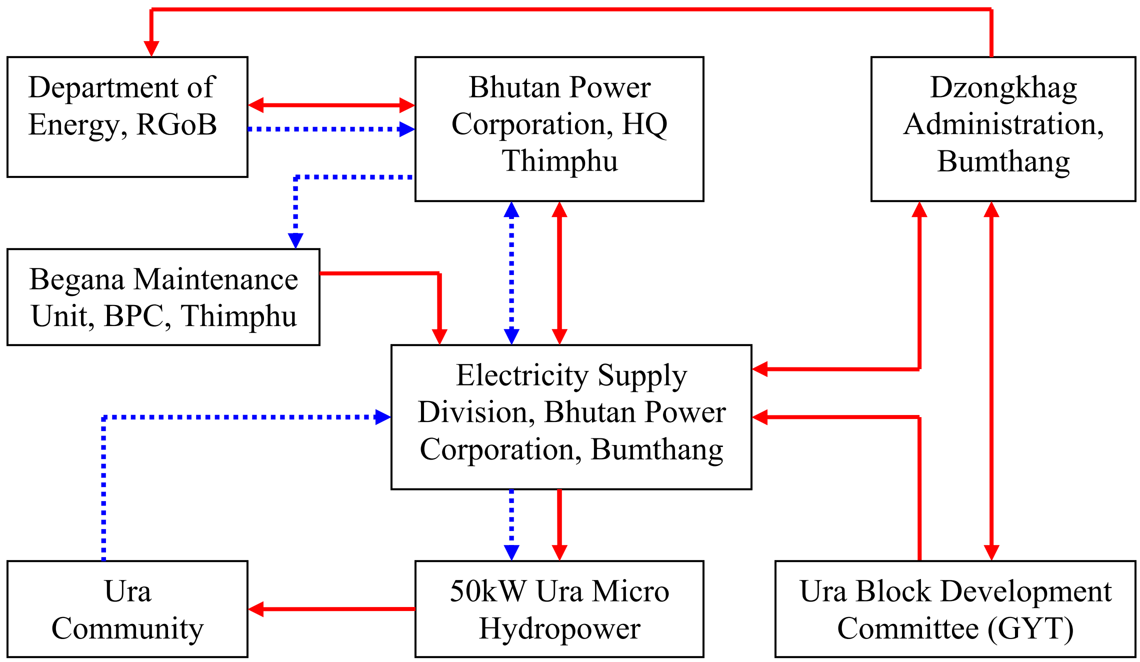

Figure 2.3: Institutional Management Structure of Ura Micro Hydropower Project. The solid lines indicate flow of institutional coordination and services. The dashed lines indicate cash flow.

Since the BPC was incorporated there have been three tariff increases. Notification has been again issued to increase the tariff for three more years from 1st July, 2007 (Wangdi, 2007). There are three customer classes: 1) Low Voltage (LV) consumers, 2) Medium Voltage (MV) consumers and 3) High Voltage (HV) consumers. There are three tariff classes for the LV consumers, the details of which for 2007-2008 are shown in Table 2.3 below.

Table 2.3: BPC tariffs for on-grid LV consumers (2007-2008)

	Units consumed (kWh) per month	Tariff (Nu./kWh)	
		Nu./kWh	US Cents/kWh
Slab I	0-80 units	0.75	1.67
Slab II	81-200	1.25	2.78
Slab III	201-	1.4	3.11

Source: BPC, 2007

According to BPC's 2006 annual report, total revenues from electricity sales and other revenues in 2004-2005 were over Nu. 927 million (USD 20 million) while its total expenditures including depreciation charges were Nu. 1,057 million (USD 23 million) (BPC, 2006a). This translates into a net loss of USD 3 million. It was observed from the abridged Profit and Loss Statement of BPC in 2004-2005 that this loss was primarily due to writing off of the Nu. 67 million (USD 1.5 million) Khaling mini hydropower system that was damaged in the 2004 floods and low tariff rates resulting from high subsidies (BPC, 2006a). Although the average generation cost for a unit of electricity was Nu. 1.2 per kWh (US 2.67 cents/kWh), BPC buys it from medium and large hydropower systems at Nu. 0.30 per kWh (US 0.67 cents per kWh) for domestic supply.

At the present, there are some micro hydropower systems that can feed into the grid, and as the grid expands it is expected that some more micro hydropower systems will be able to feed into the grid also (ADB, 2006, ADB, 2007). Once the grid arrives, there will be no incentive or reason for the BPC to continue running and managing the micro hydropower systems based on the current tariffs. There is currently no proper framework for the injection of power from the micro hydropower systems into the grid. In fact, BPC is considering outsourcing O&M services of micro hydropower systems and eventually handing them over to the communities (ADB, 2006, RED, 2006).

2.6.2 The Chendebji Community Managed Model

The e7 funded the 70 kW Chendebji Clean Development Mechanism (CDM) Micro Hydropower Project in 2005. The objective of the Project is to reduce Green House Gas (GHG) emissions and to contribute to the sustainable development of the community by constructing a Micro Hydropower station in an un-electrified Chendebji village under Tangsibji Geog, Trongsa Dzongkhag. Figure 2.4 and Figure 2.5 below shows a schematic overview and location of Chendebji Project.

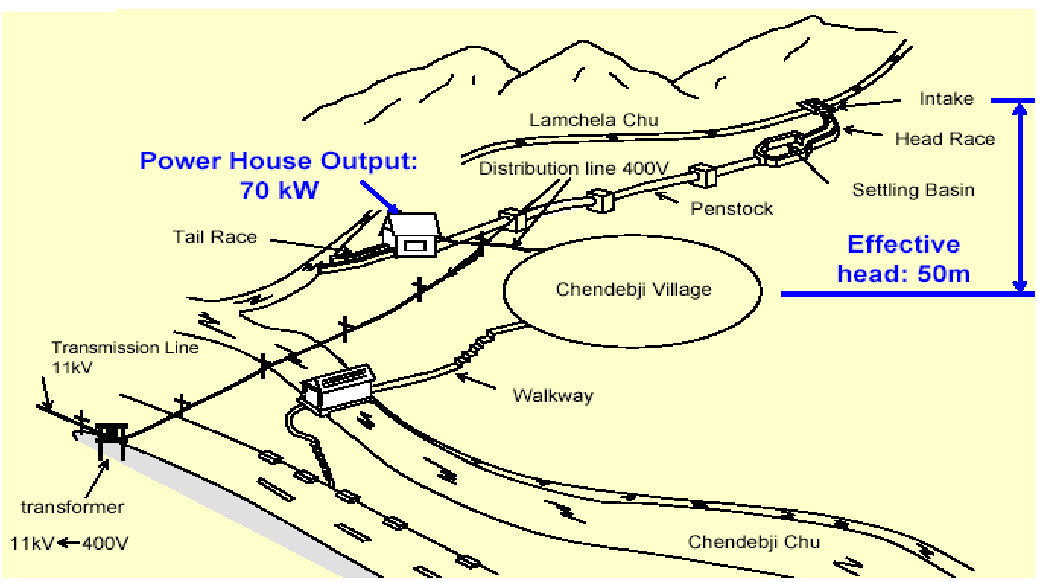

Figure 2.4: Overview of Chendebji CDM Micro Hydropower Project
Source: e7, 2003

Figure 2.5: Location of Chendebji CDM Micro Hydropower Project with Chendebji community in background.
Photo: Karma P Dorji, 2007

The funding agency, the e7, is an NGO formed in 1992 and consists of nine (9) electricity companies from G7 nations. The e7 has the vision of examining and co-operating on major global electricity-related issues, with an emphasis on the global environment and sustainable energy development (e7, 2003).

A portion of project funding comes from the CDM. CDM is one of the agreements approved within the Kyoto Protocol that was adopted at the third session of the Conference of the Parties (COP3) to the United Nations Framework Convention on Climate Change (UNFCCC) at Kyoto, Japan in 1997. Of the Kyoto Protocol agreements, only the CDM is relevant to Bhutan. The purpose of CDM is to assist Parties not included in Annex I (mainly developing countries) in achieving sustainable development and in contributing to the ultimate objective of the Convention (reduction of greenhouse gas emissions). In addition, the purpose of CDM is to assist Parties included in Annex I (mainly developed countries) in achieving compliance with their emissions reduction commitments under Article 3 of Kyoto Protocol. With ratification by Russia, the Kyoto Protocol came into force on 16 February 2005 (UNFCC, 2007).

The hardware component of the Chendebji project budget was US$ 563,198 (about Nu. 25 million), and was entirely funded by the e7 Fund in the form of grants and in-kind aid. The RGoB's cash counterpart funding for the project was about Nu.1.3 million. The project was expected to generate about 580,000 kWh (units) of energy annually and reduce about 500 tonnes of Carbon Dioxide (CO_2) equivalent per year once it was fully commissioned. The project assumes that the reduction in CO_2 emissions is based on the displacement of other energy sources available to the Chendebji village. These include diesel power generation, kerosene lighting, and fuel wood. Therefore, the development of micro hydropower system to provide energy for these same services offsets the CO_2 emissions that would have been emitted through the use of these other sources. The added advantage of this project is that the RGoB can sell/trade its share of Carbon Credits (called CERs) to potential buyers in developed countries.

The project was constructed under a turnkey contract awarded to a Bhutanese Contractor and was commissioned on 29 August 2005. In order to promote community participation in the operation and maintenance (O&M) of the project, the DoE signed an agreement with Trongsa Dzongkhag (District Administration) and the Chendebji Local Community on 31st July 2006 (CMHMC, 2006).

A Chendebji Micro Hydro Management Committee (CMHMC) was established with assistance from the DoE and Trongsa Dzongkhag. The members include at least the Trongsa Dzongdhag (District Administrator), the Gup (Village Head Man), the community Tshogpa (Community Leader), a senior citizen of the community and a representative from DoE. The DoE still holds the ownership of the project, provides technical back-stopping, and provides subsidies for procurement of major spare parts and equipment (Note: Since the project is fairly recent, no intervention from RGoB has been needed). CMHMC appoints a working level committee (2 operators from amongst the local populace) to look after the daily O&M of the project, perform billing and collection of energy sales, and maintain an O&M fund established for the project. The Operation and Maintenance Fund is maintained at the Bank of Bhutan, Trongsa. CMHMC has fixed a flat tariff of Nu.1.10 per kWh (US 2.4 cents per kWh) for the domestic consumers and Nu.1.30 per kWh (US 2.9 cents per kWh) for the commercial consumers based on BPC's block 2 and block 3 2005 tariff. The working committee gets token salaries of US$67 per month per person from the fund. BPC provides preventive maintenance and operator training at the request of the committee through DoE, with a fee for its services. The fees get paid from the same fund. Figure 2.6 below shows the institutional management structure of the Chendebji micro hydro model.

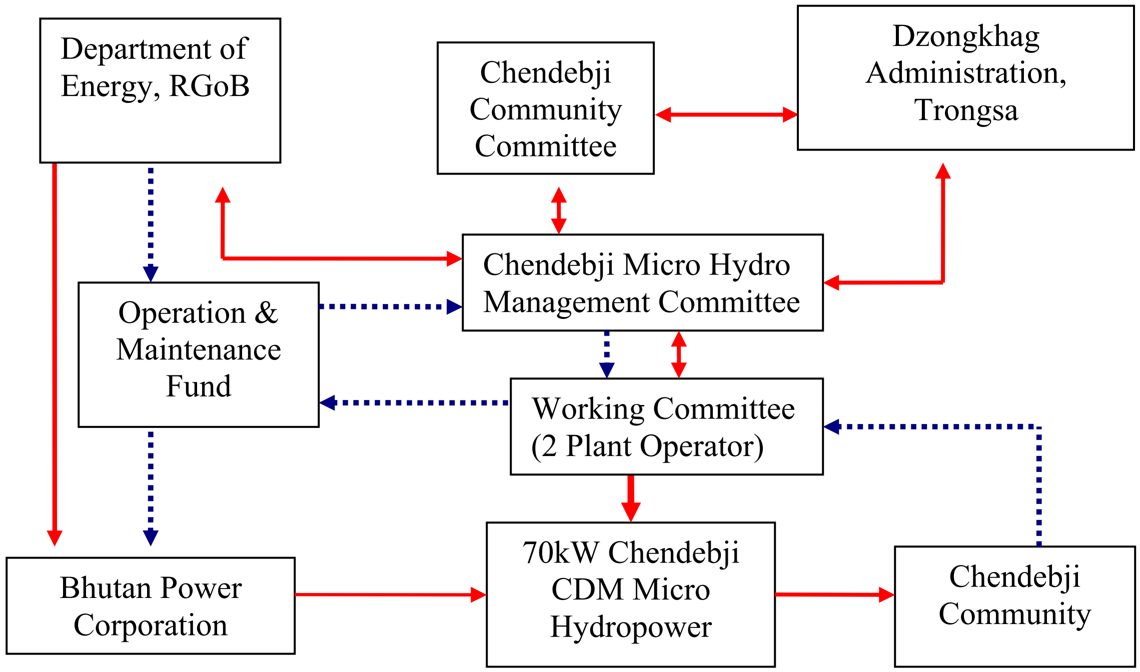

Figure 2.6: Institutional Management Structure of Chendebji CDM Micro Hydropower Project. The solid lines indicate flow of institutional coordination and services. The dashed lines indicate cash flow.

CHAPTER 3. LITERATURE REVIEW

3.1 Micro Hydro Power System

The basic principle of hydropower systems is that if water can be piped from a certain level to a lower level, then the resulting water pressure can be used to perform work. If the water pressure is allowed to move a mechanical component, then that movement involves the conversion of water energy into mechanical energy. Hydro turbines convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, a grain mill or some other useful device (Fraenkel et. al., 1991, Mewang, 2007). The system requires a sizeable flow of water and a proper change in elevation, called the effective head, which should be obtained without having to build elaborate and expensive structures. Figure 3.1 shows the main components of a "run-off-river" micro hydro power scheme. Each component has been described briefly below.

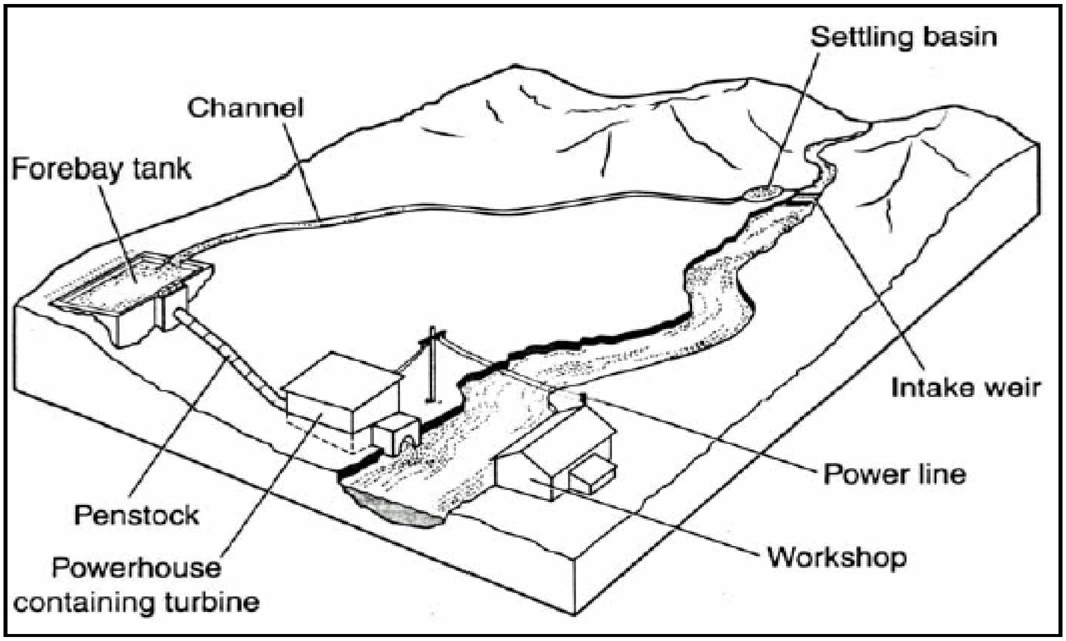

Figure 3.1: Layout and components of a typical micro hydropower installation.
Source: Anderson et al., 1999.

The source of water is a steam or sometimes an irrigation canal. Small amounts of water can also be diverted from larger flows such as rivers. The most important considerations are that the source of water is reliable and not needed by someone else. For example, in Bhutan's Chendebji micro hydropower station the water intake for the village is located upstream of the power plant water intake. This arrangement has not caused any impact on drinking water supplies (e7, 2003). Springs make excellent sources, as they can often be depended on even in dry weather and are usually clean. This means that the intake is less likely to become silted and requires less cleaning.

Run of the river schemes require no water storage; the water is instead diverted by the intake weir into small settling basin where the suspended sediment can settle. A grid to prevent the flow of large objects such as logs, which may damage the turbines, usually protects the intake. The diverted water is drawn via a channel into the forebay tank. The channel is usually a concrete or steel pipe along the side of a valley to maintain its elevation. The forebay tank holds sufficient water to ensure that the penstock is always fully submerged to prevent suction of air to the turbine. It also acts as water reservoir during lean season. The water flows from the forebay tank down a closed pipe called the penstock. The penstock is often made of high density materials and exposes the water to pressure; hence the water comes out of the nozzle at the end of the penstock as a high pressure jet. The power in the jet, called hydropower (a.k.a. hydraulic power), is transmitted to a turbine wheel, which changes it into mechanical power. The turbine wheel has blades or buckets, which cause it to rotate when they are struck by the water jet due to momentum transfer. Hydro-turbines convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, a grain mill or some other useful device. The water returns back to the same stream via the tailrace in the powerhouse (www.microhydropower.net).

The electricity generated is delivered to load centers through a distribution system or power lines connected to the households. Depending on the generation voltage level and distance of the load centers from the power house, distribution transformers can be used for stepping up (at the source) and stepping down (at the end user) voltage.

The installed capacity and energy output is calculated using standard equations:

$$P = (Q \times \rho \times H \times g \times \eta)/1000$$

Where:

P = power or installed capacity in kilowatts

Q =discharge rate in cubic meter per second

ρ = density of water in kg per cubic meter

H = effective head in meters

g = acceleration due to gravity and is 9.81 m/s^2

η = efficiency of hydro turbine generator in %

And Annual Output Energy (kWh) = P x hr x CF

Where:

P = power or installed capacity in kilowatts

hr = Annual continuous generating duration (8760 hours in a year)

CF = Plant Capacity Factor (typically 95% for run-of-the-river type systems)

According to the international small hydro atlas, there is no international consensus on the definition of small hydropower. In Canada "small" can refer to upper limit capacities of between 20 and 25 MW, in the United States "small" can mean 30 MW. However, a value of up to 10MW total capacity is becoming generally accepted (Anderson et. al., 1999, Fraenkel et. al., 1991). Small hydro can be further subdivided into mini hydro, usually defined as < 500 kW and micro hydro < 100 kW. The classification of hydropower is shown in Table 3.1. What remains the same is that small hydropower is often environmentally benign and makes hydropower a very attractive energy alternative which can make a significant contribution to future energy needs. A well designed small scale micro hydropower scheme can blend with its surrounding and have minimal negative environmental impacts. It is one of the most environmentally favorable energy conversion options available, because these schemes are run of the river not requiring damming or the creation of water reservoirs (Fraenkel et. al, 1991, Mewang, 2006). However, there are still some emissions associated with the technology during other life cycle stages. The chain of manufacturing the generating and transmission equipments processes are important source of emission (IEA, 1998).

Table 3.1: Classification of hydropower

Type	**Capacity**
Large hydro	>100 MW
Medium hydro	10-100 MW
Small hydro	1-10 MW
Mini hydro	100 kW - 1 MW
Micro hydro	5 - 100 kW
Pico hydro	< 5 kW
kW (kilowatt) = 1000 Watts. MW (Megawatt) = 1,000,000 Watts)	

Source: Anderson et al., 1999

Over the last few decades there has been a growing realization in developing countries that micro hydropower schemes have an important role to play in the economic development of remote rural areas, specifically in mountainous regions. Depending on the end-use requirement of generated power, the output from the turbine shaft can be used directly as mechanical power or the turbines can be connected to an electrical generator or alternator to produce electricity. For many rural industrial applications such as milling, carpenter workshops or pumping water, shaft power is suitable, but many applications require conversion to electrical power. For domestic applications, like light bulbs, radios, televisions, rice cookers, heaters, refrigerators, and food processors, electricity is required. This can be achieved by delivering power directly to home via a small electrical distribution system, or by means of batteries which are charged at the power house. This system is commonly used where cost of direct electrification is prohibitive due to scattered and sparsely populated housings (Anderson et al., 1999)

3.2 Micro Hydropower Development and Institutional Arrangement: Experiences from Developing Countries.

Reviewed literature demonstrates that the success of micro hydropower is clearly context specific. For instance, Khennas et al. (2000) claim that the specific context should be looked at in the terms both a micro and macro level of analysis. The micro level of analysis refers to the available resources and demand of a particular site. The macro level refers to the specifics of the institutional arrangements. The experiences from

Nepal, Sri Lanka and Peru demonstrate that integration of these specificities is necessary for sustainable development of a micro hydropower.

In Nepal, the first hydro power plant was established in 1911 with a capacity of 500 kW, according to Thapa (1995). Since then, micro hydropower technology has been disseminated and power has been generated so far in about 60 districts. Altogether about 1,072 micro hydropower plants including mills for agro processing have already been installed in the country. Micro hydropower development is governed by two acts passed in 1992: the Water Resources Act and the Hydropower Development Policy Act (Pandey, 1994). There are several government, semi-government, non-government organizations and private companies involved in the development and dissemination of micro-hydro power in Nepal. For instance, the Ministry of Water Resources (MOWR) is directly responsible for electricity and supervises the Nepal Electricity Authority (NEA) and Electricity Development Centre (EDC). The Nepal Electricity Authority (NEA) is a semi-autonomous institution responsible for the generation and supply of energy. However neither NEA nor any other government authority appears to be responsible for isolated grids. NEA has been able to cover 15 percent of the total population through expansions from the national grid. The service provided by NEA is largely been limited to urban and semi-urban areas (Aitken et al., 1995). EDC promotes private sector participation, grants licenses for independent generation and sales to NEA under the auspices of MOWR. It also assists Independent Power Producers through a range of activities including site identification for small and medium scale projects. EDC supports the Electricity Tariff Commission (ETC), which was set up in 1993 as an independent body to regulate electricity tariffs and ultimately to arrange for power sales between NEA and private power producers. The Ministry of Science and Technology (MST) has a mandate to promote national science and technology and oversees the Alternative Energy Promotion Centre (AEPC). The mandate of AEPC is to promote renewable energy technologies to meet the needs in rural areas of Nepal, but as a technology based organization it does not become involved in creating appropriate frameworks for rural tariffs or the organizational frameworks necessary for the creation of decentralized power companies. Shrestha and Amatya (1998) points out that contractor such as Development and Consulting Services (DCS), Intermediate Technology Development Group (ITDG) and others have been instrumental in the growth of micro hydropower (MHP) to date. However, without district-level capacity for repair and maintenance, breakdowns become costly in both money and time, technicians and equipment have to be sent in from Katmandu or further. Junejo (1997) and Rijal (1997) argue that even this level of support is in jeopardy, as DCS is now no longer working in the MHP industry. Since MHPs are usually located in remote areas far from road heads, maintenance becomes expensive when one considers transportation costs for equipment and travel costs for technicians. One dilemma is that in many cases, as Junejo (1997) claims, locally manufactured equipment is inferior in quality to imported equipment, as well as more prone to expensive breakdowns.

In Sri Lanka, according to Khennas et al. (2000) and Ariyabandu (2002), establishment of an Electricity Consumer Society (ECS) at the conceptual stages of a project has proven to be an important impetus for development of micro hydropower plants. A society is formed by the villagers consuming the electrical power delivered by the village hydropower plant. The office bearers, selected at an annual general meeting, are responsible for the management, financial control, load regulation, maintenance and resolution of any disputes arising from electricity usage within the community.

In Peru the municipal authorities have played a particularly important role in owning and operating micro hydro installations. This is partly because they are the entity that has access to government funds and can raise local resources through taxation. The municipalities are usually district or provincial capitals with a population that usually exceeds 500 people. Many reports indicate that the electricity service managed by them tends to have a greater coverage (higher electrification coefficient) than those operated by 'peasant communities' or private operators, because the mayors tend to justify themselves by providing services to as many families as possible (Velasquez, 1989, Martinot and Reiche, 2000). However, Ramirez (1995) argues that such a political factor has negative consequences, as there is a change over of Micro Hydro operating staff at each change of mayor (re-elected every four years). Access to central government funds means mayors are under no pressure to charge cost-covering rates for the service and generally politicians are reluctant to raise tariffs. All but one of the municipal plants reviewed had a negative financial balance and high rates of outstanding payments (23%), even though rates are relatively low, equivalent to $3.20 per month per user.

Private owners have also played an important ownership role. For instance, in Nepal, there are numerous cases where an individual has successfully developed and owned micro hydro businesses. An Ashoka award recipient Bir Bahadur built a micro hydropower plant in his hometown of Barpak. Over the past decade he has led the construction of 22 hydropower plants in five districts across Nepal. He founded the Barpak Service Federation to give technical advice and perform needed repairs. Furthermore, to support power management, he has founded the Center for Nepal Micro-Hydropower Entrepreneurship, connecting hundreds of plant managers for trainings and idea exchanges, and uniting them to advocate for rural development in national policy (Ghale, 2004).

Similarly, the concepts of district-scale hydros are gaining popularity in rural Nepal. Communities have taken the initiative to electrify themselves through formation of 'district hydros' instead of waiting for the national grid to supply them with electricity. An example is the Lamjung Electricity Development Co. (LEDCO) in Nepal, a community owned company dedicated to developing modern forms of energy through renewable energy technologies. LEDCO was formed in 1994 with investment shares from a number of Village Development Committee (VDCs), the District Development Committee (DDC), and individuals in Lamjung District (Panday, 1997).

Finally, as noted by Khennas et al. (2000), regardless of the financing mechanisms or the strategies of governments and aid agencies, the critical factors for micro hydropower development have been the existence of these individuals or agencies that have had the skill to put the various elements of a micro hydro project together (technology, finance, project management, institutional structures) and the tenacity to see it through to operation. The success of the community-based model will depend on the institutional linkages put in place to achieve sustainability. The community will not be able to effectively manage the micro hydros without the support of the other institutions.

3.3 Micro Hydropower and Productive End Use

A contentious part of the micro hydropower debate centers on justifying the level of productive and social benefits in program areas, given the relatively high cost of building, operating and maintaining the systems. Providing rural families with a few light bulbs may not have the dramatic economic effect that electricity planners or politicians anticipate. The identification of complementary conditions that enhance the productive usage of electricity for added income is an important part of examining the condition under which micro hydropower projects are selected. Evidence from a variety of case studies suggests that rural households engage in multiple income generating activities and rely on micro hydropower for diversifying income portfolios.

However, there are conflicting reports and differences in opinions regarding the financial viability of micro hydropower and its impacts on the improvement of people's livelihoods and productive end uses. Several authors have offered explanations for these differences. Khennas et al. (2000) claim that micro hydropower is likely to be more financially viable if the electricity generated can be used to supply power to a profitable cash generating enterprise. Experiences from Sri Lanka support this claim. For instance, all the energy production from an 11kW micro hydro facility in Yanahul, Sri Lanka is devoted to supply power to a privately owned broiler chicken farm (Kennas et al., 2000). The initiative to incubate fertilized eggs was promoted as an across the board business strategy aimed at reducing costs by incorporating activities and/or processes, thus severing the dependence on suppliers of broiler chicks. Only one person in the plant is involved in supplying energy to the incubating plant. The same person is also responsible for maintenance, for the entire process of incubation and hatching of baby chicks, as well as for selling soft drinks.

Rana-Deuba (2001) suggests that access to modern energy produced by micro hydropower in Nepal has resulted in or contributed to the establishment of micro enterprises especially for women. In mountain villages women traditionally bear the burden of energy collection and use, so any changes in energy source and usage thus affect women disproportionately. The availability of electricity itself, as well as the time freed up through electricity use enables income generation opportunities especially for women. In a village in the Annapurna conservation area, a couple started a poultry farm with their free time and hot water generated through electricity. Another example cites a woman who took a small loan for an incense-rolling machine. She has already repaid her loan and now generates 50 percent profits with the sticks she sells through a distributor in Katmandu. Similarly, Balla (2003) reports a similar variety of micro enterprises established and/or expanded following micro hydropower rural electrification projects in the Kirinyaga and Meru Districts of Kenya.

Some authors recommend that feeding the surplus power into the grid could provide a better load factor and the potential for reliable cash flow (see Ghaley et. al, 1999, Greacen, 2003) For instance, Ghaley et. al. (1999) found that in Nepal, the Electricity Act of 1993 opened up investment opportunities in the electricity sector from national, foreign or joint venture companies and made provision for concessional loans to generate and distribute electricity. The policy has also waived the license fee for surveys, generation, transmission and distribution, and stipulated that the Nepal Electricity Authority (NEA) will provide compensation to existing private owners and operators of a micro hydro plant if the grid is extended to their customer area. As a result, there are many cases where particular entrepreneurs have not only invested in micro hydro but have sold power to their neighbors and started up a number of businesses.

In Sri Lanka the high returns to one of the plants was a consequence of the high value imputed by the electricity sales from the micro hydro plant. The plant provided electricity to the Tea Estate where, otherwise, only expensive and unreliable power from the grid would be available (Khennas et. al., 2000, Ariyabandu, 2002). In other words, connecting to the electricity grid allowed for increased revenues due to an increased market size (demand).

Although the opportunity exists for grid integration, micro hydro often faces unfair competition from a highly subsidised grid, for example, subsidised fossil fuels and large hydropower. Due to the seemingly cheaper fuels, the utilities have no interest in purchasing the micro hydro power. As a result, the potential for success related to increased revenues (and demand) is forgone. For example, Greacen (2003) found in Thailand, the Provincial Electricity Authority (PEA) is expanding the electricity grid into remote villages already powered by micro hydro electricity. The incentive to expand the grid is in a large part due to the subsidy it receives from the Ministry of Energy. With large government budgets it has little incentive to avoid extending the grid to remote and uneconomic areas.

Community micro hydro villages make particularly attractive targets for PEA because these households make easy and good customers who are already accustomed to paying electric bills and own many electrical appliances. On the other hand, the Department of Energy Development and Promotion (DEDP) doesn't bother to save the micro hydro systems because DEDP is rewarded on the basis of the number of community systems it builds. When PEA comes in, DEDP often removes the generator and turbine and installs them in a new village, essentially double-counting the same equipment.

3.4 Summary of Literature Review

There is no standard model that can be readily used for a particular country. The appropriate system that will achieve the electrification of off-grid rural households best depend on the given socio-economic and cultural conditions of the targeted beneficiaries and the resources available.

The most important driver is having clear policy directives that stimulate development of micro hydropower. One way to achieve such policies is by waiving the requirement of a license for operation of generators below pre-determined capacity and encouraging mini-grid distribution in rural areas. Bhutan's Electricity Act 2001 has provision for free licenses up to 500kW but does not clearly specify about the grid distribution.

Micro hydropower is likely to be more financially viable if the electricity generated can be used to supply power to productive end uses. However, the studies show that such productive end uses are often difficult to develop. It may well be that micro hydro should be promoted for its role in securing livelihoods, or developing small enterprises, rather than as the rural electrification programme. Income generation from electricity is important for the continued financial sustainability of micro hydropower. Wherever feasible, grid integration with micro hydros provides compelling possibility for generating additional revenues, thereby reducing financial subventions making systems more viable. However, inefficient targeting of subsidies could jeopardize realizing such potential as the case in Thailand.

There is also a need for capacity building for all stakeholders particularly community organizations, local private enterprises, and technicians. Community and user participation is very important. They need to be consulted and informed so that the benefits are likely to accrue with the target beneficiaries.

CHAPTER 4. METHODOLOGY AND APPROACHES

This study consists of a combination of quantitative and qualitative methods, including structured questionnaire surveys, key informant interviews, analyses of electricity generation and consumption, life cycle cost analyses and institutional assessment of two sites having different management models of off-grid micro hydropower based rural electrification in Bhutan. The field survey used in my thesis was approved by the Human Subjects Review board, my thesis chair, and the Research and Graduate office at Humboldt State University. The human subject policy requires the information gathered to be kept confidential to protect the respondent's anonymity. Accordingly, I maintained these protocol during the field survey which was conducted during the summer of 2007 in the Chendebji and Ura villages. The guiding questions framing the survey were:

> What difference does access to electricity make to people's livelihood and activities?
>
> How reliably do current supplies meet their energy requirements?
>
> What stakes do the communities have in managing rural social infrastructure?
>
> What are the implications of decentralization policies?
>
> What levels of technical know-how do the people in the villages have?

4.1 Primary Data Collection

Primary data were collected through a semi-structured questionnaire survey in two case study sites, the Chendebji and Ura villages. The primary data consist of number of households and population, occupations and sources of income, energy sources, energy consumption patterns, electrical appliances and energy expenditures. A sample questionnaire is attached as Appendix 1.

The Chendebji village, in the Trongsa District, is located at 2260 meters above sea level and is about a 6 hour ride from the capital, Thimphu. The community has a primary school, an agriculture and livestock extension office, a Basic Health Unit, a non-formal learning center, and more than 50 households. The 70kW Chendebji micro hydropower plant is operated and managed by the Chendebji Micro Hydropower Management Committee.

The Ura village with 158 households, located in the central part of Bhutan in the Bumthang District. It has a lower secondary high school, the Thromshingla National Park Management Office, Basic health and agriculture extension units, a Block Development Committee (GYT) office and a few small scale business establishments. It is approximately a 14 hours to ride from the capital, Thimphu. The 50 kW Ura micro hydropower plant is owned, operated, and managed by the Bhutan Power corporation. Figure 4.1 shows the location of the two sites.

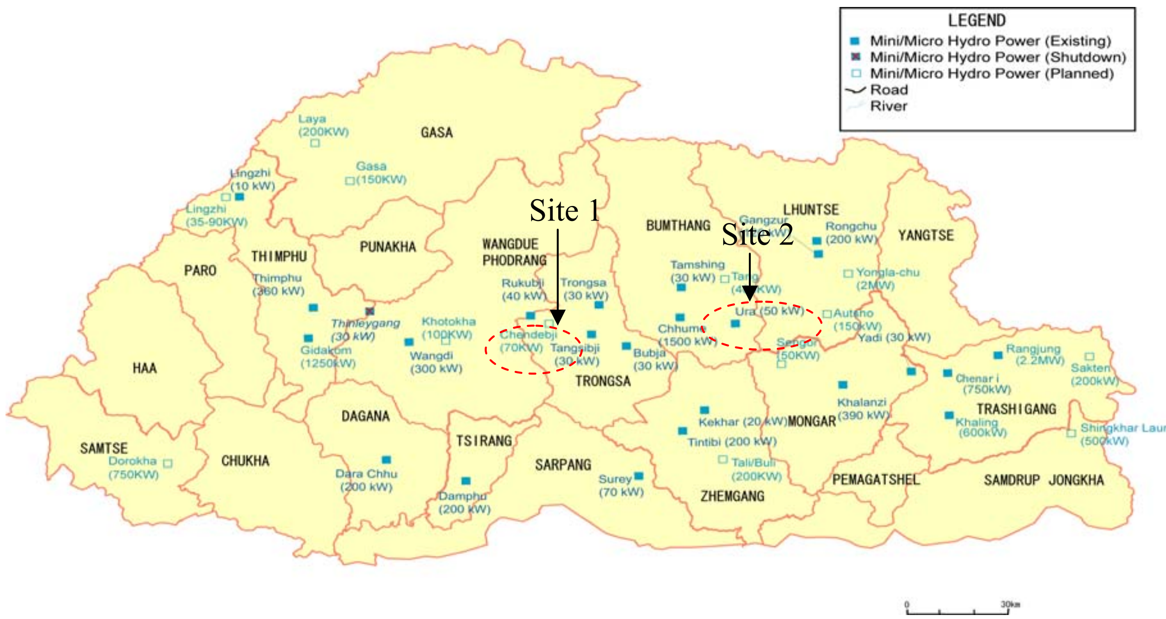

Figure 4.1: Map of Bhutan showing location of two case study sites and distance from capital, Thimphu. Map Source: REMP, 2005

I conducted a semi-structured questionnaire surveys of 22 households in Chendebji and 53 households in Ura village with prior permission from the Gup (Village leader). Although an attempt was made to collect random samples, most of the households (70%) were either locked or occupants were out in the field harvesting potatoes in both villages. At night, most families are also out in the fields guarding their crops from wild boars. In some cases, I used the assistance of the village Gup and micro hydropower operators to identify households that would be representative of the village. This may have introduced certain degree of bias in my sampling method. The limitation of this method is discussed later under section 4.4. I also collected the information using on-site observations. For instance, I physically counted the number of electrical appliances and lighting devices in each household. The electricity consumption data were collected by reviewing electricity bills and payment receipts. These data were further verified with the BPC and Chendebji committee (CMHMC). The data collected is compiled and attached. See Appendix 2 for reference.

4.2 Secondary Data Collection

Secondary data were collected from relevant government offices, corporate agencies, and other archives. The data consist of national policies and plans, acts and regulations, project documents, and established data archives. Information about operating histories, revenues generation, management systems, technological performance, supply reliability, operational issues and cost, inventories of spare parts, and associated costs with the micro hydros were collected through the Department of Energy, Bhutan Power Corporation, and Chendebji Committee. Separate interviews were held with key informants, including the BPC manager in Begana, Bumthang and Wangdue, project officers in the DoE and plant operators at both sites. These interviews provided supplementary information and helped in cross verification of data collected from the questionnaires. Interview methods were supplemented with direct field observations and generation data from micro hydro log books.

4.3 Data Analysis Approach

I used primary and secondary data, information gathered through key informant interviews, field observations, and insights from the literature to address my key research and sub research questions as discussed in chapter 1:

1) Assessment of the socio-economic significance of access to electricity
2) Assessment of electricity demand and supply to address issues related to generation capacity and equity of access to electricity.
3) Assessment of electricity generation and supply costs to address the economic inefficiency and subsidy issues of micro hydro schemes
4) Assessment of institutional arrangements and capacity.

I used the income, electricity consumption, and expenditure data to analyze the socio- economic significance of access to electrification in rural Bhutan. For the assessment of the electricity demand and supply, I used electricity sales and generation data. Levelized cost analysis was used for assessing the financial viability of the micro hydro schemes. Finally, I used insights from various literature sources, information gathered through key informant interviews, and on site observations to assess the institutional policies and human resources.

4.4 Limitation of the study

Owing to time and resource constraints, comprehensive socio-economic impacts of electrification, and a technical assessment of the micro hydropower systems have not been dealt with in detail. Further, as described in section 4.1, although an attempt was made to capture complete sample data sets in both villages, because of the coincidence with harvest season, many in the sample population were not available for the questionnaire survey. This may have introduced certain degree of bias in my sampling method. However, it should be noted that the results of this study involve many data sources, and therefore the potential bias from the survey would be balanced out by the trends seen in secondary sources of data. I have noted this wherever applicable throughout my report.

CHAPTER 5. FINDINGS AND DISCUSSIONS

5.1 Summary of Findings

Several studies on the impacts of rural electrification in Bhutan claim that electrification has created significant income generating activities through establishment of micro-enterprises and development of agriculture (IPSA, 2003, Bhandari, 2006). However, based on my field investigation, I argue that electrification has improved the quality of life but has not triggered any substantial income generating activities. The electricity demand for income-productive use is insignificant compared to the main uses: lighting and cooking. Less than 3% of the households in Ura and Chendebji communities are involved in running micro-enterprises like small grocery shops or hotels. Despite minimal electricity demand for productive end use, I assert that the domestic peak load surpasses supply due to increase in households and population size. Other studies have indicated that electrification leads to growth of population and number of households as the medical system becomes established and the outflow of the population to surrounding major towns and electrified areas decreases (e7, 2003, IPSA, 2003, REMP, 2005). I also argue that the financial viability of micro hydropower projects is inherently dependent on the level of subsidies and availability of donor grants.

The levelized cost analysis in this study shows that revenues from electricity sales do not meet the operation and maintenance costs of the micro hydropower systems. The shortages are 19% and 48% for Ura and Chendebji, respectively. There is a need for a subsidy to meet this gap. However, this need for a government subsidy can be offset if the hydropower is integrated into the grid. Finally, most end users have not been sufficiently informed of the benefits and limitations of micro hydro systems. This has led to many misconceptions regarding the reliability of the technology and what it takes to make the systems sustainable. The following sections present the validations of my main claims.

5.2 Income and Cost of Energy

It is widely recognized that priorities for ordinary people with low income and limited access to modern amenities are: adequate food supplies for the family, shelter to protect the family and its animals from scorching sun/rain, and a decent income to buy the basic necessities. However, it is also recognized that capability to diversify is beneficial for households. Having alternatives for income generation can make the difference between minimally viable livelihoods and impoverishment. Effective utilization of electricity for productive use can enhance income significantly. In this section I present findings from an investigation of energy consumption patterns and impacts on livelihood in Ura and Chendebji communities. In order to understand the energy consumption patterns, I investigated the economic activities, sources of income, and monthly consumption of electricity. In making the analysis, I focused on annual cash income, size of land holdings, possession of livestock, and expenditure on electricity per unit consumption as economic indicators.

5.2.1 Economic Activities and Source of Income

Analyzing the source of income from my survey data shows that the Ura and Chendebji population largely derives its livelihood from agriculture and in many cases, subsistence activities. These households are predominantly engaged in agricultural and forestry activities (including collection of non-timber forest products), activities which are both seasonal and yield low incomes. The main source of cash income comes from the sale of farm and dairy products. On the average, a household produces about 2000 kg of field crops (mainly potatoes) annually, which are sold for income (at Nu. 10/kg, US$ 0.22 for potatoes). They do not sell these products within the village; they go to relatively large towns, such as Phuentsholing (commercial hub of Bhutan), Trongsa, and Bumthang for business. Less than 3% of the total households in both villages are engaged in home based businesses such as a small grocery cum bar or a hotel. The civil servants such as health assistants, teachers, road engineers, and forestry officials posted in the two villages hold significant proportions of the rural cash economy compared to the average household income of the villages. Table 5.1 provides a summary of income sources for households in Chendebji and Ura villages.

Table 5.1: Main economic activities.

Economic Activity	% Households	
	Chendebji	Ura
Waged/salaried - Government/Official	5%	4%
Agriculture	78%	73%
Traders & Small Business Operators	2%	3%
Plant & Machinery Operators	2%	1%
Skilled Workers	2%	4%
Laborers & Unskilled Workers	9%	11%
Other	2%	4%

Source: Field Survey, 2007 (See Appendix 2)

The Table 5.1 validates that the majority of families that benefit from the micro hydropower projects are engaged in the agricultural sector. It also shows that the villages are characteristically similar in terms of the distribution of income sources. About 5% of the total households are engaged in waged and salaried activities, consisting of government and corporate employees. The "Other" category includes monks and *gomchens* (semi-monks) engaged in religious activities. As mentioned earlier, only 3% of households are engaged in small scale non-agricultural businesses. The common features of these households includes: limited land holding, low agricultural productivity, food insecurity, lack of access to financial capital, limited sources of income and limited access to markets. When I asked how poverty affects households in his village, the Ura Gup (village head) suggested that the immediate effects included borrowing money from local money lenders with high interest being charged, often catching the household in a debt trap. Other households borrow food and then work to pay off the debt. Poor households all around Bhutan share similar characteristics. They have few or limited economic assets in terms of land, animals, and other capital. They are primarily dependent on their labor to get an income and they buy the majority of their food (Personal communication with the Ura Gup, 2007). Poor households find it difficult to create a surplus of either time (for work) or goods, as they end up working to pay off debts rather than to accumulate food or cash.

Intuitively, land and livestock ownership should provide a reliable indicator of household income. On the average, Chendebji community has 3.9 acres dry land per household compared to 4.3 acres in Ura village. This acreage is comparable with the national average. The national average land holdings according to an agronomic survey conducted in late 1980s are: 58% of the farm households in the country (34,050 out of 59,430) had less than 4.8 acres, more than 27% (16,050) owned less than 2.47 acres. Of the households, 9% (5,900, which is approximately 40,000 people) were dependent on less than 1.2 acres (RGoB, 2000). Other studies have shown that the percentage of holders of less than 4.8 acres was far higher than the national average in areas where food insecurity was also prevalent (MOA, 2006). This is mainly characterized by micro-climates and micro-environments suggesting that most of these landholders have rather harsh condition and infertile lands, a case in point for the Chendebji and Ura village. Because of the lack of rule of primogeniture in Bhutan, there is a tendency over time towards a diminishing size of land holdings (RGoB, 2000). Pema (name changed) in Ura quotes incidences where families adopt particular strategies to counter this tendency and it is reinforced by migration away from the villages to urban areas. While migration to urban areas may inhibit the decrease in size of landholdings, it also decreases the size of the agricultural work force and increases the labor burden on those who remain. According to a Park Manager in the Ura village, the Nature Conservation Act of Bhutan prohibits opportunities for conversion of some of forested areas to agriculture land in the interest of conservation. Both the villages fall under buffer zones of the national protected parks.

The dependence on potatoes as the only cash crop in both villages exposes the communities' livelihood to considerable risk. Impacts of climatic change in the form of hostile seasonal conditions and incessant damage of crops by wild boars are seen as main causes of poor harvests. Many respondents share the same misfortunes. When asked about this year's yield, Tashi (name changed) responded that last year's yield was not that good and this year it's even worse. Everyone in the village has guard huts, guard dogs, and farmers spending day and night in the fields guarding the crop against wild boars. According to a farmer the boars have started coming to fields that are closer to his home and he said he was running out of options. Another farmer said that she had to plant potatoes twice because boars dug out the whole crop. A poor harvest would mean low cash income and potentially lead to a chain of economic dependence.

Although livestock constitutes one of the main sources of cash income for the communities, there were signs of resentment owing to the inherent economics of pastoral economy. Sangay (name changed), who owns 120 yaks and over 30 cattle in Ura, admits that while these livestock provides him with a modest income, managing them is also regarded as a labor intensive activity. He plans to sell all his livestock eventually, since slaughtering is prohibited under Bumthang Dzongkhag, owing to religious norms. The Dzongkhag has numerous historical religious heritages and sacred sites. The only means to derive income from livestock is through sales of diary products, which is seasonal and fetches low income due to lack of market and storage facilities. Figure 5.1 below shows a typical Bhutanese kitchen set up in Ura where women carry out most of the household chores.

Figure 5.1: Typical Bhutanese kitchen set-up in Ura where household's chores are mainly carried out by women. A woman is in the process of churning milk.
Picture: Karma P Dorji, June 2007

Rural credit in Bhutan is available to less than 5 per cent of the population (RMA, 2003). There are no NGOs providing micro credit services in Ura and Chendebji, except for the Bhutan Development Finance Corporation (BDFC), a development bank which provides limited loan portfolios with high interest rates (Personal communication with Manager of Rural Loan Section, Bhutan Development Finance Corporation, Thimphu on July 20, 2007). Poor outreach of BDFC to needy households has led to more than 30 per cent of farm households continuing to depend on unscrupulous private money lenders at interest rates of around 50 per cent per annum (MOA, 2006). Credit has been identified as the principal external stimulus that the poor should receive, and inadequate access to credit for the poor has been recognized as one of the major structural deficiencies of developing nations (Ramanujam and Ugyen, 2006). Poor people need small loans and they have no material collateral to offer. Conventional banking is not geared to operate in such situations and does not extend access to credit to the poor. However, there have been many successful experiments tried out in neighboring countries to improve outreach of credit institutions to meet the credit requirements of the poor among farm households and those engaged in off-farm activities. One such experiment is that of the Grameen Bank of Bangladesh, which had advanced credit even to the poorest among the poor using group solidarity, cooperation and peer pressure (Yunus, 2006).

In summary, the communities in both villages are challenged by various factors that inhibit their ability to increase their incomes. Based on personal interviews with

Dzongdhags (District Administrator), Gups and other village elders, various reasons given for low incomes are as follows:

- The landscape, topography, and the terrain are rugged. The agricultural land is therefore unproductive. Low income households own marginal and degraded land;
- Landholding is small and limited and the fertility is low. Therefore farmers are compelled to practice shifting cultivation;
- The incomes from traditional livestock are limited due to low milk outputs, limited access to grazing land, and limited access to improved breeds of livestock. The perception is that with improved breeds of livestock the herdsman could enhance their income as these breeds produce more milk with fewer heads of cattle to manage.
- Most villages are in remote locations far away from urban centers and have limited access to financial services and markets;
- Most families rely on subsistence farming and have no income left for savings. Fluctuations in agricultural productivity directly affects their means of subsistence and hence poverty is prevalent in rural families;
- People use most of their food grains to prepare alcohol for their own consumption. This results in a grain deficit in the home, and the families have to buy grains from the market, which further drains their limited disposable income;
- Many families migrate to urban areas in search of jobs and education for their children. This results in a reduction of labor which affects the rural economy;

Other studies have made similar observations (IPSA, 2003, REMP, 2005, Mewang, 2006). In this section I have discussed the economic activities and sources of income for the communities in Ura and Chendebji. In the next section, I will present the level and distribution of income.

5.2.2 Household Income

In 1992, the national average household income was about Nu. 2,164 per month based on rural household income and expenditure surveys (HIES, 2000). By 2006, according to estimates, the national per capita income per year reached Nu. 59,498 (US$1322) (NSB, 2006). On a monthly basis, this would be a per capita income of Nu. 4,958 (US$110). Assuming a national average family size of 6 persons, and that 2 are income earners, the average monthly household income per family in 2007 would have been Nu.9,916 (US$220). On the contrary, based on my survey data, the average annual cash income per household in Ura and Chendebji is estimated to be Nu 44,500 (~US$1000). On a monthly basis, this amounts to approximately Nu.4,000, 40% lower than the current national average. This validates the lack of income generating activities and dependence on subsistence farming as a main source of income. Table **5.2** shows the cash income distribution in Chendebji and Ura.

Table 5.2: Annual cash income distribution by household.

Annual Cash Income	**% Households**	
	Chendebji	**Ura**
High (Above Nu. 95000) (US$ 2111)	9%	11%
High Medium (Between Nu. 55000 - 95000) (US$ 1222 – 2111)	31%	14%
Low Medium (Between Nu. 25000 - 55000) (US$ 1222 – 555)	23%	37%
Low (Below Nu. 25000) (US$ 555)	37%	38%

Source: Field Survey, 2007 (See Appendix 2)

Note: The percentage households is estimated with survey sample size n = 22 and 56 in Chendebji and Ura respectively. The total households in Chendebji and Ura are 51 and 158 respectively. This stratification may not be a complete representation of the area under investigation due to inadequate samples.

The above table shows that about 10% of households earn more than US$ 2000 per annum. This includes small business owners, government and corporate employees and a few inherently wealthy sections of the community. About 68% of households earn less than US$ 1000 per annum, with income mainly based on agriculture. This translates into less than US$ 100 per month and US$ 3 dollars a day. These indicators validate the positive correlation between the total income and the share of income derived from non-farm sources. With a relatively smaller share of the total income, agriculture based households consuming less electricity due to less disposable income. This can be seen from the electricity consumption and expenditure on energy discussed in the next section.

5.2.3 Expenditure on Energy

Existing energy uses in rural areas are characterized by reliance on diverse sources of energy, where households and community facilities use different fuels for lighting, cooking, heating, and agricultural activities (IPSA, 2003). The more popular fuels used in Ura and Chendebji in addition to electricity include fuelwood, kerosene, diesel, dry cell batteries, and Liquid Petroleum Gas (LPG). Fuelwood is the primary source of energy for both villages. About 97% of households use fuelwood for cooking and heating. According to a survey result of the Bhutan Energy Data Directory 2005 (DoE, 2005), the average annual fuelwood consumption by rural electrified and unelectrified household is 7.8 tonnes and 10.4 tonnes per household respectively. This shows that electrified households consume 25% less fuelwood in comparison to un-electrified households. This reduction in fuelwood consumption can mainly be attributed to the shift to electrical appliances for cooking. The higher efficiency of electrical cooking devices compared to biomass cook stoves also contributes towards lowering overall energy consumption. Diesel is mainly used for powering mills and some farm machines. Some prosperous households use LPG stoves for cooking in both communities. However, the availability and high cost of these fuels in comparison with fuelwood (which can be collected without payment in rural areas) is seen as a major barrier for market penetration of these fuels. The landed cost of LPG cylinders in Ura is almost three times higher than the price in larger markets due to high transportation costs. Rural communities, therefore, rely heavily on more than one source of energy for cooking, and LPG is used only as a tertiary source of energy. Electricity is used extensively for lighting. In many cases, kerosene is used as emergency substitution for electric lighting.

The average electricity consumption per household in Chendebji and Ura are 130 kWh/month and 98 kWh/month and average expenditures are Nu 143/month (US$ 3.18 per month) and Nu. 107/month (US$ 2.38 per month), respectively. For those households defined as low-medium and medium income groups, the average monthly electricity usage reduced significantly to 87 kWh/month with average expenditures of Nu 96/month (US$ 2 per month). This is lower than the average monthly consumption by rural households of 120 kWh/month as reported by DoE and BPC (DoE, 2007b, BPC, 2006b). A few respondents said that they have higher expenditure at harvest time when, for example, they are required to sort potatoes through the night and require lighting for the task. Figure 5.2 shows the monthly expenditure on electricity in Ngultrum.

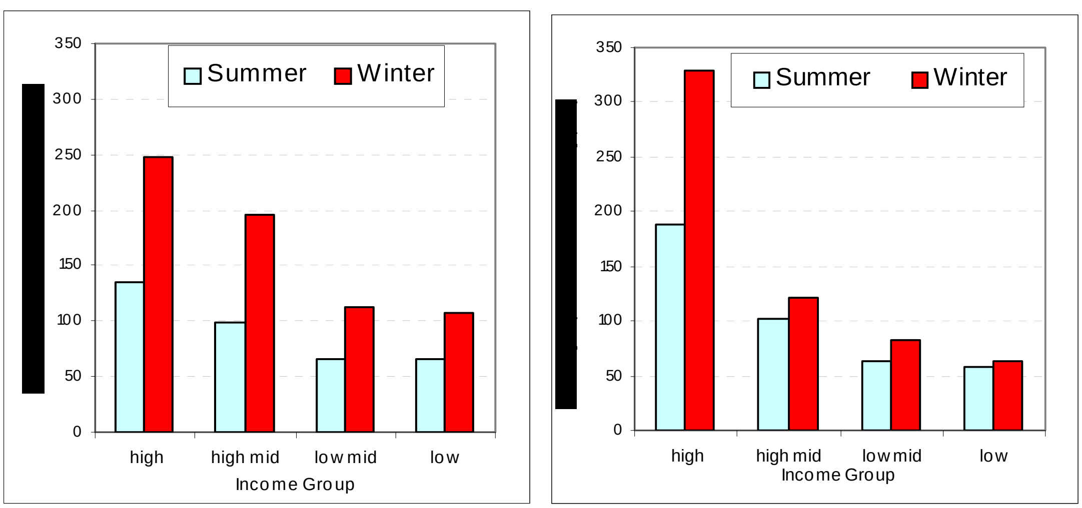

Figure 5.2: Monthly expenditure on electricity in Ura (left) and Chendebji (right). Electricity consumption data are recorded from the actual monthly electricity bill. Source: Field Survey, 2007 (See Appendix 2)

There is a clear correlation between income earning ability and expenditures for electricity in Ura and Chendebji, as is seen in the graphs above. The higher level of electricity use by higher income groups in winter is mainly contributed by electrical heating and cooking. Expenses for other fuels, food, and non-food consumption are not reflected in this study, although it would have bearing on the results of an income and energy expenditure analysis. This was avoided partly because of difficulties in estimating and quantifying the monetary values of those commodities and also due to a lack of reliable data. However, key respondents did mention that they are still spending a high proportion of their monthly expenditures on alternative fuel sources. This leads to the conclusion that households, once electrified, are using electricity primarily for lighting and cooking rice while using fuelwood and LPG for all other cooking and heating needs. During off peak periods of the day, electricity use remains low compared to generation in these communities. However because households demand electricity at the same periods of the day, shortages associated with peak loads are occurring. The next section presents an in-depth analysis of the demand and supply issues related to the effective management of rural micro hydropower systems.

5.3 Analysis of Electricity Demand and Supply

Understanding growth in electricity demand is crucial for determining the need for new electricity generation or conservation opportunities. End use electricity consumption depends on resource endowments, economic growth and other political, social and demographic factors. In order to ascertain this claim, I evaluated the electricity supply and demand situations in Ura and Chendebji. The basic premises of my demand forecasting are household and population growth, agriculture GDP growth, income elasticity and energy consumption. Other studies have applied similar parameters (Worley, 1998, TATA, 2000, SMEC, 2002, REMP, 2005). In this section I present the factors leading to growth in demand, and the results of power demand forecasts as well as their consequences on the energy balances in Ura and Chendebji villages.

5.3.1 Population and Household Growth

According to the feasibility study report for the e7 Bhutan Micro hydropower CDM project conducted in 2002, the population of Chendebji village has changed little in the past decade, and it is not probable that the population will increase abruptly in future. However, the study predicts that the population will increase following electrification due to the establishment of a medical system and a decrease in the outflow of population to surrounding major towns and electrified areas. The study projects the population of Chendebji village will double itself to about 600 people with 59 households, 1.5 times the present number of people (300) and 1.4 times the present number of households (42), after 10 years.

Similar trends were noted in my field investigation. There was an addition of 11 households and 20 people in the span of 5 years in Chendebji. The growth rate is analogous to the national population growth rate of 2.5% per annum and the integrated master plan study for Dzongkhag-wise electrification of Bhutan, 2.59% per annum. The same growth rate was applied in Ura community based on information gathered through field interviews with village elders. Figure 5.3 shows the projected households and population increase for 2020. This projection will assist in assessing the demand and supply of electricity in two ways. First, it establishes actual demand and supply baselines. Second, it provides a basis for forecasting the electricity demand growth. This will be discussed in next section.

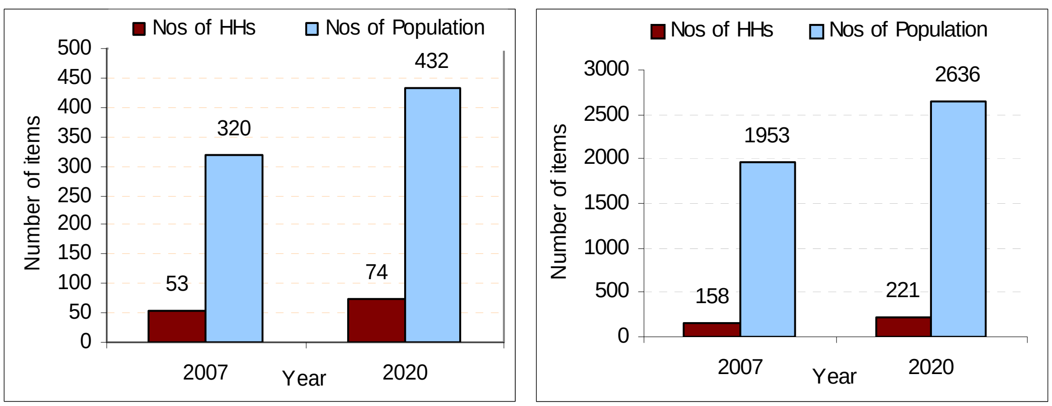

Figure 5.3: Projected growth in the number of households and population in Chendebji (left) and Ura (right) villages.

Studies have shown that electrification drives population and household growth, rural development and improvements in quality of life (Tshering and Tamang, 2004, Bhandari, 2006). However, as discussed in section 5.2.1, there are underlying concerns of rural to urban migration mainly due to urbanization processes occurring in Bhutan. There are two broad categories of migration factors: A movement of an entire family is often associated with employment. For example, a family moves when its primary earner is a civil servant and is posted to a new site. Alternatively, on the individual level, a migrant might be simply attracted away from their village by a desire for the kinds of changes that urban setting offers. Commercial activity, consumerism, and popular entertainment tends to attract young people, for instance. A recent study conducted by Bhutan's ministry of agriculture observed that if the present trends in rural to urban migration continue, it will cause serious economic imbalances: labor shortages in rural areas, increasing urban unemployment, and choking of urban civic amenities (MOA, 2006). In the above projections, I have not considered the factual numbers of migrants partly because of a lack of data and difficulties quantifying migration patterns. I have shown in this sub-section how the population and households are increasing in these communities. In following section, I present the current electricity supply and demand portfolios of Ura and Chendebji micro hydropower systems.

5.3.2 Electricity Generation

As it was explained in chapter 2, in the past Bhutan's Department of Power managed, operated, and ran all the micro hydropower sytems. Those micro hydropower systems were handed over to the Bhutan Power Corporation (BPC) when it was corporatized in 2002. The BPC is now responsible for the operation, maintenance, and overall management of the micro hydros including the 50kW Ura micro hydropower. The distribution of power in Ura is provided with around 4.9 km of 6.6kV line and four 6.6/0.4 kV transformers. Ura's micro hydropower system was built in 1986-87 with financial assistance from the Japan International Cooperation Agency. Since its commission, it has not faced any major problem other than periodic clogging of the intake weir and water channels during monsoon seasons (Personal communication with Ura MPH care taker during field survey, 2007). However, it is worth mentioning that none of the stakeholder agencies have kept track of past or present generation data. The only available generation data is based on BPC's data on actual metered energy sold. For details of energy sales data collected from Customer Electricity Service Division, Bumthang, BPC, see Appendix 3. Figure 5.4 shows the total energy sales in Ura from January 2003 to June 2007 based on the average energy sales recorded in BPC's Monthly Performance Reports.

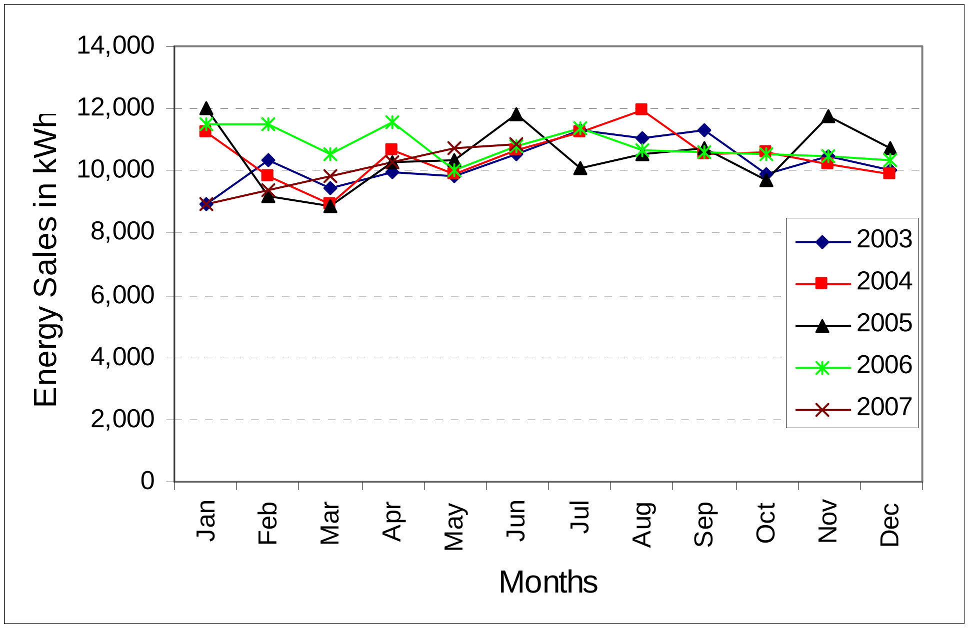

Figure 5.4: Monthly energy sales in kWh of Ura Micro Hydropower. The average monthly energy sale is about 10,400 kWh per month. The generation has been consistent through out the year since its source is a perennial stream.
Data Source: Bumthang Customer Service Division, BPC, 2007 (See Appendix 4)

Due to the unavailability of generation data, I estimated the future annual generation of the Ura micro hydropower plant to aid in assessment of the supply and demand energy balance. Assuming 92% plant capacity factor (for example see e7, 2003), which is a standard value for a run-off-the-river type station that takes into account annually planned inspection/maintenance outages and unplanned shutdowns, the annual output of the Ura power station is calculated as follows:

Annual Output (kWh) = Capacity (kW) x Annual continuous generating during (hrs)
x Capacity factor (%)

Annual Output (kWh) = 50 kW x 8,760 hrs x 0.92 = 402,960 kWh

Comparing this figure with total annual energy sales of 126,150 kWh, only 36% of the net generation is being utilized, accounting for an estimated 12% distribution loss. A similar scenario was observed in Chendebji case.

As I mentioned in chapter 2, due to BPC's reluctance to take over the operation of new micro hydros, when the Chendebji micro hydro was completed in 2005, an alternative management model was sought. As a pilot scheme the Department of Energy has ventured ahead with a community based management model for the Chendebji project. The operation and management of the plant is handed over to the community through the formation of the Chendebji Micro Hydropower Management Committee (CMHMC). Subsequently, CMHMC has appointed two plant operators and they have been trained with basic O&M skills by BPC. Based on generation records in operation log books and the monthly energy sales maintained by the plant operator, I evaluated the energy balance of supply and demand in Chendebji. For detailed generation and energy sales data, see Appendix 3. Figure 5.5 and Figure 5.6 indicate that there is adequate supply to meet the demand. Approximately 11% of the energy generated is sold excluding the distribution losses which accounts for about 12% in general. Based on my analysis, over 77 % of the energy generation in Chendebji is subsequently dumped back into the stream as non-utilized waste heat. There is a currently a generation surplus of approximately 30,000 kWh/month.

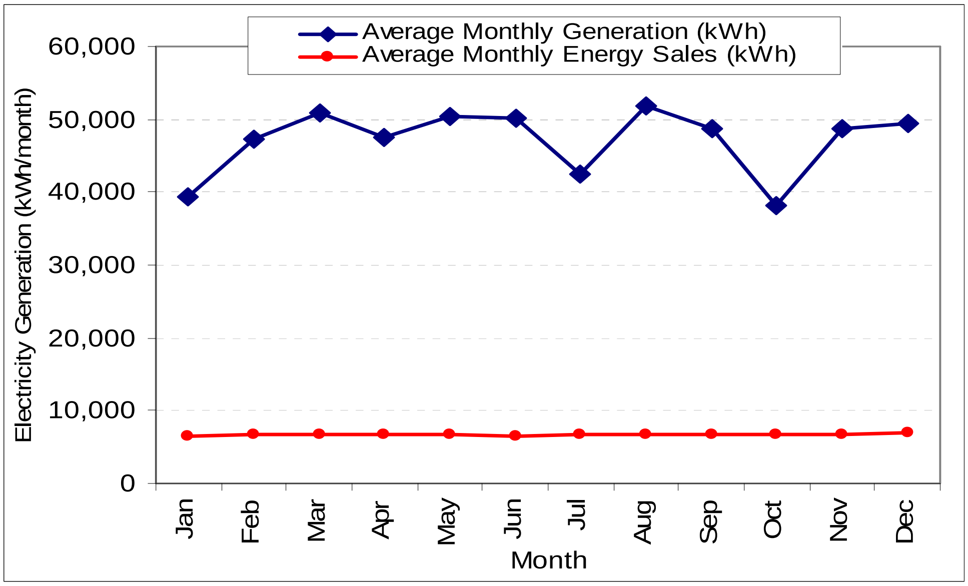

Figure 5.5: Average monthly generation and sales in year 2006 by the 70 kW Chendebji MHP. The average monthly generation is about 47,000 kWh.
Source: Field Survey, 2007 (See Appendix 4)

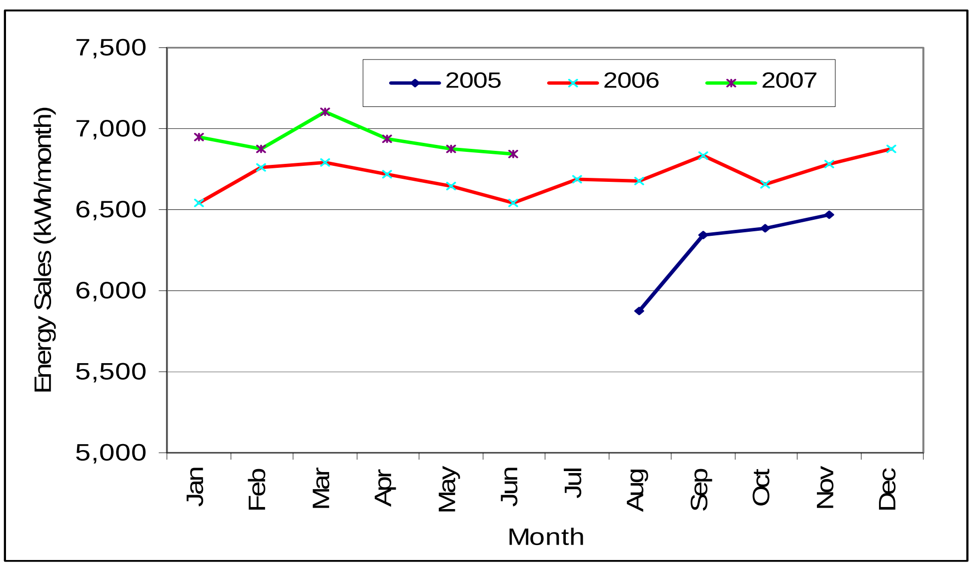

Figure 5.6: Monthly energy sales in kWh in Chendebji. The increase in demand over three years is mainly attributed to increase in households, electrical appliances and population. Source: Field Survey, 2007 (See Appendix 4)

Although, there is surplus generation, the installed capacity is not able to keep up with the peak loads. I will discuss this in detail in the following section.

5.3.3 Peak Loads

For determining peak demand in the two communities, I used the 2005 survey data from the Rural Electrification Master Plan (REMP) in addition to my survey data. The REMP sample consisted of 29 households in 7 villages electrified by off-grid micro hydropower, including Ura village (REMP, 2005). The REMP survey investigated the possession and hourly usage of home electric appliances. Due to a lack of appropriate instruments, I could not conduct a thorough energy audit to gather complete information on the use of electrical appliances. Although the REMP data may not reveal the complete scenario of the villages under investigation, it provides a sound basis for comparing projected demand and supply since the villages in my investigation share similar socio-economic conditions of other villages surveyed under the REMP project. The REMP survey results reveals that 65% of the electrified households utilize electric rice-cooker (640W in average) and 29% households use an electric water boiler (REMP, 2005), which is similar to my estimation, as shown in Table 5.3. Not many variations are observed in the possession and utilization of electrical appliances between the Chendebji and Ura communities. Chinese made electrical rice cookers and water boilers are the most common electrical appliances, and are used extensively in both villages. Figure 5.7 shows typical use of rice cookers, curry cooker and a water boiler in the Ura village.

Figure 5.7: A typical use of electrical appliances such as rice cookers, curry cooker and a water boiler in the Ura.
Photo: Karma P Dorji, 2007

For lighting, 60 and 100 Watt incandescent lamps are the most common bulbs used in both villages, owing to their low cost. A few compact florescent lamps (CFL) are used in the high income group in both villages. A 60 W incandescent lamp costs about Nu.15 (US 33 cents per lamp) compared to Nu. 350 per CFL (US$ 8).

Table 5.3: A distribution of electrical appliances by household numbers with sample size of n=22 and 56 for Chendebji and Ura respectively.

Electrical Appliances	% Households	
	Chendebji	**Ura**
Fluorescent Lamp (40 W)	36%	0%
Compact Fluorescent Lamp (18W)	5%	9%
Incandescent Lamp (60 or100 W)	100%	100%
Rice cooker (640W)	95%	70%
Curry cooker (1000W')	27%	21%
Water Boiler (650W)	45%	32%
Mixers (250W)	9%	4%
TV (66W)/Radio(25W)/ Refrigerator (80W)	32%	13%
Pumps/Tools	5%	2%
Others (Heaters 1000W)	32%	0%

Source: Field survey, 2007.
Note: % distribution does not indicate the % utilization factor. It indicates the number of appliances in terms of possession.

Average daily load curves for Ura and Chendebji domestic consumption were generated by estimating the peak loads using the REMP data, combined with my survey data. REMP estimated peak loads of 0.82 kW per household in the winter season and 0.62 kW per household in the summer season from their results of the survey of 29 electrified households (REMP, 2005). As shown in Figure 5.8, the largest peak load time occurs at approximately 8 o’clock in the evening for cooking and lighting, and other peak loads appear during breakfast and lunch times. During the daytime, loads are very low with the exception of a small lunchtime peak. After the dinner hour, night time loads are also very low. Detailed calculations are shown in Appendix 4.

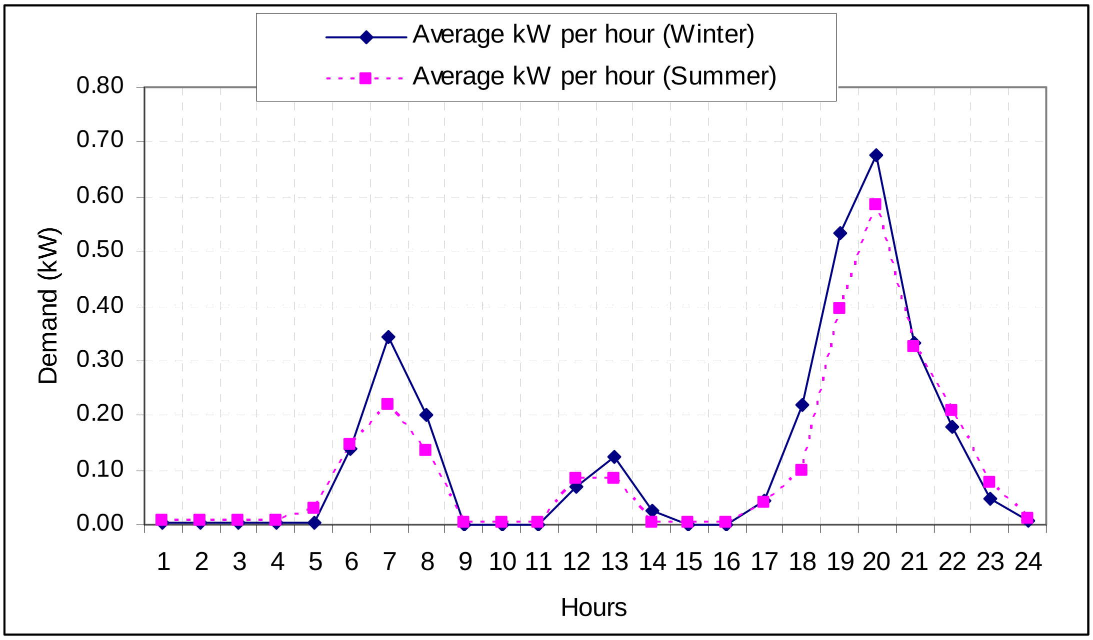

Figure 5.8: Typical daily load curve generated using REMP data of 29 households in 7 villages electrified with off-grid micro hydropower system. Estimated average peak loads are 0.68 kW in winter and 0.55kW in summer per household which coincidentally occurs at 8pm. Source: REMP, 2005

For the estimation of a peak load per household, I assumed a total average electricity consumption of 97 kWh per month per household (average of 86 kWh in Ura and 108 kWh in Chendebji), a diversity factor (the ratio of the sum of the individual maximum demands of the various parts of a power distribution systems to the maximum demand of the whole system; the diversity factor is always greater than unity) of 1.2 (peak load/average peak load i.e.0.82/0.68), and a load factor of 25% [(120 kWh/30 days/24 hours)/0.68 kW = 0.25]. The peak loads of Ura and Chendebji were projected as shown in Table 5.4 using the equation given below.

$$\text{Peak Load of Village} = \frac{\text{Peak Load per Consumer x Number of Consumers}}{\text{Diversity Factor}}$$

Table 5.4: Forecasted peak loads for year 2007 and 2020.

Village	Installed generation capacity (kW)	Nos. of Households		Total Peak Load (kW)	
		2007	**2020**	**2007**	**2020**
Ura	50	158	221	90	125
Chendebji	70	53	74	30	42

Source: REMP, 2005 and Filed Survey, 2007 (See Appendix 2)

Note: The average peak load for Chendebji may be a little higher than at Ura given the surplus supply.

It is estimated that the current peak load of Ura is almost 80% higher than installed capacity of 50kW with the projected peak load by 2020 surpassing the installed capacity by 75kW, even when considering only domestic loads. The micro hydro currently serves over 158 consumers and is only sufficient to meet their lighting needs. Although the use of heaters and electrical appliances such as rice cookers are not permitted according to the operator, the restrictions are apparently difficult to implement, leading to low voltage problems (brownouts). Frequent power shut downs and acute brownouts in Ura during peak load hours were common plights observed during my field investigation. Almost 100% of the respondents in Ura confirmed that there are frequent power outages and brownouts during peak load hours. The electricity supply provisions are far from adequate and power shortages can only be alleviated if the grid is extended to Ura. There are also some cases whereby technical solutions like load limiting switches were used according to BPC technicians, but they were often bypassed by the households.

On the contrary, Chendebji is not experiencing power outages during their peak load time, since the estimated peak demand accounts for only 50% of the installed capacity. But given the government's plan to expand the Chendebji grid network in the next few years to more villages within the vicinity of Chendebji, the reserve peaking capacity may not be adequate to meet the additional loads and Chendebji residents might experience similar plights to those in Ura. The estimated current peak load of Chendebji is 43% less than installed capacity of 70kW and it is anticipated to increase by 12kW by 2020.

In response to peak load issues in Ura and potential future issues in Chendebji, there is a substantial potential to reduce the peaks by replacing incandescent lamps with compact fluorescent lamps (CFL). From my survey data, on the average each household has 3 incandescent bulbs which translate to a total of 160 and 474 incandescent lamps in Chendebji and Ura village, respectively. Assuming 50% are 60 Watt and 50% are 100 Watt, the power consumption for lighting at any given time is 38kW and 13kW for Ura and Chendebji, respectively. If the same numbers of incandescent lamps are replaced with 18W CFL lamps, the peak load can be reduced by 32kW and 11kW at Ura and Chendebji as shown in Table 5.5. However, CFLs can be damaged by brownouts and voltage surges; they are more sensitive to power quality than incandescents.

Table 5.5: Peak Load reduction by replacing incandescent lamps with CFL.

Village	Number of Incandescent Bulb		Power Consumption (kW)	Power Consumption (kW) by equal nos. of 18W CFL lamp	Peak Reduction (kW)
	60W	100W			
Ura	237	237	38	6	32
Chendebji	80	80	13	2	11

Source: Field Survey, 2007 (See Appendix 2)

BPC has carried out CFL projects in urban towns like Bumthang and Trongsa on a cost sharing basis mainly to reduce the peak loads and use of diesel generation (Personal communication with BPC Manager at Trongsa and Bumthang, 2007). Under the current 9th five year plan, a grid extension of a 132 kV Tingtibi – Trongsa - Bumthang line is underway and is scheduled to be completed by end of 2009 (9th FYP, 2005). There is also a plan to extend a 33kV grid line to Ura under the 10th Five Year Plan (Draft 10th FYP, 2007). Until such time there will be acute power shortages in these areas. However, introducing a similar CFL project by itself will not completely resolve the shortage of power in Ura as it will reduce only a portion of the peak demand.

Cooking using rice cookers also contributes to a substantial portion of the peak loads. From my survey, 95% of households in Ura and 70% of households in Chendebji uses rice cookers. Assuming that all rice cookers are rated at 640W and are turned on at the same time on "cook" mode for half an hour and "warm" mode for another half hour, the estimated peak loads are 47 kW for Ura and 21 kW for Chendebji as shown in Table 5.6. In a laboratory setting a similar volume rice cooker was measured using a digital power meter and was found to consume 610 W on ‘cook’ mode and 240W on ‘warm’ mode.

By shifting the time of the use of rice cookers, peak demand can be reduced substantially. Such a measure would require strict enforcement or off-peak tariff incentives. Requiring cooking during off-peak times can still provide the same service by covering rice cookers with an insulated box to help keep the rice warm to be eaten during their normal meal time. This would not only reduce the peak load, but would also improve the plant load factor by utilizing the off-peak energy which is otherwise dumped back into the stream as non-utilized waste heat. By improving the load factor, brownouts will be reduced and hence introducing CFL measure will be complimentary in effect.

In the future, peak loads will continue to increase as the number of appliances increases due to growth in population and households. Additionally, based on projected demand, there will still be surplus generation capacity during off-peak times. An effective load management plan is therefore necessary to address this issue. The validation of this argument is presented in the next section.

Table 5.6 : Estimated Power Consumption by Cooking using Rice Cooker.

Village	Number of Rice Cookers (640W)	Power Consumption (kW)		Total Power Consumption (k W)
		Cooking Mode	Heating Mode	
Chendebji	50	15	6	21
Ura	111	34	13	47

5.3.4 Demand forecast

To forecast the electricity demand, I used an average consumption per household of 86 kWh/month for Ura and 108kWh/month for Chendebji and an estimated growth rate of energy consumption based on GDP growth rate and the income elasticity of Bhutan's agricultural sector. The GDP growth rate of the agricultural sector is estimated to be 3.4% based on the average rate of 1991-2003. For the detailed derivation of the growth function, see Appendix 5.. Income elasticity is assumed to be 1.2 (Generally applied in South East Asian region Source: REMP, 2005). Other studies have applied similar parameters (Worley, 1998, SMEC, 2002).

Demand growth is calculated using the following equation:

$$\left[AMEC \times \left(1 + \left(AGDP - HGR\right) - IE\right)\right]^{\left(T_t - T_b\right)}$$

Where:

$AMEC$ = Average monthly energy consumption in kWh per household

$AGDP$ = Agriculture GDP Growth Rate

HGR = Growth Rate of Household Number

IE = Income Elasticity

T_t = Target Year

T_b = Base Year

Table 5.7 shows the result of demand forecast for Ura and Chendebji.

Table 5.7: Forecast of energy consumption in MWh

Village	Averaged Monthly Energy Consumption kWh per HH	Number of Households			Estimated Annual Energy Consumption (MWh)		
		2007	2009	2020	2007	2009	2020
Ura	86	158	166	221	162	174	258
Chendebji	108	53	66	74	69	87	109

Source: Field Survey, 2007 (See Appendix 2)

As it was noted in earlier section, the annual energy generation of the Ura and Chendebji MHPs are 403 MWh and 564 MWh respectively. This indicates that there is enough generation capacity including technical and non-technical losses to meet the projected demand by 2020 even with increase in population and households. It also creates an opportunity for the communities to feed the surplus energy to the grid by the end of 2009 assuming grid extension is completed. Further, by interconnecting with grid, the peaking loads in both communities can be met from the grid power. The revenues accrued from the export of surplus energy to BPC will supplement the operation and maintenance cost, thereby enhancing the sustainability aspects of the micro hydropower systems. An analysis of financial viability and the benefits of feeding surplus electricity in to the grid are discussed in the next section.

5.4 Analysis of Financial Viability

Based on a financial analysis, I found that the total revenues accrued from energy sales at the current tariff do not meet the annual operation and maintenance, and levelized repair and replacement costs. There is evidence of a need for subsidy to meet these costs. It is justifiable to provide a capital subsidy for off-grid micro hydropower consumers given that the on-grid consumers receive both a capital subsidy as well as an operational subsidy which results in electricity tariffs that are well below the actual cost of supply. Further, once the grid arrives, micro hydropower can feed in surplus energy into the grid offsetting the need for government subsidy.

Financial sustainability of a project is defined as the project running indefinitely using monies that are generated from its own resources. In order to determine the financial viability and sustainability of the two schemes for micro hydropower plants, I have estimated the level of subsidy required to meet the O&M costs and levelized repair and replacement costs. System component life and recurrent operational costs were assumed as shown in Table 5.8 in order to assess the price of electricity per kWh.

The capital costs are taken from project reports and, as noted in the remark column of the Table 5.8. About 95% of the capital costs are grants and RGoB equity in-kind and cash mainly covering the logistic and counterpart cost. It may be noted that I have assumed capital cost as sunk costs (a grant) and estimated O&M, and repair and replacement costs required to sustain the micro hydropower system sustainably. BPC allocates a capital budget of Nu. 1.100 million (US$0.025 million) for operating and maintenance of all micro hydros (BPC, 2006a). Similarly, the Chendebji micro hydro plant operators indicated that the Chendebji micro hydropower management committee has allocated annual O&M budget of Nu. 0.088 million (US$2000). Based on the Rural Electrification Master Plan Report and BPC's district electricity service division expenditure budget statement, I estimated the cost of O&M as an aggregate cost by summing cost of electromechanical and distribution (Low Voltage lines and distribution transformers) line spare parts and used yearly and monthly wages of the operators which roughly works out within the allocated budgets. Additionally, there were other incidences where the DoE assisted BPC to source spares for micro hydro projects built with Japanese assistance. The problem with acquiring spare parts is, according to DoE and BPC official, the original suppliers of the equipment no longer exist and are not interested in supplying the spare parts, or do not stock the spares as the technology has become outdated. Consequently spare parts are not readily available or are very expensive. In estimating the cost of repair and maintenance, especially the cost of generator and turbine auxiliaries and civil infrastructures, I used prices based on recent purchases made by DoE for Sengor 100 kW Micro Hydropower in 2006 (Personal communication with Sengor Project Manager at DoE, 2007, GEF, 2005). It may also be noted that I have assumed the repair and replacement costs will be incurred after 20 years from the commencement of the micro hydropower project and once major overhaul is completed, the system can run for another 15 years. These assumptions are based on BPC's micro hydropower technicians at Begana, Thimphu. For instance, Ura micro hydropower has been running for 18 years and BPC took over in 2002. A major overhaul is expected within two years from now. Once overhauled, the system should run for another 15 years. The result of financial analysis of the Ura and Chendebji systems are presented in Table 5.9. For details of the calculations, see Appendix 6.

Table 5.8: Assumptions on financial input parameters.

Parameters	**Chendebji**	**Ura**	**Remarks**
Economic Lifetime Period of micro hydropower plant (Years)	35~40	35~40	Considering a conservative scenario. Civil components are expected to last over 40 years and electromechanical components last more than 35 years according to Chendebji CDM feasibility report.
Real Interest	8%	8%	Nominal interest of 13% with Inflation adjusted (Average Inflation at 5% per annum) (source: RMA, 2007).
Capital Cost of Project (US$)	563,199	530,250	95% Grant and 5% Government Equity (Constant Dollar 2006).
Operation and Maintenance Cost per year (US$)	$3,538	$4,200	Includes Operator, electromechanical spare parts and distribution line operation and maintenance cost. Source: BPC, DoE and Chendebji MHP.
Repair and Replacement (US$) after 20 years	$38,649	$36,284	Cost of generator & turbine auxiliaries and civil infrastructure based on recent purchases by Dept. of Energy for Sengor 100 kW Micro Hydropower in 2006.
Salvage Value (US$)	$53,431	$50,500	Assuming 10% of the capital cost.
Current Tariff (US$/kWh)	$0.026	$0.024	Average weighted price per unit
CO_2 emission reduction (kg.CO_2/kWh)	0.9	na	Baseline of kg.CO2/kWh used in Chendebji CDM Project. Source: e7's Chendebji Feasibility Report, 2003
CO_2 emission value (US$) per tCO_2	$4~$20	na	www.grida.no/climate/ipcc_tar/wg3/341.htm
Total capacity of electricity generation per year (kWh)	564,144	402,960	Capacity factor of 92%
Annual electricity sales based on 2006 (kWh)	80,523	129,779	Based on current electricity sales records as discussed under electricity generation section.
Load factor based on electricity sales in year 2006.	14%	31%	Calculated by dividing annual energy sales by total annual electricity generation.

na = not applicable

Table 5.9: Result of Financial Analysis

#	**Items**	**Chendebji**	**Ura**
1	Annual Operation and Maintenance (US$)	$3,538	$4,186
2	Levelized Repair and Replacement Cost per Annum (US$)	$711	$793
3	Total annual cost of electricity generation (US$)	$4,250	$4,979
4	Average cost of electricity US$ per kWh to required to meet the annual O&M cost and levelized Repair & Replacement Cost (1+2 divide by annual energy sales)	$0.053	$0.038
5	Energy Sales and Revenue Computation at existing tariff		
i	Revenues from electricity sales per year to domestic consumers	$1,975	$3,403
ii	Revenue from CO_2 emission reduction (CER) per year (US$ 10 per tCO2)	$725	n/a
iii	Total revenue excluding CER.	$1,975	$3,403
6	Difference in Tariff (Item 3 - current tariff)	$0.028	$0.012
7	Subsidy required per year to meet the annual O&M, and levelized Repair & Replacement Costs (US$)	$2,281	$1,576

The cost of electricity per kWh depends on the energy sales. The total cost of electricity generation per kWh is a constant. Since the current tariff is constant, the only ways to recover the current expenses is by increasing the electricity sales or provide a subsidy. Based on year 2006 annual electricity generation and electricity sales, micro hydropower systems were operating at load factor of 14% in Chendebji and 31% in Ura (refer Table 5.8 for calculation details). The Figure 5.9 and Figure 5.10 show that in order to meet the combined costs of O&M and levelized repair and replacement at current tariff, micro hydropower systems should be operating above 35% for Chendebji and 50% for Ura, respectively. However while operating below these load factors, the required costs to meet the O&M and levelized repair and replacement costs have to be covered by subsidies. In order to meet this difference, an annual subsidy of US$ 2,281 for Chendebji and US$ 1,576 for Ura would be required.

Thus it is evident from analysis that the total revenues accrued from sales of energy at the current tariff do not meet the combined costs of annual operation and maintenance, and levelized repair and replacement. A subsidy of 71% and 58% of the combined annual O&M and levelized repair and replacement costs would be required for Chendebji and Ura, respectively.

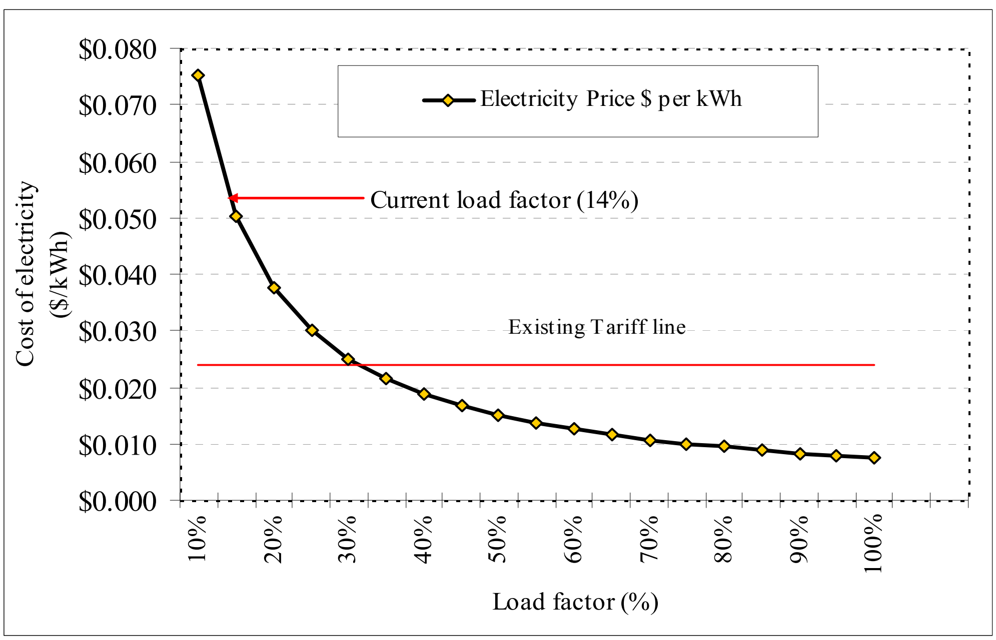

Figure 5.9: Relationship between the cost of electricity and system load factor for the Chendebji Micro Hydropower Project.

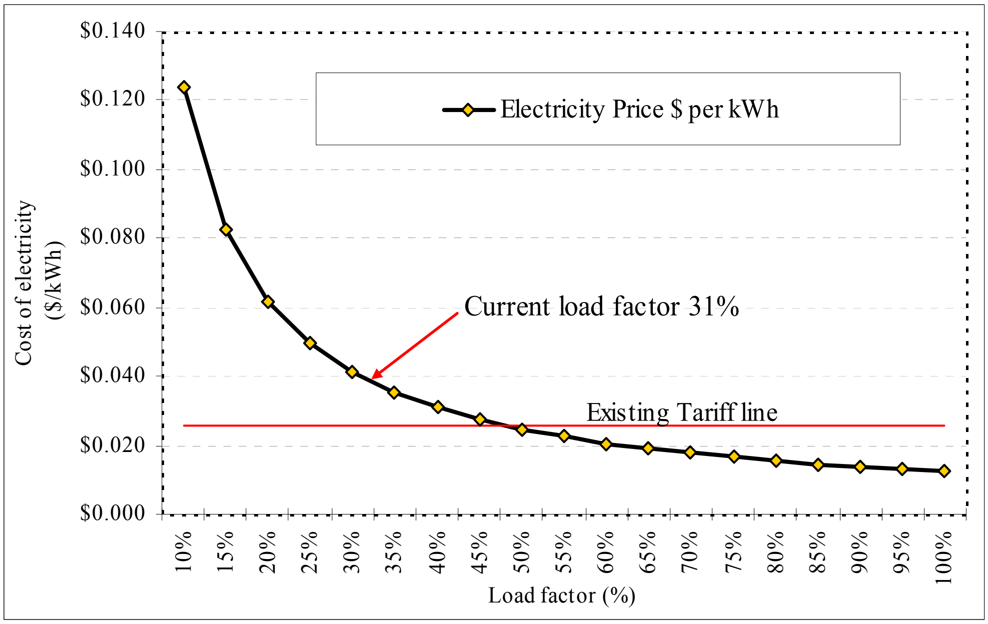

Figure 5.10: Relationship between the cost of electricity and system load factor for the Ura Micro Hydropower Project.

Additionally, about 20% of annual O&M costs could also be met if Chendebji receives the revenues from the carbon credits. It may be noted that this revenue is calculated based on annual energy sales at US$ 10 per tCO_2 and it can also vary according to the price of the credits. However, Chendebji is yet to receive carbon credits as discussed in section 5.4.2.

The cost of O&M cannot be met by simply raising the tariffs, as households with agriculture based incomes are limited in their purchasing power. In addition, electrification alone has not caused an increase in the rural income as there has been no development of productive end-use projects. With current tariffs and domestic demand as they are, meeting operational costs through tariffs has become a contentious yet pertinent issue as the RGoB and the communities seek to justify the low tariffs against the clamor of international donors. One way to address this limitation is by exploring a potential for integrating a micro hydropower with the grid. This will be presented in the next section.

5.4.1 Integration of Micro hydropower to Grid

Compared to the grid where power capacity is not a problem, micro hydropower offers a limited amount of power, and this may not be adequate to meet all the energy needs of the consumers. Furthermore, the grid consumers receive both a capital subsidy as well as an operational subsidy as the electricity tariffs are well below the actual cost of supply. These will have to be kept in mind when developing a subsidy scheme for the off-grid consumers to ensure some level of equity between the on-grid consumers and the off-grid consumers. At present, regardless of how wealthy or poor the recipients are, the amount of subsidy provided is the same. There is currently not much differentiation in the tariff for micro hydro consumers. As I discussed under section 5.2.3, based on the electricity consumption and expenditure, there is clear evidence that wealthier consumers tend to utilize more electricity because of the staggered or flat tariff structure. Since only 12% of the country will be provided with off-grid electrification, and the grid consumers receive substantial amount of both capital subsidy and operational subsidy, there should a commensurate amount of subsidy for the off-grid consumers. For example, the capital cost for electrifying an on-grid consumer has been estimated at about $1,700, and the cost of supplying one unit of energy to a rural household has been estimated at about Nu.4.5 per unit (US 10 cents). On-grid rural consumers only pay Nu.1.13/unit (US 2.5 cents per unit) of electricity consumed. BPC buys power from large hydropower generating companies at subsidized rate of Nu. 0.30 per unit (US 0.67 cents) (REMP,2005, BPC, 2006b).

However, as discussed in earlier sections, once the grid arrives, there will be no incentive or reason for the BPC to continue running and managing the micro hydros based on the current tariffs; experiences from Thailand and Sri Lanka have shown a similar situation. Managing the micro hydropower systems will become more financially attractive if the export sale price, or the firm power price, is used for injection of power into the grid. The firm power price is negotiated based on firm (maximum) power supply, which is a contracted capacity to be supplied for the contracted time of day or on a whole day basis. For instance, based on its declared availability, a micro hydropower plant is obliged to supply the contracted power, within a certain variation range, for a certain period - at least a year. The firm power price is typically higher than the cost of generation, and the negotiated contract period can be renewed every year.

A firm power feed-in tariff could potentially displace the need of a capital subsidy. Even BPC shares the same opinion that if the firm power pricing approach were used, the decommissioned micro hydropower systems might become financially viable and might be potentially renovated by the BPC (Personal communication with the Customer Service Manager at BPC, Thimphu, 2007). To illustrate this point, assuming a feed-in tariff at a price equal to the current export tariff Nu. 2/kWh (US 4.4 cents/kWh) to

India, feeding off-peak surplus energy from these micro hydropower systems can generate additional revenues of US$ 17,000 and US$ 21,000 per year for Ura and Chendebji, respectively. These amounts not only meet the annual operating costs of micro hydropower systems, but also generate surplus revenue, displacing a need for any subsidies. However, it would be unlikely that either BPC or the RGoB will pay this high tariff to the relatively small energy inputs from the micro hydropower systems.

Alternatively, assuming the BPC's current electricity import tariff Nu. 0.30/kWh (US 0.67 cents/kWh) from larger hydropower corporations, feeding off-peak surplus energy from these micro hydropower systems to grid would generate annual revenue of US$ 3246 for Chendebji and US$ 1828 for Ura, respectively. This amounts to 92% and 44% of the annual O&M cost required for the Chendebji and Ura micro hydropower systems. Besides, every unit saved in domestic consumption has an opportunity cost of exporting at a Nu. 2/kWh (US 4.4 cents/kWh). Thus, there is a compelling rationale for the BPC and the RGoB for grid integration rather than decommissioning the micro hydropower systems once these areas are connected to the grid.

Although RGoB plans to extend the grid in the 10th FYP, the RE Master Plan does not clearly indicate grid extension to Ura, but a grid extension to the neighboring Shinkhar village is clearly incorporated (REMP, 2005, ADB, 2007). The proposed 11 kV line to Shinkhar village passes near Sombrang village (which is presently supplied by Ura micro hydro). As an interim measure this line can be tapped at Sombrang and interconnected to the existing 6.6 kV distribution lines through one 11/6.6 kV interconnecting transformer (ICT). Preferably, the Ura micro hydro should be synchronized to the grid but can also continue operating as a stand-alone system after transferring most of the loads to the grid. However, Ura is expected to grow, as discussed in section 5.3, and will require more capacity. The 11 kV line from Garpang to Shinkhar (and Ura) will be on the order of 36 km in length. Voltage problems and high energy losses can be expected sooner or later as the loads on it grow. For the long term, it would be better to bring a 33 kV line up to Shingneer and install a 33/11 kV step-down substation from where power distribution can be done through 11 kV feeders.

For the Chendebji village and surrounding areas, REMP has indicated a planned 33kV grid extension from the Yurmothang 132/66/33/11 kV substation. The Chendebji micro hydro distribution system is 11kV. Interconnecting the Chendebji micro hydro system with the proposed grid can be realized with 33/11kV ICT.

5.4.2 Clean Development Mechanism

As mentioned in chapter 2, the e7 funded the 70 kW Chendebji Clean Development Mechanism (CDM) Micro Hydropower Project in 2005. Although in principle, the RGoB and e7 agreed to share the allocations of CDM credits generated by the project, the issues related to transaction cost are yet to be resolved. According to DoE Project Manager, the verification and certification requires yearly visits by an external expert which increase the transaction costs for small scale CDM projects. Further, there is also an internal disagreement between the Bhutan’s National Environment Commission, the DNA (Designated National Authority), and DoE with regard to sharing the allocation of CDM credits. DoE argues that this benefit should be given directly to the Chendebji

O&M fund, while, NEC argues that they should be entitled to receive this benefit to cover the validation and verification cost in the event that they are designated to carry out the task. The project has not received any CDM credits as of 2007.

In the preceding sections, I have shown how revenues from energy sales are not adequate to meet basic operation and maintenance costs, and have argued for the need of subsidies to meet the financial gap. As the economics are but one part of the issue, in the next section I will explore the institutional capacity in terms of human resources including institutional arrangements, roles of communities, and management and technical skills.

5.5 Assessment of Institutional Capacity

I use qualitative methodology to assess the institutional capacity of the key agencies and the communities involved in the implementation of micro hydropower. My findings indicate that although Renewable Energy Division under Department of Energy, RGoB, has been entrusted recently with additional task of handling implementation of micro hydropower, there is shortage of experience and institutional capacity. On the other hand, BPC has a fair amount of experience-based competence, yet due to constrained budgets and access to spare parts BPC has shown a disinterest in operating and managing micro hydropower systems. Further complicating the management issue, most end users have not been sufficiently informed of the benefits and limitations of micro hydro systems leading to many misconceptions regarding the reliability of the technology and what it takes to make them sustainable.

The Renewable Energy Division (RED) under the DoE is the main executing and focal agency of off-grid renewable energy plans and programs (RED, 2006). According to some RED officials, there is limited experience and expertise in the RED for designing, making specifications, procuring equipment, managing contracts, and supervising and monitoring constructions of micro hydro plants. This is because the Planning and Coordination Division (PCD) under DoE carried out most of the previous tasks such as site identification and planning, technical design preparation, procurement and construction, review and monitoring of micro hydropower (ADB, 2006). Furthermore, only PCD has the capacity to assist communities in preparing a Clean Development Mechanism (CDM) and environmental related documentations (e7, 2003). On the other hand, PCD conducts feasibility studies related to development of large hydropower, national transmission and distribution network expansions. In the past, after securing the funds, execution of rural electrification (RE) through grid expansion is handed over to BPC. Recently, recognizing the importance of parallel development of off-grid renewable energy programs, RED has been entrusted with the additional task of handling the implementation of micro hydros (RED, 2006, Personal communication with RED Manager, 2007).

BPC, on other hand, operates the transmission and utility aspects of the power sector including the management of 16 micro hydros. According to a BPC manager in Bumthang, operation and maintenance of RE distribution is very expensive for BPC. Furthermore, all the RE loans taken by the government are passed on to the BPC at 6% interest. The additional task of running and maintaining off-grid micro hydros not only increases their expenditures, but also the difficulty in providing reliable and efficient services. However, the counter argument according to DoE is that BPC cross subsidizes RE operation and maintenance through income from wheeling charges levied on exported power. BPC has an internal HRD (Human Resource Development) group and maintains a technical training facility at Begana. This same group is also responsible for monitoring and maintenance of all the micro hydros owned by BPC. When asked about the pertinent issues related to maintenance and operation of micro hydros, most technicians indicate that the most difficult problems that BPC faces with micro hydros is the budget and access to spare parts (Personal communication with BPC technicians at Begana, Thimphu in June, 2007). The principal difficulty faced by government owned corporations is the dichotomy inherent in reconciling both social and community service obligations and commercial profit maximization objectives. The recommended approach is that the RGoB defines the areas where it wants BPC to provide service and then compensates BPC for costs that it is unable to recover by tariffs (RED, 2006).

The communities currently do not have any role in the construction or operation and maintenance of grid extension RE systems and only a handful of people are involved in micro hydropower maintenance. For instance, only two people in Chendebji are identified by the community as being responsible for daily operation and maintenance of the system. BPC and DoE have provided basic O&M training to these operators. When asked about their technical competence, the operators indicate that often they face difficult tasks beyond their capacity and have to wait for the team from Begana, BPC to fix the problems. Otherwise, they boast about the confidence in performing basic operations, maintaining logbooks, meter reading and collection, cleaning intakes and water channels. One of the two operators also showed signs of discontentment with the level of wages given the amount of vigilance they have to maintain. They claim that they could actually earn more by working in the field. Further, when asked about the selection procedures and commitment of the technicians for the micro hydros, the operators indicate that leaving their village after acquiring the skills will be breaching the undertaking they have signed with the community management committee. They also suggest that the village community itself needs to be involved in the selection process and they should ensure that the technician remains at the village.

Besides, most end users have not been sufficiently informed of the benefits and limitations of micro hydro systems, leading to many misconceptions regarding the reliability of the technology and what it takes to make them sustainable. When informed about the benefits of using CFLs instead of incandescent light bulbs, most consumers felt that access to such information and market will definitely be beneficial for them. Finally, when asked about who should manage the micro hydro system, the respondents had varied opinions. Figure 5.11 and Figure 5.12 shows the summary of the results in Ura and Chendebji respectively.

Clearly, based on my aforementioned analysis, there is a need for development of a comprehensive program that includes the capacity building of not only the people at the RED but also the communities and the private sector. Technicians and local community organizations need to be strengthened by providing refresher training and awareness education in order to continuously maintain and upgrade the skills of the stakeholders.

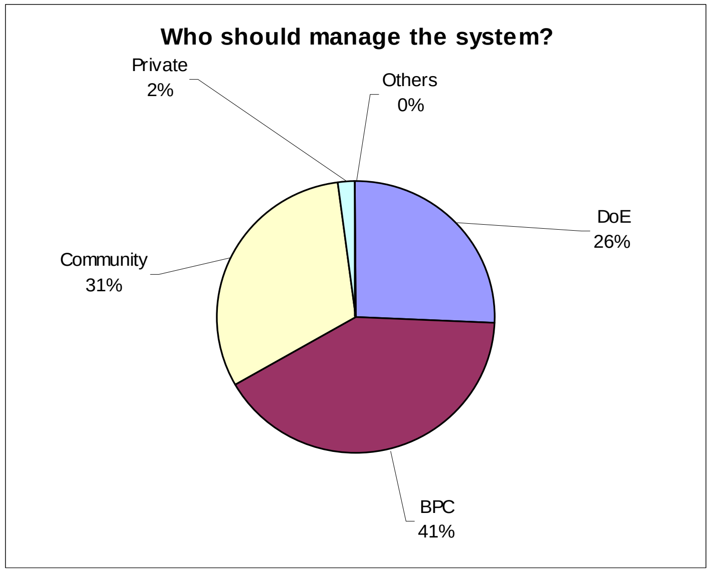

Figure 5.11: Respondents in Ura with sample size n=52

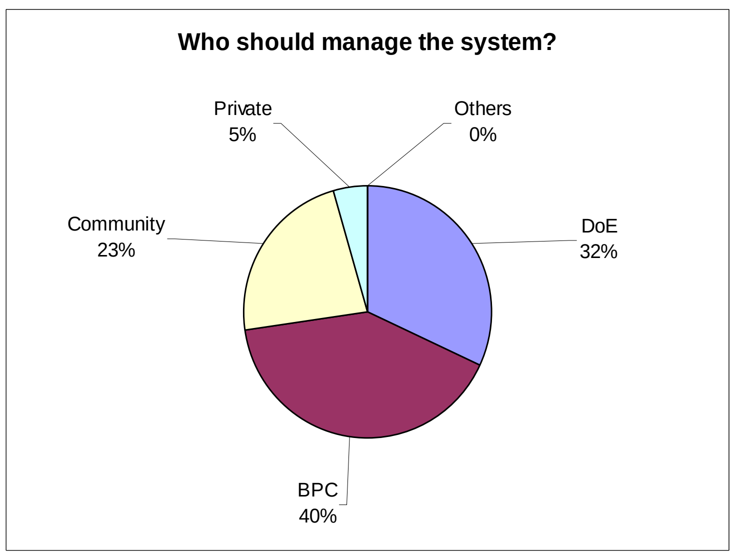

Figure 5.12: Respondents in Chendebji with sample size n=22.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The summary of main findings, based on the analysis undertaken in the preceding chapters, is presented in this section followed by sets of key recommendations.

6.1.1 Policy and Plans

The enactment of the Electricity Act in 2001, Dzongkhag Yargay Tshogdu and Geog Yargay Tshogchung Acts in 2002, and supplemented with other sets of crucial policy and program documents provides clear policy directives on future development and management of energy program in Bhutan. Such steps will clearly have significant positive impacts on the future energy security and the socio-economic well being of Bhutan and its people. This policy directive is specially significant in terms of spelling out the development of distributed non-conventional renewable energy for electrifying off-grid areas, which otherwise might be marginalized, with preference given to building large hydropower developments that are techno-economically cheaper per kW installed for grid electricity and export of surplus energy.

The renewable energy policy and program for sustainable development (draft report) provide institutional and financial plans for development of solar photovoltaic system and micro hydropower, as off-grid energy services.

6.1.2 Socio-Economic Benefits

The benefits of rural electrification are undeniable, especially for the enhancement of rural people's livelihood. Evidence from other developing countries reveal that access to electricity in combination with simultaneous access to markets and other infrastructure has contributed to growth of rural areas in clear and compelling ways. However, evidence from my case studies in Bhutan shows that access to electricity by itself, does not result in increased income generation. The electricity demand for productive uses is insignificant; the power is mainly used for lighting and cooking. Less than 3% of the households in the case study communities are involved in running small grocery shops and hotels.

6.1.3 Electricity Demand and Supply

Despite minimal electricity demand for productive uses, there is clear evidence from Ura village that domestic peak loads surpass supply capacity due to population growth. The estimated current peak load of Ura is almost 80% more than installed capacity of 50kW and the projected peak load by 2020 will surpass the installed capacity by 75kW, even considering only domestic loads. A similar trend is inevitable for other micro hydro sites. As the number of electrical appliances increases with an increase in the number of households and population, the demand will overshoot the installed capacity of the micro hydro. The estimated current peak load of Chendebji is 40 kW, 43% less than the installed capacity of 70kW, and is anticipated to increase by 12kW by 2020. However, with RGoB's plan in the 10th FYP to connect the Chendebji micro hydropower to several villages within the vicinity, there is clear evidence that demand will surpass installed capacity. There is a need for institutional measures to address this trend in order to ensure equitable distribution and efficient management of the facilities.

6.1.4 Financial Viability

The financial viability of a micro hydropower project in Bhutan is inherently dependent on the level of subsidies and capital donations. The revenue from energy sales for domestic consumption alone will not be sufficient to meet the combined costs of the annual operation and maintenance, and levelized repair and replacement. Based on year 2006 annual electricity generation and electricity sales, micro hydropower systems were operating at load factor of 14% in Chendebji and 31% in Ura. In order to meet the costs of O&M, and levelized repair and replacement, an annual subsidy of US$ 2,281 for Chendebji and US$ 1,576 for Ura would be required.

However, as the grid expands, it is expected that some of these micro hydros will be able to feed into the grid. As discussed in chapter 5, once the grid arrives, there will be no incentive or reason for the BPC to continue running and managing the micro hydros based on the current tariffs. Managing the micro hydros will become more financially attractive if the export sales price or a firm power price is used for injection of power into the grid. An export power or firm power feed-in tariff could potentially displace the need for a capital subsidy.

6.1.5 Institutional Capacity

The success of the community-based model will depend on the institutional linkages put in place to achieve sustainability. With the current settings, the community will not be able to effectively manage the micro hydros without the support of the other institutions. Besides, most end users have not been sufficiently informed of the benefits and limitations of micro hydro systems, leading to many misconceptions regarding the reliability of the technology and what it takes to make them sustainable.

Finally weighing the strengths and weaknesses of both models, a community management model looks promising given the reluctance of BPC to manage and opportunities for feeding into grid. It is important to gain a better understanding of strengths and weakness of the community managed model to help clarify the framing of policies and options for future replication.

6.2 Recommendations

This study has clearly shown that access to electricity by itself, other than enhancing convenience, does not result in increasing a rural people's ability to use electricity productively to generate income. Therefore, while determining energy use as an instrument of development, attention must be given to livelihood and income generating opportunities for the rural communities to enhance their economic self reliance and increase purchasing power. Development of a community-based integrated delivery model linked to micro hydropower installations is necessary where financial and income-generating strategies are developed. Together they will provide a viable community based livelihood approach where energy forms a central part. The purpose of this approach is to increase the degree to which the operation and maintenance costs are recovered from the users themselves, and to increase the utilization factor of the installations through encouraging livelihood activities.

One major problem with micro hydro communities is rapid growth in peak demand. Initially there is excess supply as the community is getting used to the benefits and conveniences of electricity. As the number of electrical appliances increases and there is also an increase in the number of households, the peak demand overshoots the installed capacity of the micro hydropower. This leads to low voltage problems and brownouts. Promotion of energy efficient appliances could also address peak load issues as well. Replacing incandescent bulbs with CFLs alone can result in substantial reductions in the peak demand, however, this reduction in demand is not sufficient to address peak supply shortages. Other peak power uses, such as the use of rice cookers, should be addressed through incentives to cook during off peak times, or through agreements between users to spread the demand over a larger period of time.

Aside from providing practical energy services to off-grid areas and alternative energy for grid-connected households, the long term impact of such measures will be substituting RE for imported fuels, maximizing revenue from exported hydro power and reducing pollution.

Sales to the grid when power is in excess could provide for better load management and more potential for reliable cash flow. The feed-in tariff could be fixed at BPC's current electricity import tariff Nu. 0.30/kWh (US 0.67 cents/kWh) from larger hydropower corporations. And should be increased proportionately with increase in national domestic tariff. This is being recommended because if there are micro hydropower systems that can supply to the grid, they should be allowed to be economically viable to sustain operation and maintenance. Furthermore, the grid consumers receive both a capital subsidy as well as an operational subsidy as the electricity tariffs are well below the actual cost of supply. These will have to be kept in mind when developing a subsidy scheme for the off-grid consumers to ensure some level of equity between the on-grid consumers and the off-grid consumers.

A legal framework needs to be developed for enabling either the community or utility or any other private entity to take over the management of micro hydropower system if it becomes a viable business based higher export prices or firm power pricing. The framework should determine who would be responsible for paying the higher prices for power injected into the grid. This framework should be in place to ensure that there is an alternative in case BPC does not want to manage future micro hydropower systems.

Finally, most end users have not been sufficiently informed of the benefits and limitations of micro hydro systems, leading to many misconceptions regarding the reliability of the technology and what it takes to make a system sustainable. An awareness and educational program complimented with refresher training has to be provided in order to continuously maintain and upgrade the skills of the stakeholders.

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APPENDIX

Appendix 1: Sample Questionnaire

Survey Form
The Sustainable Management of Micro-hydropower Systems for Rural Electrification: The case in Bhutan

June - August, 2007

Survey by: Karma P Dorji
Humboldt State University

1. Date: ______________________
2. Time began: ________________ Time ended: __________________
3. Village Name: __________________________
4. Dzongkhag: ____________________________
5. Number of family members: _______________
6. Occupation(s) (Please insert * for the corresponding answers)

Number	Government /Corporate	Trader & Small Business operator	Technician/Plant Operator	Skilled	Framer	Labor/ Unskilled	Any others

7. **Housing Unit** (if possible attach picture)

7.1 Type:

Temporary		Permanent	

7.2 Building Material:

Wood	Stone	Concrete	Mud Blocks	Others

8. **Agriculture**

8.1 Area of land owned

Approx. area of Dry land: (in acres or langdos)		Approx. area of Wet land: (in acres or langdos)	

8.2 Land Ownership (Insert *)

Owner	Renting	Shared	Others

8.3 What crops do you produce?

Rice	Corn	Buck wheat	Wheat	Others

8.4 What vegetables do you grow?

Potato	Turnip	Mustard	Peppers	Others

8.5 How much did you harvest last year/season?

Crops	Rice	Corn	Buck wheat	Wheat	Others
Total harvest (in kg)					
% Consumed					
% sold					
Vegetables	Potato	Turnip	Mustard	Peppers	Others
Total Production (kg)					
% Consumed					
% sold					

8.6 How much did you earn last year/season from sales of agriculture produce? (In Ngultrum)

Less than Nu. 1000	Between Nu.1000 – Nu.10000	Above Nu. 10000

8.7 What types of livestock and how many of these do you raise? (Number of heads)

Cattle	Horse	Sheep	Goat	Yak	Pig	Poultry	Others

8.8 Do you own a machine?

Tractor/Truck	Taxi/Light vehicle	Irrigation Pump	Mills	Others

9. Socio-economic

Do you have a business at home?

Yes	No

9.2 If yes, what is type of business?

Shop	Workshop	Mills	Construction	others

9.3 What is your main source of income? (List in priority)

Income from agriculture	Income from livestock	Government salaries/pensions	Remittance from relatives	Business income	Rental income	Others (Specify)

9.4 Amount of annual cash income (Nu per year) _________________

10 Energy

10.1 List of sources of energy? (Indicate answers by inserting * in 2nd and 3rd column)

Type of fuel	Main	Secondary
Fuelwood		
Kerosene		
Liquid Petroleum Gas (LPG)		
Electricity		
Others (specify)		

10.2 Energy used for cooking and heating? (Indicate answers by inserting * in 2nd and 3rd column)

Type of fuel	Cooking	Heating	Lighting & Security
Fuelwood			
Kerosene			
Diesel Oil			
Liquid Petroleum Gas (LPG)			
Electricity			
Others (specify)			

10.3 How do much did you spend on energy resources last month?

	Fuelwood	Kerosene	Diesel/Petrol	LPG	Electricity	Others
In Ngultrum						

11. **Electricity**

11.1 Is your house metered or point basis? (If point basis, go to question 13.3)

Metered	Point Basis

11.2 Monthly consumption in kWh (Request for electricity bill, if possible for last 6 months)

	Summer	Winter
Monthly kWh		
How much did you spend? In Ngultrum		

11.3 What kind of appliances do you use? (Fill in numbers and wattages)

FL	ICAN	CFL	PP	Rice Cooker	Curry Cooker	Water Boiler	Mixers	TV/Radio/ Refrigerator	Pumps/ Tools	Others

FL = Fluorescent Lamp, ICAN = Incandescent Lamps, CFL = Compact Florescent Lamp, PP = Power Point

11.4 How many hours did you use following appliances yesterday?

FL	ICAN	CFL	PP	Rice Cooker	Curry Cooker	Water Boiler	Mixers	TV/Radio/ Refrigerator	Pumps/ Tools	Others

11.5 Do you share/split the electric usage or bills? If so how much? How do you decide?

____

____

11.6 To whom do you pay the electric bills?

Head of village	
Bhutan Power Corporation	
Community Committee	
Others	

11.7 How often are you suppose to pay?

Weekly	
Monthly	

11.8 How often did you experience dimming of lights last month? Or Years? (Approx. hrs)

Daily	
Weekly	
Monthly	
Yearly	

11.9 How often did the power trip or fail for more than 30 minutes last month?

Non	Between 1 to 15	More than 15

11.10 What do you miss most when there is blackout?

Lighting	Cooking	Heating	Others

11.11 How long did it take to restore the service last time?

Minimum Days	1 day or less	Between 1 to 7 days	More than 7 days
By whom?	Bhutan Power Corporation	Village Technicians	Private firms/technicians
Do you contribute labor?	Mandatory	Volunteer	Get paid

11.12 Do you think capacity of power generation inhibits your capacity to consume?

Yes	No	Can't say

11.13 Do you intend to buy more electric appliances? If so, what are those?

Lighting equipments	Cooking Appliances	Entertainment Appliances	Power Tools	Others

11.14 Do you think electricity is affordable?

Current tariff	High	Low	Can't say
If increased, will you be able to afford?	Yes	No	Stop using

11.15 Who should manage the system?

Government	
Bhutan Power Corporation	
Community	
Private	

Appendix 2: Survey Data

(Data not able to convert to Word/PDF, can be located in printed copy HSU Library)

Appendix 3: Peak Load Estimation Data

(Data not able to convert to Word/PDF, can be located in printed copy HSU Library)

Appendix 4: Generation and Energy Sales Data

1. 70 kW Chendebji Micro Hydropower Data

a) Generation Data

Month	kWh		
	2005	2006	2007
Jan	-	39,468	62,853
Feb	-	47,254	63,438
Mar	-	50,850	71,652
Apr	-	47,584	80,820
May	-	50,389	86,732
Jun	-	50,270	92,204
Jul	-	42,431	na
Aug	14,401	51,838	na
Sep	16,848	48,826	na
Oct	6,305	38,165	na
Nov	2,652	48,637	na
Dec	-	49,400	na

Source: Chendebji micro hydropower log book.
na = not available (Data recorded in July, 2007)

b) Electricity Sales Data

Month	kWh		
	2005	2006	2007
Jan		6,546	6,946
Feb		6,760	6,870
Mar		6,790	7,100
Apr		6,720	6,940
May		6,650	6,873
Jun		6,543	6,847
Jul		6,690	
Aug	5,879	6,678	
Sep	6,340	6,836	
Oct	6,384	6,653	
Nov	6,467	6,784	
Dec		6,873	

Source: Chendebji Energy Sales Record, 2007.

2. 50 kW Ura Micro Hydropower Data

a) Estimated Generation Data

Month	kWh
Jan	34,224
Feb	30,912
Mar	34,224
Apr	33,120
May	34,224
Jun	33,120
Jul	34,224
Aug	34,224
Sep	33,120
Oct	34,224
Nov	33,120
Dec	33,120

Note: Assumed Plant Factor = 92%

b) Electricity Sales Data

Month	kWh				
	2003	2004	2005	2006	2007
Jan	8,942	11,250	12,017	11,482	8,903
Feb	10,342	9,822	9,199	11,474	9,360
Mar	9,422	8,946	8,894	10,519	9,817
Apr	9,962	10,667	10,271	11,550	10,274
May	9,847	9,862	10,322	9,997	10,731
Jun	10,564	10,650	11,822	10,762	10,835
Jul	11,302	11,240	10,102	11,362	
Aug	11,040	11,962	10,532	10,691	
Sep	11,320	10,560	10,717	10,609	
Oct	9,863	10,574	9,695	10,527	
Nov	10,472	10,234	11,749	10,444	
Dec	10,046	9,894	10,713	10,362	

Source: Customer Service Division, Bumthang, BPC, 2007

Appendix 5: Derivation of Growth of Electricity Demand Formula

1. Derivation of electricity demand growth formula:

$$\left[AMEC \times \left(1 + \left(AGDP - HGR\right) - IE\right)\right]^{\left(T_t - T_b\right)}$$

Where:

AMEC = Average monthly energy consumption in kWh per household

AGDP = Agriculture GDP Growth Rate

HGR = Growth Rate of Household Number

IE = Income Elasticity

T_t = Target Year

T_b = Base Year

Mathematical explanation of above formula:

Target: I am deriving the average demand per household not the total demand.

Preconditions: There are no statistics regarding rural per capita income.

Assumption:

i. Agricultural GDP was the closest proxy to rural income level

ii. Growth of total agriculture income = growth of agriculture GDP

Logic 1:

Rural per household income (RI) = (*AGDP*)/(*HGR*)………………..1

Logic 2:

Growth rate of rural per income per household = $\frac{d\left(RI\right)/dt}{RI}$ ……….2

Where:

'd' is derivative with respect to time 't'

Taking natural log of both sides of equation#1

ln RI = ln AGDP – ln HGR…………………………………………..3

Taking derivative of both sides of equation # 3

d/dt[ln(RI)] =d/dt[ln(AGDP) – ln(GHR)]

1/RI d(RI)/dt = [d(AGDP)/dt]/AGDP – [d(GHR)/dt]/GHR.................4

Therefore equation 4 is equal to AGDP – GHR

i.e. growth rate of agricultural GDP - growth rate of household number.

2. **Agriculture GDP Growth Data**

Year	**GDP Agricultural Sector Growth Per Annum (%)**	**GDP Growth**
1981	2.4	10.0
1991	3.2	3.5
1992	-2.0	4.5
1993	3.6	6.1
1994	3.9	6.4
1995	4.0	7.4
1996	6.5	5.2
1997	3.0	7.2
1998	2.8	6.4
1999	5.2	7.7
2000	4.5	5.5
2001	3.2	7.1
2002	2.6	6.7
2003	4.0	6.5
Average 1991-2003	**3.4**	**6.2**

Source: Statistics National Accounts 2002

Appendix 6: Annual Operation and Maintenance Costs, and Levelized Repair and Replacement Costs estimation for the Chendebji and Ura Micro Hydro Electric Systems.

1. Chendebji Micro Hydropower

Sl. No.	Item	Qnty	Units	Unit Rate (USD)	Dollar Amount
1	**Operation and Maintenance**				
	O&M Cost of Electromechanical Equipments	1	Lumpsum	$1,336	$1,336
	O&M Cost of Operator (Man-power)	24	Nos	$67	$1,600
	O&M Cost of the Distribution Lines	1	Lumpsum	$380	$380
	Preventative maintenance charges to BPC	2	Nos	$111	$222
	Sub-total				$3,538
2	**Repair and Replacement**				
	Replacement of Turbine and Generator auxiliaries	1	Lumpsum	$32,000	$32,000
	Civil infrastructure	1	Lumpsum	$6,649	$6,649
	Sub-total				$38,649
3	**Energy Revenues per Year**				
	Electricity Sales from domestic consumers*	78,963	kWh	$0.024	$1,930
	Electricity Sales from commercial consumers*	1,560	kWh	$0.029	$45
	Sub-total				$1,975

*Using Energy Sales in 2006

1	Economic Parameters:	
a	Years in Life-Cycle:	30
b	Investment Rates:	13.00%
c	General Inflation Rate:	5.00%
d	Net Discount Rate (b - c) =	8.00%
2	Present worth of Repair and Replacement Cost	$8,292
3	Levelized Repair and Replacement Cost per annum*	$711
	*Assuming major overhaul after 20 years and it should last for another 15 years	
4	Annual total generation in Year 2006 (kWh)	565,112
5	Ratio of electricity sales per year to the total annual generation	14%
6	Average cost of electricity US$ per kWh to recover the annual O&M cost and levelized Repair & Replacement Cost	$0.053
7	Current tariff in US$ per kWh	$0.024
8	Difference in Tariff	$0.028
9	Subsidy Required per year in US$ assuming current average electricity sales per year	$2,281

2. Ura Micro Hydropower

Sl. No.	Item	Qnty	Units	Unit Rate (USD)	Dollar Amount
1	**Operation and Maintenance Per Year**				
	O&M Cost of Electromechanical Equipments	1	Lumpsum	$2,626	$2,626
	O&M Cost of Operator (Man-power)	12	Nos	$67	$800
	O&M Cost of the Distribution Lines	1	Lumpsum	$760	$760
	Sub-total				$4,186
2	**Repair and Replacement**				
	Replacement of Turbine and Generator anxiliaries	1	Lumpsum	$30,000	$30,000
	Civil infrastructure	1	Lumpsum	$6,284	$6,284
	Sub-total				$36,284
3	**Energy Revenues per Year**				
	Electricity Sales from domestic consumers*	129,779	kWh	$0.026	$3,403
	Sub-total				$3,403

* Using Energy Sales in 2006

1	Economic Parameters:	
a	Years in Life-Cycle:	30
b	Investment Rates:	13.00%
c	General Inflation Rate:	5.00%
d	Net Discount Rate (b - c) =	8.00%
2	Present worth of Repair and Replacement Cost	$7,785
3	Levelized Repair and Replacement Cost per annum*	$793
	*Assuming major overhaul after 5 years (since it was constructed in 1988) and it should last for another 15 years	
4	Estimated annual generation at 92% capicity factor (kWh)	402,960
5	Ratio of electricity sales per year to the total annual generation	32%
6	Average cost of electricity US$ per kWh to recover the annual O&M cost and levelized Repair & Replacement Cost	$0.038
7	Current tariff in US$ per kWh	$0.026
8	Difference in Tariff	$0.012
9	Subsidy Required per year in US$ assuming current average electricity sales per year	$1,576