ECE 510- SUSTAINABLE ENERGY SYSTEMS

Energy Balance and Solar PV Systems for Sustainable Development in Off-Grid Rural Areas of Bhutan

PROJECT REPORT

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ABBREVIATION

ADB	Asian Development Bank
BDFC	Bhutan Development Finance Corporation
BPC	Bhutan Power Corporation Ltd
CHPCL	Chukha Hydropower Corporation Ltd
DOE	Department of Energy
DHR	Department of Human Resources
DSB	Druk Solar Batteries
EC	Environmental Clearance
FYP	Five Year Plan
GEF	Global Environment Facility
GPS	Global Positioning Systems
GNH	Gross National Happiness
IEMMP	Integrated Energy Management Master Plan
JICA	Japan International Cooperation Agency
LPG	Liquefied Petroleum Gas
MoA	Ministry of Agriculture
MLHR	Ministry of Labor and Human Resources
MDG	Millennium Development Goals
MOU	Memorandum of Understanding
NGO	Non-Government Organizations
O & M	Operations and Maintenance
RE	Renewable Energy
RESCON	Rural Energy Service Concessionaire
REMP	Rural Electrification Master Plan
RGoB	Royal Government of Bhutan
RSPN	Royal Society of Protection of Nature
RUB	Royal University of Bhutan
SCF	Save the Children Fund
SNV	Netherlands Development Organization
Toe	tonnes of oil equivalent
UNICEF	United Nations Children’s Fund
UNDP	United Nations Development Programme

I. Executive Summary

The RGoB has set a national policy of bolstering socio-economic development in the rural areas. As one of the key requirements, providing sustainable energy services to the rural areas will directly support in achieving the Millennium Development Goals (MDGs). The Department of Energy (DOE) has launched this activity of determining how the remaining households and public institutions in the rural areas can be provided with energy services to improve living conditions. Renewable energy (RE) in the form of Solar Photovoltaic (PV) and mini/microhydro resources (also referred here as micro-hydels) are found to be practical and economical under certain conditions and could serve the energy needs of off-grid households.

For more than ten years already, Bhutan has conducted a number of technology demonstration projects and rural electrification delivery schemes for solar PV. The need for an integrated national RE policy and implementation plan became more important recently in view of the development of DOE's 10th Five Year Plan (2008-2013) for rural electrification. The lack of long term planning for the repair and maintenance support has adversely affected the popularity of solar as a choice of electrification. No long term planning has been possible because of the lack of a renewable energy policy that centrally addresses the sustainable development of the RE program. The formulation of a National Renewable Energy Policy is currently under process. This paper discusses the proposed Institutional model that needs to be put into place for ensuring that Solar PV systems are sustainable in years to come.

II. Country Situationer

Energy is an essential input for all socio-economic development activities in Bhutan. Like every other developing country, energy is recognized as a priority sector in Bhutan for poverty reduction and sustainable development. However, the target households belong to the lower income group who would need financial assistance and some form of subsidy so that the RE project developers and the Rural Energy Service Concessionaire (RESCONs) can get reasonable returns on costs.

Although the country has surplus power generation, the high cost of grid extension has kept a large percentage of the rural population out of the national power grid. According to past rural electrification projects, it is estimated that the cost for electrifying one rural household is about US $ 1,800 – US $ 2000. The estimated cost for rural electricity supply is in the range of Nu. 4.50 Per unit (1 US Dollar = Nu 40), so even the on grid rural consumers even receive a substantial operational subsidy.

In 2005, a Rural Electrification Master Plan (REMP) was formulated under assistance from Japan International Cooperation Agency (JICA), which aims at electrification of 100% of rural households by 2020. According to this REMP, 88% of the rural households will be connected to the grid, and 12% of the rural households (about 4000 households) will be provided off-grid access by 2020. For off-grid electrification, small solar home systems and micro-hydel were found practical for the targeted households based on techno-economic considerations.

III. Energy Profile- Supply and Demand situation

Energy is required for cooking, lighting, heating/cooling, for transport and to provide motive power and processing energy for all income generating activities such as agricultural, commercial and industrial purposes. Functioning of modern systems like information technology, multi-media, telecommunication, bio-medical technology including the computer operations in offices and good governance largely depends upon the ready availability of commercial form of energy such as electricity.

Bhutan, despite being a landlocked and one of the least developed countries, is fortunate to be blessed with abundant natural renewable resources such as water, forest, wind and sun that can be tapped to meet the growing energy needs. Like every other developing country, energy is recognized as a priority sector in Bhutan for poverty reduction and sustainable development.

According to the Integrated Energy Management Master Plan (IEMMP) Report besides having substantial hydro-power potential, Bhutan is also rich in biomass, has some coal deposits, and there is possibility of harnessing solar, wind, waste to energy and biogas. However, Bhutan does not have any petroleum resources.

Bhutan has the highest per capita consumption of firewood with a per capita consumption of 1.3 tons per person. While the export of electricity was 32.8% of total exports, the import of petroleum was 8.3% of all imports in 2004. **Fig.1** below shows the various energy forms in 2004.

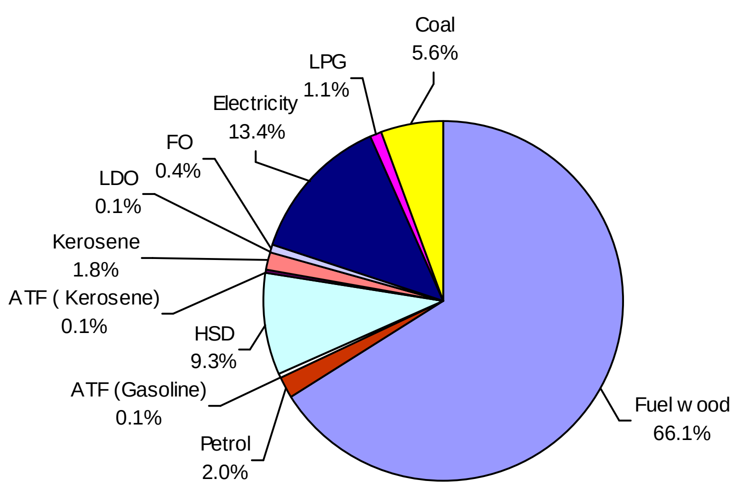

Fig. 1 Various Energy Forms Used in Bhutan
(2004 Total toe = 483,025, Source: IEMMP Report)

The sector-wise consumption of fuel is shown in **Fig. 2** below.

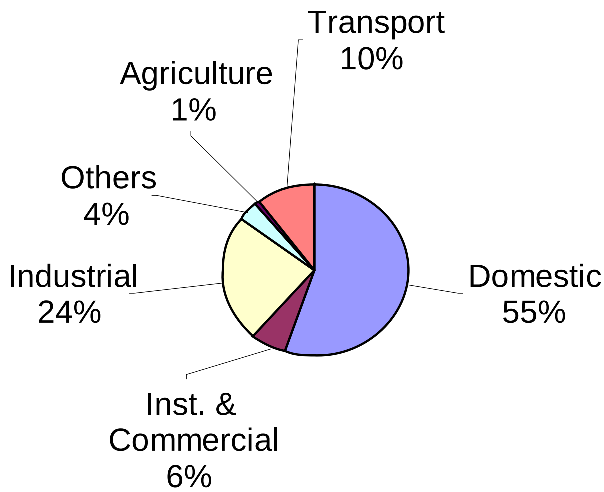

Fig. 2 Sector-wise Energy Consumption
(2004 Total toe = 483,025, Source: IEMMP)

Due to the large altitudinal difference and swift flowing rivers, ***hydro-power*** is considered the greatest natural resource of Bhutan. As of 2007, hydropower is contributing about 60% of the country's annual revenue and accounts for about 30% of the Gross Domestic Product (GDP). The Energy sector has developed 1,488 MW (only 6%) installed capacity from the list of techno-economically feasible and identified potential sites of 23,760 MW. More than 60% of the Bhutanese population has access to grid electricity as of 2007. By the beginning of the 10^{th} FYP(June 2008) it is expected that the internal demand for electricity would reach 200 MW (peak) while about 85% of the total energy generation would still be exported.

However, the energy needs for domestic consumption is dominated by traditional biomass fuel (66%) mainly for rural population and imported fossil fuels (diesel, petrol, LPG, coal, kerosene etc.), the demand for which is increasing at an alarming rate. The rising oil price in the global market is a concern to the Bhutanese economy as it leads to rise in inflation. The rise in prices of goods and services adds to increase in cost of development activities. Presently, Bhutan imports about 70,047 tones of oil equivalent (toe) and spends about Nu 2.1 billion (US $ 52.5 million) per annum. Thus the import of petroleum products consumes a substantial percentage of foreign export earnings. The rising demand in the transport sector warrants more import of petroleum energy, which is not only polluting in nature and contributing to climate change but its continued use is not sustainable in the long run.

The development of hydropower industry has been recognized to be the primary driving force for the economic development of the country and accordingly the Vision 2020 document has set targets of adding 2000 MW by 2012, and 3000 MW by 2017. A major share of the electricity generated in the country is exported to India market. In 2004-2005, 1622 million kWh of electrical energy, constituting over 68% of the total electricity generated was exported to India.

The majority of the domestic energy consumption is directed towards industrial and commercial activities. The power tariffs in general are subsidized by the revenues from international energy sales with rural areas getting more liberal subsidies. A tariff and subsidy policy is being developed for the electricity sector that will look into these issues.(Refer Table 1- Electricity tariff for rural consumers)

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%).

Table 1-: Electricity tariff for rural consumers

For Low Voltage - Domestic Customers:		July 1, 2007 onwards	July 1, 2008 onwards	July 1, 2009 onwards
		Energy Charge US cents./kWh		
Block I (Lifeline)	Up to 80 kWh/month	**2**	**2**	**2**
Block II	81 to 300 kWh/month	**3**	**3**	**4**
Block III	Above 301 kWh/month	**4**	**4**	**5**

(1 USD = Nu 40)

IV. Revenue from Sale of electricity to India

1. Chukha Hydro Power Corporation Ltd

Since commissioning of its first two Units in 1986, CHPCL has been meeting the electricity requirements within Bhutan, as well as exporting surplus power to India. In the initial years of operation, almost 90 percent of the power was exported to India. By year 2005 end, CHPCL's annual export of energy out of its total generation had decreased to about 81.44% with the increase in domestic load. With the full commissioning of the Tala Hydroelectric Project from 2006 onwards, major share of domestic demand is met by Tala and CHPC now exports about 98 percent of its total generation

Table-2- Generation and Sales

Year	Generation (MU)	Export to India (MU)	Sale to BPC (MU)	Revenue from India (Nu. Million)	Revenue from BPC (Nu. Million)	Remittance to Government (Nu. Million)
1986	164.030	154.630	5.640	40.720	0.560	
1987	1079.700	1016.040	43.920	233.170	3.760	
1988	1429.580	1313.180	90.260	270.220	9.120	

1989	1607.120	1430.160	137.100	279.610	13.710	
1990	1539.500	1386.490	134.350	374.340	13.440	
1991	1684.580	1470.350	178.840	397.250	17.880	
1992	1533.780	1321.090	187.350	355.140	18.730	
1993	1671.620	1452.950	178.430	526.110	18.770	
1994	1662.430	1403.640	223.920	519.230	41.610	
1995	1862.220	1474.210	351.610	732.780	105.480	
1996	1906.870	1495.820	371.050	747.520	109.890	453.270
1997	1777.230	1329.650	385.660	1287.930	116.250	1,066.201
1998	1780.640	1339.090	382.450	1339.090	114.630	1,376.266
1999	1943.740	1472.190	409.160	2038.310	123.030	1,755.536
2000	1908.320	1460.480	388.420	2242.310	116.540	1,928.704
2001	1889.160	1393.170	482.030	2089.750	140.180	1,840.756
2002	1802.800	1338.280	478.370	2007.420	143.540	1,623.517
2003	1956.739	1477.287	504.297	2215.940	151.290	1,871.473
2004	1927.584	1488.940	528.084	2233.420	158.430	2,121.280
2005	1831.253	1491.351	587.539	2982.702	177.267	2,243.980
2006	1877.903	1814.420	444.726	3525.536	134.665	2,586.617
2007	1788.700	1880.186	195.705	3760.372	58.711	

Export tariff is Nu 2/kWh

The contribution to the Royal Government of Bhutan in 2006 was Nu 2586.615 million. (USD 64.6 million)

2. Kurichhu Hydropower Corporation Ltd

Table-3 – Generation and Sales

Year	Generation (MU)	Export to India (MU)	Sale to BPC (MU)	Revenue from India (Rs. Million)	Revenue from BPC (Nu. Million)
2001	40.27	35.72	1.09	62.403831	0.328271
2002	241.81	208.17	20.71	361.292781	6.212393
2003	278.11	238.67	19.94	417.359033	5.982681
2004	345.36	290.89	51.22	508.403637	15.3654466
2005	366.22	302.44	59.85	528.978492	17.9540748
2006	365.30	296.14	65.17	517.990032	19.5520578
2007	379.71	224.38	151.69	392.118489	139.3653437

2001-2007, Nu 2788.546 million (USD 69.7m)

3. Tala Hydroelectric Project Authority

The 2006-07 annual revenue was estimated to be close to Nu 3000 million.

V. Off-Grid Rural Electrification through Solar Photovoltaic's System

Solar electrification programs have been implemented in Bhutan since the early 1980s, primarily through international initiatives. The erstwhile Department of Power (DoP) programs in solar energy began in 1988. Since then, a number of solar electrification projects have also been independently implemented by the Department of Education and the Ministry of Agriculture (MoA). Development assistance agencies such as Government of India, RSPN, Danida and SNV have also supported these initiatives. Unfortunately, the records for solar installation for the period prior to 2000 does not exist and it is difficult to track the number and location of the solar sets 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.

At present, there are several models (some centralized, some more decentralized) for solar electrification as numerous agencies have also been involved in the solar electrification activities. A number of National Departments/ Agencies such as Departments of Energy, Agriculture, Home Affairs, Health and Education, have been involved independently in the solar electrification process. The donor agencies involved in solar electrification programs have mainly been from countries such as The Netherlands, Switzerland, Denmark and India. ADB and UN agencies have been active in renewable energy field only in a limited way. Although several NGOs such as Helvetas, SNV, SCF and RSPN have been actively involved in the implementation of the solar electrification programs in Bhutan, key financial institutions have played only a limited role so far in financing the solar electrification systems. Bhutan Development Finance Corporation (BDFC), the only exception, has been involved in extending the end-user financing for solar PV home systems. A few solar water heating systems have also been installed by UNICEF and UNDP/GEF funding to provide hot water in community institutions such as schools and monasteries.

Earlier, there were two private sector enterprises active in the sale and service of solar PV systems in the country namely Tshungmed Solar and DSB enterprises. However, Tshungmed has shut down. DSB is the only major service provider but its capacity to provide strong technical support and backup is limited.

VI. Known Problems associated with off-grid solar PV electrification

Some of the problems associated with off-grid solar electrification in Bhutan include:

i. Inadequate designs. Although there are only four major components in a solar PV system (modules, batteries, electronic controls and lights), the operation of the system is dependent on the proper matching of these components and a system design that is appropriate for the site and load patterns. In particular, under sizing of modules, unreliable controllers, frequent lamp failures and poor quality batteries have been common problems that have led to early failure of the installed systems.

ii. Inadequate local knowledge of design, maintenance and proper use of systems. The general lack of experience, knowledge and technical skills for long term planning, analyzing data, designing systems, economic analysis, proper component specification, procuring equipment based on performance not just price, proper system installation, carrying out repairs and maintenance, and reporting and monitoring at the national, local government, and community levels all are major factors adversely affecting the maximum rate of implementation of solar projects in Bhutan.

iii. Low literacy rates in remote villages. This means that written manuals and instructions have limited value. Training and support mechanisms must take this into consideration.

iv. Persons who do receive training often leave. Many local persons who are given technical training often leave their villages in search of "greener pastures." Since there is no continuing program for solar training serving the rural areas, there is no one who can properly take over the job of maintaining/repairing the systems.

v. Limited/difficult access to spare parts. Many of the villages where solar home systems have been installed are in very remote locations with no road access, sometimes requiring 3 or 4 days to reach from the nearest road. Thus spare parts are not easily available when something breaks down even when proper stocks are available in Thimphu (capital city of Bhutan) or provincial centers. Even if they are easily obtained in the village, they are often too expensive for the end-users to directly purchase for cash.

vi. Weak service infrastructure. Repairs often take months or years due to lack of cash, lack of technical support and difficulty of access to spare parts stocks. Many solar projects in Bhutan have failed due to the absence of any kind of after-sales service in rural areas. There are few private sector companies that have been doing after-sales service for solar equipment and they have their own severe resource constraints to deal with. Since it is difficult and at the same time expensive, this has limited the private sector's ability and willingness to provide after-sales service.

VII. Assumptions for developing the PV based off-grid implementation model

1. Two overarching criteria were assumed in developing the accelerated implementation model for off-grid electrification through solar PV:

- The completion of electrification for all the villages identified in the Master Plan as targeted for solar electrification would be completed over an intensive two to three year period during the 10th Plan at a per-household cost not to exceed that of the grid extensions being carried out at that same time.
- The model needs to emphasize technical and institutional sustainability with the goal of providing a solar powered electricity supply equivalent in reliability to that of a grid extension for at least a 20 year project life.

2. The basic assumptions for the formulation of the off-grid model were based on official documents and experience with solar off-grid electrification in Bhutan. These assumptions include:

- In order to provide an equitable distribution of services to all rural dwellers, the total life cycle cost of a solar household installation is to be roughly equivalent in price and quality of service to the per-household life-cycle cost of grid extensions to rural households that are made during the same installation period. In Bhutan the initial cost of grid-extensions is approximately US$2,000 per house. The life cycle cost is higher, but at this time there is no data for its calculation.
- The process of rural electrification is to be considered an investment in rural development, and not a "welfare" payment. The component to be provided by government will be to cover the capital and support cost that currently is not possible for rural dwellers to provide, and in the early years this will be as much as 90% of the cost. However, the model should include a way to reduce government inputs as rural areas increase their ability to provide payment for services. Rural dwellers are expected to increase their ability to pay over time since that has been the pattern seen in other countries following rural electrification. All industrialized nations made large public investments in rural electrification before rural areas were able to pay the full cost of those services. The rural areas in today's industrial countries developed economically as a result of that investment and within 20-50 years the rural areas became a major component of the national economy. Internationally, government investment for the provision of electricity to rural areas has proved to have national benefits through:
    - Electrification, even with limited services such as is the case of solar, has been seen to provide an impetus to rural areas for increasing modernization with particular effect on rural dweller's attention to education and health development, and on developing the means for rural communities to increase their interaction with the money economy.
- The effective ongoing cost to a household for off-grid basic lighting and communications services should be comparable to the amount paid by rural households connected to the grid for similar services. In 2006, DOE calculated that amount was about 30 Nu/month. That is far less than the real cost of operation and maintenance (O&M) of either rural grids or rural solar installations. With grid connections, the process for financing the difference is invisible since non-transparent cross subsidization from high usage urban and industrial consumers to low usage rural customers occurs. In essence, urban customers pay slightly higher electricity rates to subsidize the supply to low usage rural customers. With solar, this hidden subsidy is not available and a process for the finance of installation and operation and maintenance support for solar electrification that is in excess of the ability for rural customers to pay must be developed.
- The process of implementation must fit within the boundaries set by government policy and directives, including Off-Grid Solar Policies accepted by the Department of Energy and the decentralization of government services. The off-grid policies provide for the level of subsidy to be provided and the requirement for equity with on-grid rural users. Decentralization requires that Dzongkhags and Geogs have a significant, clearly stated role in the rural electrification process.
- Implementation is to be accelerated, therefore no new government structures such as rural energy centres for DOE or significantly increased staff can be considered since

the time scale for approvals and development of those new structures and staff is quite long and there is a substantial risk of not receiving all the funding and other resources necessary to provide for such structures and staff. To accelerate solar PV implementation, a more efficient mobilization of existing resources is needed. Those resources include (but are not limited to) those of DOE, DHR, RUB, BPC, International agencies, Dzongkhags, Geogs and the private sector (businesses, NGOs and the community itself).

- Currently resources used for sustaining rural electrification are from the same labor and financial pool as those installing rural electrification. Therefore, to accelerate rural electrification, it is necessary to minimize the use of those installation resources for sustaining existing installations. Since it is a requirement that all rural electrification services are reliable and comparable in quality, the provision of high quality installations will be important to minimize the need for frequent maintenance and repair services. For those maintenance and repair services that are needed, they need to be designed to minimize the use of resources that are needed for an accelerated implementation and should be developed at the village level where possible.
- The experience around the world – including that of Bhutan – has been that the long term periodic maintenance and technical repairs needed to keep PV systems operational requires persons who can easily access the installations, and who have received specialist training so they are competent to provide those services. To retain the persons for the longest possible term, they must receive equitable compensation for the services provided. Expecting individual households to do the maintenance on the PV systems installed in their homes has not worked well, nor has the use of volunteers for maintenance. The implementations that have worked the best and that have provided the longest term success have been ones where the users have no responsibility at all for maintenance, just as is the case with grid electrification. For Bhutan rural areas, most households do not have sufficient cash available to pay the full cash cost of repair parts, but they typically do have sufficient resources to pay – in cash, plus goods or bartered services – for a village based technician to care for their PV systems. The model needs to provide for payment to technicians, but in a flexible manner that can include non-cash payment. The requirement under is that the technicians receive a minimum of 30Nu per month (or equivalent in barter or services) for their preventive maintenance services, which includes a monthly check of the system and refilling of the battery water if needed.
- Over the past 20 years, approximately 3,000 households, monasteries, schools and Basic Health Units (BHUs) have received solar PV systems through several non-coordinated implementation processes. An unknown but clearly substantial number of those installations are not working properly and need to be brought back to full service even while there is the need to accelerate the installation of around 4,000 new systems. The O&M process must be geared to service both the existing and the future installations. This means the training of as many as 1,000 village technicians. Because the village technicians will be typically unable to assimilate more than the skills needed for routine maintenance, higher level technicians will be needed to guide and assist the village technicians when problems exceed their relatively limited technical capabilities.

VIII. The Proposed PV institutional Model for Off-Grid Electrification

Institutional Mechanism

3. In the proposed model, the following are the key players and their principal responsibilities:

Department of Energy (DOE): (Lead agency) DOE will be responsible for system design, component specification, village selection, equipment purchase and the organization of installations. DOE will need to organize the purchase and distribution of spare parts. Monitoring of systems, spare parts usage and component reliability will need to be coordinated by DOE. DOE will set standards for equipment specification, installation procedures and operation and maintenance procedures. The DOE will collect and analyze data collected by village committees, village technicians and area supervisors in order to control and improve the O&M process and future installation activity for off-grid solar electrification.

DHR/RUB: (Assists under MOU) Provide contact information to DOE and contractors of those persons who have successfully completed the Vocational Training Institutes (VTI's) electrical trades course (that includes a 30 day solar PV course module). Those persons will be the primary labor pool for installation contractors. After installations are complete, the VTIs will have the capacity to provide intermediate training in solar technology for trainers, including private contractors, local government employees, and new DOE technical staff. For the implementation process, they will assist in the development of training materials and graphical manuals for village technicians, village committees and users.

Area Supervisors (private contractor, DOE employee, BPC employee, non-DOE RGoB employee or local government employee): (Assists under contract or MOU) Trained under a DOE approved program to provide technical support to village technicians, assist in training of village technicians, maintain inventory of spare parts and distribute them through the Gups to village committees as needed. The area supervisor will be expected to visit solar electrified communities annually to check on systems and on village committee operations and assist village technicians with technical problems where necessary. The Area Supervisor will provide feedback to DOE regarding user problems and requirements. This position is expected to be part time only; typically 15%-25% of a full time person's effort is expected to be required. The primary function will be clerical, ensuring that spare parts inventory is controlled and parts properly distributed as needed. The other task is to make one annual visit to solar electrified communities for technical monitoring and assistance. If proper system designs are used and if proper village technician training is provided, little technical support function beyond the annual visit is envisioned.

Village Committee: (Assists under MOU or Contract) A Village Committee is established at the time the village is surveyed for solar electrification. If only one village is represented, the village head-man will be the Committee chairperson. If multiple villages are represented (as is proposed for villages that are less than three hours walk apart), each village head-man will be on the Committee. Other persons may be selected by the village(s) with a 3-person committee considered as the optimum. The village(s) will be encouraged to include women on the Committee.

The Committee supervises the village technician(s) and ensures that all installations receive adequate maintenance attention. It interfaces with the Gup and the area supervisor for spare parts distribution The Committee will maintain an accountable spare parts stock of lights and controllers supplied by the Gup. A village technician who needs a spare part will take the failed part to the committee who determines (based on DOE developed criteria) the cost to be charged the villager for the new part and collects the money. If the part is in the Committee's stock, the part is provided on the spot. It not in stock the Committee arranges for the new part to be provided to the technician for installation. The technician installs the part. The Village Committee will forward the failed part via the Gup to a DOE designated location for proper disposal or repair.

The Committee records the solar technician that each household has chosen as their service technician for maintenance and ensures that the selected technician performs the maintenance as required by DOE. The committee ensures that sufficient pure water is kept available in the village(s) for battery maintenance. The committee arbitrates disputes between users and technicians and provides feedback to DOE or its designated representative regarding problems that need to be addressed by higher authority in order to obtain proper service. The village committee will apply to DOE through the area supervisor for additional systems for new households that are formed within the community and will record and forward requests from existing households for the expansion of systems already installed or for the moving of existing systems when a household shifts residence to a new house.

Village technician(s): (Contract with user and Committee) Any person in the village of age 16 or above may participate in solar technician training provided to the community at the time of installation of the systems by the installation and training contractor's two person field team. If the training is passed successfully (as judged by the trainer) and if the person is accepted by the village committee as a solar technician, the person will be considered qualified to act as a solar technician in the village. Users will themselves select which solar technician is to be responsible for their system maintenance and will contract with that technician for maintenance at an agreed upon rate of compensation (cash, barter or services), then they will inform the village committee of the contract and its terms. The village technician ensures that users do not add appliances to the system without written approval from an authorized DOE representative. They ensure that batteries are properly maintained; they troubleshoot problems and, where needed, arrange for parts to replace failed components and install them.

User: (Contract with technician and committee) Each user contracts with the village committee to follow DOE guidelines in the use of the system and to ensure that a trained technician visits at least monthly to carry out maintenance needs as prescribed by DOE. The user negotiates with the solar technician for the type and amount of payment to be made (as set and approved by the village committee), preferably cash but barter services or produce may be accepted if approved by the village committee. DOE policy requires a minimum effective payment of Nu.30/month. The user must agree that the solar module and control unit is the property of the DOE (or a DOE designated agency such as local government) and must be returned if service is terminated. The user must agree to use the system in a manner consistent with DOE prepared user manuals and requirements. The user must agree to permit the village technician access to the system in the case that the house is left vacant for an extended period. If the user no longer wishes to use the services from the system, the Committee will be informed and the system moved to another location or placed in inventory as spare parts.

Installation Phase

4. DOE will establish a standard design and standard installation procedure for providing basic lighting services. The capacity of the system is defined by existing policy as sufficient energy to power two 11 W lights for 4 hours per day. The design will incorporate as many locally manufactured components as is practical while maintaining a high reliability of service. Customers that require more services will be given the option to pay 50% of the cost of a second identical system which may be used to add more lights or to connect a radio. The user may also opt to purchase additional capacity from a private vendor at full cost if the capacity of a second system is insufficient to meet the user's needs.

5. DOE purchases equipment in bulk for each year of installations plus spare parts sufficient to meet the estimated need for spare parts for the next year.

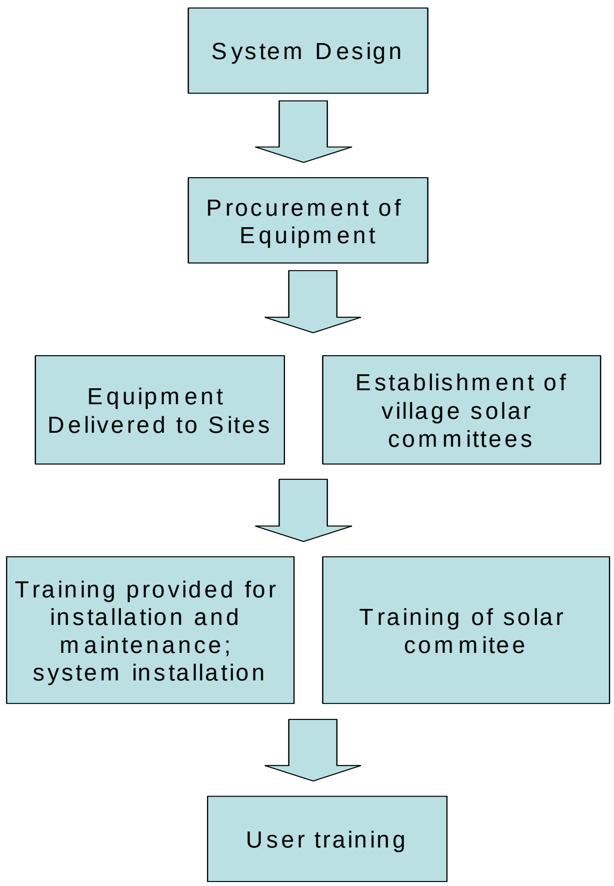

Fig- 3- Schematic diagram of Installation Phase.

6. DOE organizes equipment transport to the site (directly by DOE or through a contractor) and training is provided to installation contractor teams for installation and the training of village personnel (one to three weeks total using a DOE approved training process).

7. In the village the contractor teams will train village technicians. As part of their training, the persons being trained as village technicians will participate in the installation

of the systems. At the completion of the installation, the trainers will designate those trainees who have passed the training and they consider qualified to act as local technicians.

8. The committee is trained in its responsibilities by the contractor's field team during the installation period. The committee will make the final selection of technicians from the group passed by the trainer.

At the time of installation, all members of the user household are trained at home in the proper use of the system, informed of the warranty conditions and how to obtain maintenance and repair support. Video based training using a portable, battery operated DVD player is proposed.

Service Phase

9. The need for spare parts and repair services will be low in the beginning but at the time of battery replacement (5-10 years after installation according to the quality of the design) will be very large. Managing widely fluctuating budgets will be difficult for the DOE and for the Ministry of Finance. More acceptable will be having a constant amount budgeted annually than if annual budgets are submitted that vary greatly from year to year as will the actual cost of replacing components, particularly batteries, and providing required support services. Therefore, the DOE would forecast the need for continuing funding for spare parts and support services and prepare a 10 year budget that requests level annual funding for providing the subsidy component for the maintenance of that year's installations. That amount would be placed in an account earmarked for the villages with solar installations and managed by DOE and the MOF with withdrawals only allowed for the purpose of spare parts purchase and the provision of ongoing support services (training, contractor support for technical services, etc.).

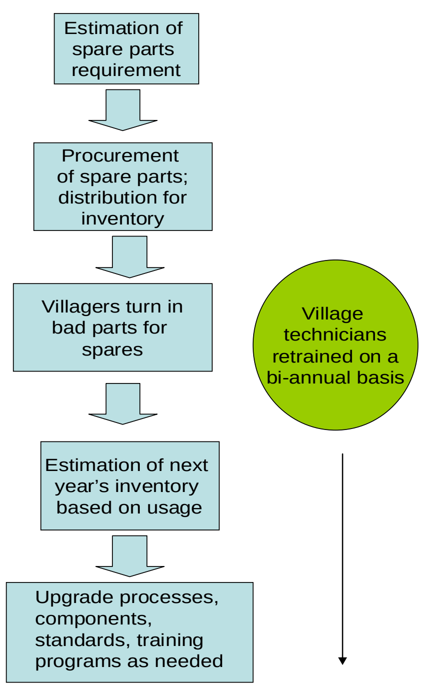

Figure 4- Schematic diagram of Service Phase

10. DOE purchases the required spare parts and distributes them to the local area supervisor for provision to the Gups for distribution to Village Committees. A large accountable spare parts stock will be maintained by the area supervisor, a smaller stock will be with each Geog and a small stock held by each Village Committee.

11. To obtain additional spare parts, the village committee will be required to turn in the failed part to the Gup to obtain a replacement. When practical the Gup will forward the failed part to the area supervisor. The area supervisor will ensure that the failed part is accounted for and delivered to the DOE for proper disposal or repair.

12. VTIs, RUB or BPC through its Begana training facility will offer one week refresher training on a bi-annual basis to DOE staff, local area supervisors and contractors.

13. Village technicians are retrained on a bi-annual basis by area supervisors or DOE contracted trainers. Once all installations are made, the schedule may be arranged so that half of all villages are reached for retraining each year. Re-training is expected to be supported by video (again using a portable DVD player) and to require 2-3 days of trainer time per each community served by a village committee. This task may also be carried out by area supervisors during their annual visit.

14. DOE will each year analyze the usage of spare parts and estimate the need for spare parts during the next year. Using that information and information from the inventory system developed by DOE and used by the local area parts distributors, the DOE will forecast the need for purchasing spare parts, request the funds from the solar repair fund, order the parts and distribute them to the area supervisors.

15. Area supervisors will visit their area at least once per year and collect maintenance logs and personally visit and interview a sample of households with emphasis on households that the committee considers to have an unusually high number of problems or complaints.

16. DOE will analyze the information from the monitoring process and upgrade, as needed, component specifications, purchasing arrangements, system designs, installation standards, maintenance standards and training programs.

Financial Structure

17. **Capital investment.** All capital investment including the cost of training and installation will be borne by Government through funds provided by international financial organizations (ADB, World Bank, etc.), bi-lateral donors (JICA, Austria, etc.), multi-lateral donors (UNDP, etc.) or from the RGoB budget.

18. **Village Technician payments.** Village technicians will be paid by users on the basis of negotiation between the user and the technician the user selects to provide maintenance; no fixed payment will be set by government though the Village Committee may set a fixer rate if it wishes. Payment may be in any form and amount agreed upon between the technician and the user that is approved by the village committee though the equivalent value must be 30Ng/month or more. The village committee will enforce that agreement both regarding the performance of maintenance duties and the payment for them by the users.

19. **Area supervisor payments.** Where area supervisors are local government employees (e.g., a Dzongkhag technician) the local government and the DOE will share the cost as provided for by a MOU. Where area supervisors are contractors hired by DOE, the DOE will include their payment as part of their annual budget.

20. **Spare Parts.** Replacement of batteries, modules, controllers, switches, night lights and light fixtures will require at least a 10% payment by users in the early years of solar implementation. It is recommended, however, that users pay the full cost of light bulb replacement. Consideration should be given to having the percentage of cost paid by users determined partly by the timing of the request for the replacement part so that extraordinarily early replacement is penalized with users having to pay a higher percentage of cost than for parts that have fulfilled their expected life of service. Proposed is 50% payment for replacing components that have served less than half their projected life. The percentages to be paid should be reviewed periodically and changed to reflect the conditions that exist with regards to rural household's ability to pay and the actual observed life of components in the field. It is recommended that a subsidy review committee be formed that includes responsible members from DOE, local government and MOF plus other stakeholders as appropriate. Their task will be to do the review and set the percentage of payment that will be required by users for the following period.

21. Since in the early years of implementation, spare part provision is expected to be heavily subsidized, finance for the purchase and distribution of spare parts will be a significant problem. Proposed is an annual budget request that corresponds to 10% of the 10 year total estimated cost to the government for the support of solar installations. That amount would in effect be equal to the levelized forecast cost for spare parts for each year's installations over the next 10 years of operation. Since the primary cost for repair parts is battery replacement with expenses increasing toward the end of the 10 year period, a levelized payment into the fund should be sufficient to cover the 10 years series of costs. Modest adjustments to the annual budget request for each year's projects may need to be made as experience is gained through experience with the installations and as costs change due to inflation. The total amount budgeted would need to be adjusted annually as more villages are electrified by solar or as systems are removed due to the electrification of villages by the grid. The amount of annual support funding is expected to fall over time (on a per-installation basis) since the percentage of user payment required for repair is expected to increase over time.

Monitoring and Evaluation

22. Earlier solar programs have not included a strong monitoring component. As a result, there is little data regarding the actual performance of the older systems or their components. Without that data, the real cost of operation and maintenance cannot be accurately determined. The model that is proposed for future implementations includes four major levels of monitoring:

- The spare parts control system is the key monitoring system for determining component life and cost. Each of the four major components in each installation will be tracked from purchase through installation to failure and replacement through the use of serial numbers or other unique part identifiers. The data will be collected by the area supervisors as spare parts are distributed and failed parts collected. Annually the data will be collected by DOE for analysis and used to help improve the component selection and purchasing process and also to note project areas that have unusually high rates of spare parts use possibly indicating poor maintenance, a need for user training, misuse of spare parts inventory or other unusual conditions that require attention.

- The village technician will be required to maintain a log of maintenance activity at each site. The log will be kept with the household and at each visit a check list completed for the preventive maintenance steps including such things as the approximate amount of battery water added, the voltage of the battery, the hydrometer reading of each cell, the replacement of parts, etc. During the annual visit of the area supervisor, the log sheets will be collected and provided to DOE for analysis in order to improve the maintenance process and to improve the system design. Although it would be ideal to have the data provided to the area supervisor on a monthly basis so problems could be identified early, the remoteness of the sites and the typically poor communications at the sites makes that impractical.
- Through the use of standardized record forms provided by DOE, the village committee will keep records of their meetings and their interactions with technicians and users and provide that information annually through the visit of the area supervisor. The data from the committee will be used by DOE to improve technician and user activities, to improve project monitoring and upgrade the training for the committee, village technicians and users.
- The DOE will maintain a record for each installation including serial numbers of installed components, GPS coordinates, house identifier, head of household identity number, etc. These will be updated annually from information provided by the village committee and confirmed by the area supervisors. The DOE will keep records of expenditures for site visits and area supervisor payments. The training expenditures for staff, area supervisors, village committees and village technicians will be compiled plus other costs of support for off-grid solar installations.

23. Additionally, monitoring will be provided through the annual visits of the area supervisor who will provide DOE a report of the visit with specific sections relating to committee, technician and user interviews as well as evaluations and recommendations for improving the system design and institutional design.

24. An annual report of the state of the off-grid solar PV electrification will be prepared by DOE at the end of the calendar year which will include statistics on O&M for the year just ended and forecasts for the spare parts requirements for the next fiscal year.

IX. Changes in existing Model

25. A number of new components have been incorporated into the implementation model that has not been a part of Bhutan's past solar implementation efforts. These include:

- Monitoring and evaluation of solar installations.
- The use of the private sector to install systems and train villagers.
- The development of capacity in the private sector to support solar implementation.
- Contracting with the private sector to provide long term services in support of solar implementation.

- A comprehensive spare parts delivery system including local government.
- Training of multiple village technicians in each community.
- Compensation for village technicians using cash, barter or service exchanges.
- The use of several area supervisors to provide for relatively fast response support services for technical assistance, stock spare parts and to be a focal point for villagers to interact with DOE.
- Contracts signed between the Village Committee, users and village technicians that spell out their respective responsibilities including compensation for services provided.
- MOUs signed between national and local government stakeholders clearly spelling out their agreed upon roles in solar implementation.
- A mechanism for multiple villages to be simultaneously electrified by solar.
- Development of the capacity and institutional structure to make solar training available for the long term in order to maintain or upgrade the skills of existing personnel and to train replacement technicians.

X. Conclusion

Although most of these new institutional components have been successfully used in other countries for rural electrification, the unique social and physical conditions in Bhutan make it somewhat risky to proceed to large scale implementation without some pilot project activity to "fine tune" the structure. The existing model has proved that it will not be sustainable and failures have already shown that as real life examples. In order to achieve 'Electricity for All by 2020", implementation modalities need to be changed in order to ensure that villages falling under Off-grid areas are provided means to access lighting which will last for a long time.

Therefore, given the importance of the need of Solar Electrification to be successful, this will need to be tried out as a Pilot Project in select areas to gauge the effectiveness of such a model.

In addition to benefiting the people, hydro power has other tangible benefits in terms of enhanced forest growth and reduction in destructive floods. This, in turn, leads to indirect ecological benefits with forests acting as carbon sinks and also offsetting local industrial pollution. Besides, hydro power generation helps in watershed development, because for hydro power projects to remain productive, it is essential to ensure that watersheds, upon which they depend, are also maintained. The myriad of development and equity issues that converge require that every feasible source of energy be explored as a driver to take the economy forward, alleviate poverty, and provide for household energy needs. Far-flung habitations, mountainous terrain, dense forests, and the need to conserve the environment add to the imperative of searching across a menu of options for feasible energy solutions. Moreover, the growing population directly threatens the existence of forest land. In such a situation there is a definitive role to be played by renewable energy resources such as biomass, solar-power, and wind. While hydro power will be the mainstay, other renewable energy options would also need to be seriously taken into account. The role of other renewable is particularly significant in the country because of its varied geography. Thus, utilization of locally available renewable energy resources is seen as a means of providing an acceptable level of energy security to the populace. In practice, this translates into the use of such technologies, which, on the one hand, enable the users to use traditional fuel more efficiently (such as the improved *chulha*) and, on the other hand, utilize locally appropriate renewable energy resources (such as Biomass, solar power, or wind energy). This, in turn, means that a remote village need not be dependent on non-existent or erratic energy supply from far-flung areas. It should be in a position to meet its own demands through indigenous energy resources.

XI. References

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