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Options for off-grid electrification in the Kingdom of Bhutan

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ABSTRACT

Bhutan sells electricity across the border to India. However large sections of its population do not have access to electricity. The harsh mountainous terrain coupled with sparse and dispersed settlements in Bhutan makes grid extension difficult, costly and economically unviable. Therefore, it is worth looking at renewable energy options to meet electricity demand in remote locations. This study aims to identify the least-cost technologies that could be used in the rural areas of Bhutan. The study analyses the energy needs of rural households, the resources available, and current policies and programs on rural electrification. The Hybrid Optimization Model HOMER for designing distributed generation (DG) systems both on and off-grid was used to find the least-cost technologies for different potential resources and to compare the cost of deploying these technologies with conventional electrification through grid extension. This paper identifies possible rural electrification options for Bhutan and compares them with extending the grid to the remote areas.

1. Introduction

Bhutan is a small landlocked country situated in Southern Asia between China and India. The latitude and longitude are 27.30°N and 90.30°E respectively. The total area of Bhutan is 38,394 sq km and its climate varies within the country from tropical to alpine [1].

Bhutan's economy depends on agriculture, forestry, tourism and the sale of hydroelectric power to India. The main occupations are agriculture and more than 80 percent of the population depends on it. There is also a handicrafts industry, particularly weaving and the manufacture of religious art for home altars. The landscape of Bhutan varies from hilly to ruggedly mountainous which makes it difficult and expensive to build roads and other infrastructure.

Bhutan is amongst a few countries where hydropower is the main source of electricity. Although Bhutan exports about 75% of its total generation capacity of 1488 MW, less than 60% of its rural households have access to electricity [2]. The Royal Government of Bhutan (RGOB) has set a target to achieve 100% electrification by the end of the year 2020. About 3900 households have been identified for off-grid electrification, where grid connection is technically, and economically infeasible [2].

In an isolated place, where grid extension is not possible, electrification using Solar Home Systems (SHS) and micro-hydro plants has been carried out since the 1980s, mainly through outside donor assistance to Bhutan [3]. Like many developing countries, SHS have had limited success in Bhutan, mainly because the project implementers did not consider the long-term sustainability aspects of the technology. User training was limited, systems were poorly designed, and there was no provision for repairs, maintenance support, and spare parts, thus many programs failed [3]. In addition, most of the micro-hydro plants are owned and operated by Bhutan Power Corporation (BPC) in the off-grid areas. These are not financially viable as the revenue is not able to meet the costs of operation and maintenance.

These experiences from the past seem to have had a profound impact on the general perception of the policy makers on the reliability and cost effectiveness of renewable energy technologies. Bhutan's Rural Electrification Master Plan (REMP) recommends renewable energy technologies (only solar and micro-hydro have been considered) to be used only in places where grid extension is practically impossible [4].

Presently, Bhutan Power Corporation, the government owned utility, which is responsible for transmission and distribution of electricity, undertakes all grid connection projects and also acts as a network operator and retailer. Most of these projects are financed through concessional loans from multilateral financial institutions like the Asian Development Bank (ADB) and the Japanese Bank for International Cooperation (JBIC). With more than 40% of rural households still to be electrified, it puts a huge pressure on the government's limited financial resources. The average cost of electrifying a household in a remote village in the previous rural electrification projects was around US$1800 to US$2000. It is

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estimated that about US$71 million would be required to provide electricity by grid extension to the remaining un-electrified households [4].

Renewable energy technologies have become commercially viable for electrification projects in remote areas due to technological improvements and cost reductions due to economies of scale. Recent studies on solar and wind resources in Bhutan by the National Renewable Energy Laboratory (NREL), have enabled mapping of solar and wind resources for Bhutan, making it much easier for project planners to access location specific data for design and technology choice [5].

This paper provides a techno-economic analysis of different renewable energy technology options for rural electrification in Bhutan using recent cost and resource data. The cost of implementing these technologies for rural electrification was also compared with the cost of grid extension.

2. The energy situation in Bhutan

Due to its geography and fast flowing rivers, Bhutan has a huge hydropower potential estimated to be around 30,000 MW. At present about 1488 MW of this resource is tapped, from which about 75% of the electricity generated is exported to India [2]. However, Bhutan imports all of its petroleum-based fuel for use mainly in the transport sector. Fig. 1 and Fig. 2 show Bhutan's energy supply mix and energy consumption by sector in 2005.

The central government agency responsible for the energy sector is the Department of Energy (DOE). After the power sector reform in 2001, the Department of Power (DOP) was splitted into three agencies:

1) Department of Energy as the central government agency,
2) Bhutan Electricity authority (BEA) as the regulator, and
3) Bhutan Power Corporation as the utility responsible for transmission and distribution.

2.1. Rural electrification in Bhutan

The cost of electrifying one rural household is about US$1800–US$2000 [7]. The capital cost is fully borne by the government, mainly financed through soft loans from the Asian Development Bank (ADB), while other agencies like the Austrian Coordination Office, Stichting Nederlandse Virijwilligers (SNV), UNDP/GEF, Government of India (GoI), Japan Bank for International Cooperation (JBIC) have also financed rural electrification through a mix of grants and concessional loans. The electricity tariff is subsidized and set at Nu. 0.75/kWh (US$0.0159/kWh) for rural households while the estimated cost for electricity supply is in the range of Nu. 4.50/kWh (US$0.095/kWh) [4].

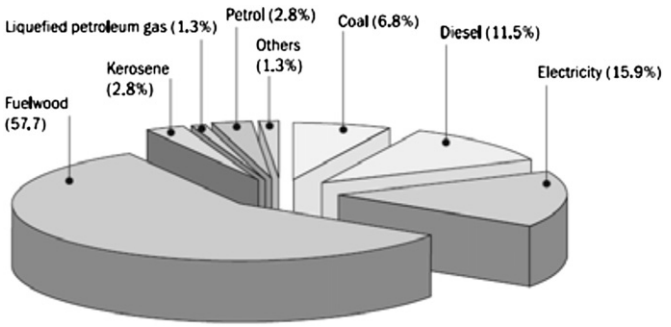

Fig. 1. Bhutan's energy supply mix. Source: Department of Energy [6].

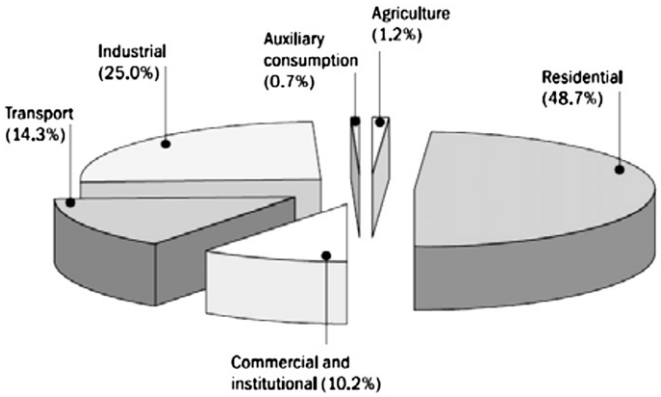

Fig. 2. Bhutan's sectoral energy consumption. Source: Department of Energy [6].

A master plan for rural electrification was formulated in 2005 with the support of the Japanese International Cooperation Agency (JICA) which aims to electrify 100% of households in Bhutan by 2020 [8]. Fig. 3 shows the cumulative achievement in rural electrification and the achievement in each developmental plan period. It also shows the targeted households to be electrified in the years up to 2020.

2.2. Electrification using renewable energy

Solar electrification in Bhutan started in the 1980s, to supply electricity for institutions, health clinics, monasteries and some of the rural households. Mini- and micro-hydroelectric systems were constructed in Bhutan in the 1980's and 1990s with grant assistance, mostly from the Japanese Government. There are currently about 22 plants in operation [6]. These plants are mainly located in areas close to roads and, in the past, provided the only source of electricity to some district centers and satellite towns. However, most of these plants are now expected to be connected to the grid with the arrival of grid electricity in most of these places.

2.3. Problems encountered by these programs

General problems in regard to the solar electrification programs were:

- Lack of maintenance support and spare parts backup as a result of which the systems were abandoned by the users. No local people were trained for maintenance.
- Users were not educated about what the system can and cannot do. For example, while most of the systems were only meant for lighting purposes, users manipulated them for other uses, like entertainment, which contributed to premature failure of components.
- The systems were inappropriately sized due to lack of radiation data.
- Lack of government planning has resulted in electrification of some villages which were going to be connected to the grid in the near future [9].

Some of the problems that have plagued the micro-hydro sector in Bhutan are [3,9]:

- High capital cost requirement. Therefore, it is not the preferred mode of electrification by the Government.
- Operation and maintenance costs were generally higher than the income from the sale of electricity in the domestic market.