Renewable and Sustainable Energy Reviews 51 (2015) 662–681

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Renewable energy based off-grid rural electrification in Uttarakhand state of India: Technology options, modelling method, barriers and recommendations

Anurag Chauhan *, R.P. Saini

Alternate Hydro Energy Centre, Indian Institute of Technology Roorkee, Uttarakhand 247667, India

ARTICLE INFO

Article history:
Received 10 November 2014
Received in revised form
8 May 2015
Accepted 28 June 2015

Keywords:
Off-grid
Rural electrification
Renewable energy
Solar radiation
Wind speed

ABSTRACT

Energy deficiency is one of the key enigmas impacting the livelihood of millions of poverty stricken people throughout the world. It is quite evident that electrification of rural areas can improve the standard of education, health conditions, living and empowering the youth of the nearby population. Uttarakhand state of India is mainly encompassing southern periphery of Himalayas. Census of India reveals that about 123 numbers of villages and 1966 numbers of village hamlets are still unelectrified in the state. Electrification of these villages/hamlets of remote hills using renewable energy resources in off-grid mode is a feasible option compared to uneconomical grid extension. State has identified small hydro power potential of 1500 MW, mean annual daily solar radiation of 4.5–5.5 kWh/m^2 with 300 sunny days in a year, enormous forest foliage, crop residue, animal waste and mean annual wind speed of 5–5.5 m/s in some places of the state. The present study comprises the utilization of single technology based system such as small hydro, biomass, biogas, solar and small wind turbines etc. and also aggregated technology, depending on the availability of the resources in the present locality. A methodological framework has been established to avail the demand and resources assessment of the area. Various barriers and issues are finally discussed, which leads to a greater obstacle, in the path of system implementation. In order to address these barriers and issues, suitable solutions are recommended in the present context.

Contents

* Corresponding author. Tel.: +91 8171015620.
E-mail address: anurag.chauhan36@gmail.com (A. Chauhan).

http://dx.doi.org/10.1016/j.rser.2015.06.043
1364-0321/

1. Introduction

The vast majority of global population lives in the developing countries and more than one third of developing nations comprise of rural areas with no access to commercial forms of energy. Energy access is a complex task in rural areas as most of the unelectrified villages/hamlets are located at remote and/or hilly terrain. Barriers in energy access include uneconomical grid extension and high transportation cost of fuels (diesel, petrol, kerosene, LPG, LNG) for cooking in remote hills. However, these remote areas are rich in availability of locally available resources such as cattle dung, waste from agricultural field, forest foliage, water streams, solar intensity, wind etc. Utilization of these resources in off-grid mode would be the most appropriate solution for energy access in rural areas [1–10].

The Uttarakhand state of India is present in the northern fringes of the country having a shared territory with Nepal in the east and China in the north. Himachal Pradesh is present in the north west of the state, while Utter Pradesh in the south [11]. The geological division of Uttarakhand can be classified into three major regions, high Himalayas in the north, lower Himalaya (Shivalik) and Indo Gangetic plain in the southern periphery. Geo political location of Uttarakhand state is represented in Fig. 1.

Per capita energy consumption is an important yardstick, which depicts a resource utilization capability of the region. It is the total useful energy generated within a region over a period of time divided by the total population of the region. Per capita energy consumption of Uttarakhand state is shown in Fig. 2. In the year 2006, per capita energy consumption of the state was 654.84 kWh that was raised to 930.41 kWh during the year 2010 [12]. Presently, Government of India promoted the involvement of building hydro projects mainly visualized by the construction of dams and run of river schemes for tapping the unharnessed power of the river channels. This has resulted in higher per capita electricity consumption of the state to 1253 kWh for the year 2013–14 against national average of 883.6 kWh.

In Uttarakhand state, most of the rural households have no access of electricity due to uneconomical grid extension in hilly terrains. As per the Census 2011, 123 numbers of villages and 1966 numbers of village hamlets are recognized for electrification in the Uttarakhand state [11]. Out of 123 (in Nos) villages, 58 numbers of un-electrified villages are present in Garhwal region, whereas 65 numbers of villages are recognized in Pauri region. Out of 1966 unelectrified hamlets, 1197 numbers of hamlets are found in Garhwal region and 769 numbers of hamlets are in Kumaon region. In Garhwal region, district Tehri has the highest number of un-electrified hamlets of 545 and in Kumaon region, Champawat district has the highest number of hamlets of 228 to be electrified. Geographical location of Uttarakhand districts cum blocks with number of un-electrified hamlets is shown in Fig. 3. District-wise list of number of unelectrified villages/hamlets in Uttarakhand state is given in Table 1.

Most of the unelectrified villages are rich in the availability of renewable energy resources like solar, small hydro, biomass etc. Utilization of these resources has the potential to meet demand of rural areas including cooking, lighting, heating and cooling and employment. Energy access in rural areas can help in improving agricultural condition, per capita income and poverty level in the state.

In the paper, renewable energy based strategies for off-grid rural electrification in the state of Uttarakhand (India) has been presented. Availability of renewable energy sources in the state has been discussed in the paper. Further, possible technology options have been proposed for energy conversion of available resources. A methodological framework has also been established for rural electrification in off-grid mode. Finally, barriers and issues are discussed that deviate from the use of renewable energy source in rural areas. Possible renewable energy strategies are also recommended in order to address barriers and issues.

2. Renewable energy resources in Uttarakhand state

2.1. Availability of renewable energy resources in the state

Uttarakhand state has enormous potential of renewable energy resources like solar, micro hydro power, biomass, biogas etc. State is rich in natural resources especially water and forests with many rivers, water streams, glaciers, dense forests and snow-clad mountain peaks. Out of 53,484 km^2 area of the state, forests are distributed in the area of 34,651 Km^2 that constitutes 64.8% of the total area of the state [13].

Pine trees (*Pinus roxburghii* Sarg.) cover total area of 0.343 million Hectares in the forest of the state and this can produce 2.058 million Tonnes dry biomass (pine needles) annually. The 0.08 million Tonnes pine needles is also available in Civil Soyam forest and Van Panchayat. Dried pine needles based briquettes (derived coal from pine needles) can be utilized as