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Technical viability of mobile solar photovoltaic systems for indigenous nomadic communities in northern latitudes

Svetlana V. Obydenkova [a], Joshua M. Pearce [b, c, *]

[a] School of Industrial Engineering and Management, Department of Energy Technology, KTH Royal Institute of Technology, United States
[b] Department of Materials Science & Engineering, Michigan Technological University, United States
[c] Department of Electrical & Computer Engineering, Michigan Technological University, United States

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ABSTRACT

This study assesses the viability of photovoltaic (PV) technology in northern latitudes as a part of energy supply system for remote nomadic camps of indigenous communities involved in reindeer husbandry. Two boundary locations were analyzed: southern Yakutia, Russia, 56°41′N; and the northernmost area in Norway, Finnmark, 68°51′N. Sixteen scenarios were simulated based on energy consumption, light sources and electric load schedules. The results show that PV-based systems are beneficial under a variety of economic conditions and fuel prices when compared to systems solely fuel-based. Incandescent lights, which are currently common for such settlements, should be replaced with LED lighting to enable easier PV system portability by reindeer sled. For areas with significant numbers of minimal solar flux days partial load scheduling is necessary for economically viable systems. The simulations showed that the specific weight of the system (excluding support structure) measured as the system total weight to the number of camp residents ratio can be reduced by a factor of two for optimized loads to 5.8 kg/person for a low energy-intensive camps and 11.0 kg/person for a high energy intensive camps.

1. Introduction

Solar photovoltaic (PV) technology has proven to be a reliable, sustainable [1] and economic source of power for isolated communities throughout the world. PV is used in diverse applications including: detached residence [2,3] or whole villages [4,5], educational centers [5], water pumps [6], and medical centers [5,7]. Small load systems range from 1.3 kWh/day/family for domestic needs to of about 23.1 kWh/day for medical centers, and are usually designed to run small electronic appliances. However in more energy-intensive applications, PV is coupled to a fuel-fed generator and/or with wind turbine in order to form a reliable hybrid electrical system [4,5,7].

The PV system properties of modularity [8], inherently stand alone [8,9], no fuel costs, very small operational cost requirements [8,10] and long lifetime [8,11] make distributed solar energy systems appropriate technologies [12] for dispersed isolated rural communities. However, the vast majority of such systems have generally been located and studied in the south – under moderate to warm environments with relatively constant levels of solar flux (e.g. from 4.6 to 5.6 kWh/m^2/day [2], or from 4.8 to 6.1 kWh/m^2/day [4]). Similar systems have been gradually introduced into some northern countries to power small navigational stations, radio repeaters, or lighthouses, residences, fish farms, water pumps with peak loads varying from 0.4 to 1.2 kW [13]. Even the Antarctic uses PV to power light bulbs, laptops and other electric appliances in research centers during summer time [14–16]. However in higher latitudes (above 45 °N) such installations usually perform either on seasonal or on a hybrid basis (i.e. with a backup power source such as a generator).

In the far northern hemisphere the indigenous people live nomadic lifestyles on the taiga (or tundra) as part of reindeer herding societies and require electric power for electric lights, telecommunications equipment and other electric appliances. These nomadic indigenous societies rely on reindeer for meat, milk and hides as well as for transportation. Thus, herders prioritize the care and well-being of their animals, which necessitates taking herds to extremely remote winter pastures rich of lichens that feature high glucose content vital to survive severe winter season, and then in the summer time to pastures where the diversity of

* Corresponding author. 1400 Townsend Drive, Houghton, MI 49931-1295, United States.
E-mail address: pearce@mtu.edu (J.M. Pearce).

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grass and shrubs compensates for the shortage of protein and minerals [17]. This natural reindeer dependence on types of forage forces herders to relocate their livestock, along with human dwellings, twice per year to a distance of up to 200 km [18].

To provide comfort and security, herdsmen use nomadic camps, using a tent that in winter can be covered by hides and heated by firewood. A relatively low electric power demand still requires the delivery of generators and fuel into the taiga, which can be challenging under extreme natural conditions that creates exorbitant fuel costs [13]. In addition, the negative environmental, health and social impacts of the use of fossil fuels in the north are well known to the community members and northern governments [19,20]. Therefore, these communities are interested in alternative sources of electrical energy.

The severe environment of the far north makes providing renewable energy a challenge to meet nomadic electric needs. Biomass-based renewables do not provide self-sufficiency of energy supply chain in nomadic camps, and hydro power is only be available for stationary sites. Wind power could be more promising in this respect, however, even small wind turbines require specially trained staff for service [21]. Furthermore, comparatively low turbine operational and maintenance costs do not include serving of the most expensive turbine components, such as gearbox and blades [22] whose failure due to an ice-formation may become an issue under extreme northern conditions [23]. The other attributes of icing related to decrease of power delivered by the turbine [23,24] and probable damage to surrounding goods due to ice take off from the blades [23], do not contribute to the viability of wind power for northern nomadic camps.

Photovoltaic (PV) systems appear to be the most technologically competitive, but also beneficial for the unique herder lifestyle, including the traditional workmanship. To investigate this resource this study utilizes the Hybrid Optimization Model for Multiple Energy Resources (HOMER) to probe the potential feasibility of PV for nomadic camps. First, background is provided for reindeer herder communities, based on two cases (one of the most southern in Russia, 56°41′N, and northernmost, 68°51′N, in Norway). Then, based on information obtained from herdsmen representatives, the electric needs of reindeer herders' nomadic camps are quantified and load profiles are modeled for technical and economic performance. Sensitivity analysis is performed for different scenarios with regard to the economic variables in Russia and Norway (e.g. fuel prices, interest rate), market analysis on the system components, technological behavior over the lifetime, portability of the system, and the effect of albedo in northern latitudes.

2. Background

Northern groups of indigenous people involved largely in reindeer husbandry, as well as in hunting and fishing account for more than 180,000 people (Table 1) and are spread out over a vast geographic region (Fig. 1). The most numerous society of indigenous people potentially involved in reindeer herding of over 120,000 is concentrated in Russia; however, there are also other people who may partially be active in reindeer husbandry, such as Komi, Tuvan, and Yakuts, rural population of which amount to 118,530, 134,899 and 284,834, respectively [25].

According to reindeer husbandry traditions, summer and winter pastures are usually divided between reindeer-herding groups, cooperatives or small crews and brigades [27,29]; each of those may comprise several families [30,31]. Every crew usually sets up its own nomadic camp, which can accommodate sixteen or more people. These camps consume a relatively low amount of electricity, about 1.44–2.73 kWh/day, depending on the electric appliances deployed.

Designing PV systems for reindeer herders is complicated by four primary challenges: 1) the nomadic lifestyle, which necessitates a mobile PV system able to be transported via reindeer-sleigh; 2) PV racking, which cannot use standard ground mounts (permafrost prevents pole mounts), ballasted racks (reindeer transport) nor roof/integrated in buildings (tents are the primary structure); 3) extreme temperatures (−40 °C) effect on battery performance and lifetime and 4) wide seasonal and daily variations in solar flux.

3. Methods

The PV systems were modeled with HOMER (v2.68 beta) following stages outlined in Fig. 2.

The two case study locations evaluated are 1) the southern area of Yakutia, Russia (56°41′N; 120°46′E) – the Russian case and 2) one of the northernmost regions in Norway (Finnmark, 68°51′N; 24°43′E as the winter pastures and 70°03′N; 23°27′E as the summer pastures) – the Norwegian case (Figs. 3 and 4). The Norwegian case is in the Arctic Circle and the Russian case is located at higher altitudes of 1009 m above sea level.

Due to the ample variations of power consumed by the camps depending on the number of habitants and/or economic means, two scenarios were developed for each case study location, namely: high and low energy intensive camps (Fig. 5). Incandescent lamps are in a common use in camps. Both these and more energy-efficient light-emitting diode (LED) sources are considered. Additionally, two scenarios for electric load were considered, bringing a total analysis to 16 cases as summarized in Fig. 5.

3.1. Data acquisition

3.1.1. Nomad camp electrical assessment

Power consumption by two nomadic camps of Evenk communities was investigated when the camps were settled remotely in the taiga, in the southern part of Yakutia, the Russian Far East. The data on power demand was obtained from communities' representatives via e-mail and phone interviews.

Communities differ in the quantity of members, tents deployed in the nomadic camp and the number of appliances. For instance, the community “Agdan”, comprising 16 people, uses eight tents, while the other community called “Nadezhda”, comprising 17 people, possesses only four tents.

Electric power supplied by generators is used to provide interior lighting and charge telecommunications equipment such as satellite phones, which are gradually replacing once popular radio-transmitters, more rare mobile phones (due to the remoteness from any cell towers), and also to power laptops and video-players. This equipment is used on a daily basis, several hours per day. For the lighting, local communities usually rely on 40 or 60 W incandescent lamps. In addition, there are small washing machines with a nominal load of 1 kg of clothes [32], which are used as required, but usually at least once and twice per week in winter and summer seasons, respectively. Washing machines are normally used in several consecutive cycles during one day.

The information on electrical equipment, power draw, and times of use for both communities is summarized in Table 2. Data on power consumption by mobile phones and laptops was obtained from Lawrence Berkeley National Laboratory [33]. Standby power, and the rest of data was obtained from manufacturer catalogs.

Generators are run all year round, from 6 p.m. till 11 p.m. in winter, and from 8 or 9 p.m. till 11 p.m. in the summer season. The most common types of generators are model DDE GG950 DC, gasoline-fired, with the rated capacity of 650 W and cost about US$150 [34]. These communities use gasoline as −40 °C