Available online at www.sciencedirect.com
ScienceDirect
Solar Energy 133 (2016) 85–93
SOLAR ENERGY
www.elsevier.com/locate/solener

Selecting photovoltaic generation sites in Tibet using remote sensing and geographic analysis

Siheng Wang [a,b], Lifu Zhang [a,*], Dongjie Fu [a], Xu Lu [c], Taixia Wu [a], Qingxi Tong [a]

[a] *State Key Laboratory of Remote Sensing Science, Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing 100101, China*
[b] *University of Chinese Academy of Sciences, Beijing 100049, China*
[c] *Clark University, 950 Main Street, Worcester, MA 01610, United States*

Received 18 August 2015; received in revised form 26 March 2016; accepted 28 March 2016

Communicated by: Associate Editor Arnulf Jaeger-Waldau

Abstract

Harnessing solar energy through photovoltaic (PV) generation of electricity is a promising method, expected to reduce greenhouse gas emissions at a relatively low cost. A primary obstacle for the large-scale exploitation of solar energy in regions with poor electrical infrastructure is that the output of the PV systems is hard to match their connection with the electric grid, due to the lack of strategical planning. This study aims to map the most promising locations for potential PV investments in Tibet, China, where solar radiation is in abundance, presenting an opportunity to install PV stations across the country. Geographic information science (GIS) overlay was implemented, considering solar energy distribution, local terrain and native land cover. Several remotely sensed data were employed as input, including time series of solar radiation data, land cover data and digital elevation model data. In total, 4005 sites were selected, with the majority in the regions of Shigatse and Ngari. The results were discussed according to their distance to existing electricity substations, to evaluate the difficulty to be connected to the grid. The work highlights a method for the selection of suitable PV power generation sites, and provides a guidance for the construction of these stations, particularly in Tibet-like regions with poor electrical infrastructure, and harsh environmental conditions.

Keywords: PV station; Site selection; Remote sensing; Solar radiation; GIS

1. Introduction

Solar energy is a promising method expected to reduce greenhouse gas (GHG) emissions, as the large-scale conversion from solar energy into electricity is made possible by improvements to the cost and efficiency of photovoltaic (PV) modules (Devabhaktuni et al., 2013; Razykov et al., 2011). China has become the largest producer of GHG in the world since 2010, and the GHG emissions of China, which is expected to account for 32% of those of the world in 2020, is mainly due to the consumption of electricity (Chu, 2015). Hence the state government has launched a series of programs to support the research and development (R&D) of PV industry over the past decades (Zhao et al., 2015). Under the promotion of Feed-in-tariff (FIT) scheme, China has become both the leading producer (Razykov et al., 2011) and the leading consumer (Zhao et al., 2015) of PV modules. According to statistics from the National Renewable Energy Center, in 2014, the newly installed PV capacity in China is about 10.6 GW h, accounting for over 26% of the world. Among the total installed PV capacity, about 83% is contributed by large

* Corresponding author.

http://dx.doi.org/10.1016/j.solener.2016.03.069
0038-092X/

ground-based power stations, while the rest is the distributed PV generation. Although the development of distributed PV generation has been accelerated in recent years, the main opportunities for PV investments in China still concentrate in open spaces (Grau et al., 2012). This is because the ground PV stations are mainly located in the western part of the country, e.g. Xinjiang, Qinghai, and Tibet, where solar energy is in abundance, unpopulated desert is widely distributed, and the state government intends to promote the local economy through the exploitation of renewable energy (Ming et al., 2015).

Tibet, located in the southwest China, presents a promising opportunity to install PV stations. The region possesses the richest solar energy resource over the country, receiving an annual solar radiation of 7000–8400 MJ m^{-2} and about 2900–3400 h of sunshine (Wang and Qiu, 2009). Besides, the state government granted special policies to encourage the PV installations in Tibet. For example, the projects located in Tibet can receive an extra FIT of RMB 0.15 Yuan/kW h over the projects in other parts of the country. However, the current situation for the PV development in Tibet is far from satisfying. By the end of 2014, the total installed capacity (grid-connected) in Tibet is 15.1 MW h, ranking only the 21th among the 31 provinces. This is due to the harsh natural environment, making it inconvenient to build PV plants, and the poor electrical infrastructure, making it difficult to connect PV generations to electric grid. An embarrassing phenomenon has occurred in the PV industry of Tibet: on the one hand, some PV stations cannot address the local power demand due to the insufficiency of the output (Ming et al., 2015); on the other hand, the output of some PV stations has largely exceeded the local transmitting capacity. The four PV stations located in Shannan take turns to generate electricity as the grid is unable to transmit the power if they work at the same time (Chinairn, 2013).

One of the main reasons for the mismatch between the PV output and grid capacity is the lack of unified planning (Ming et al., 2015). Traditional plan for PV investments is somewhat arbitrary. Firstly, hardly do the planners consider the solar energy distribution at regional scale. To our knowledge, previous studies evaluating the potential of PV investments of Tibet only use solar energy maps under coarse spatial resolution (e.g. Ming et al., 2015; Wang and Qiu, 2009; Zhao et al., 2015). Yet to select a potential PV site, data with finer spatial resolution should be used, as the solar radiation may vary significantly due to local terrain and climate (Šúri et al., 2005). Secondly, the evaluation of the difficulty to connect PV generated electricity to grid was barely made. Under situations with poor infrastructure and harsh natural environment, the transmitting distance to grid connections (substations) is essential for the connection of PV generations (Song et al., 2015). Thirdly, although in-situ inspection is necessary to build a new PV station, a preliminary estimation of the candidate locations considering some primary constraints is helpful to the plan, while this work has not been made.

The objective of this study is to provide a series of potential PV sites in Tibet to help building new PV stations under strategical planning. The factors taken into consideration include the intensity of solar radiation, local terrain and environment, and the spatial distance to the nearest substations. We used several satellite sensed data as input, including time-series of solar radiation data, digital elevation model (DEM) data, land cover data. It should be noted that although other factors like building cost and local demand also affect the selection, the results provide a primary support to the decision of PV investments, and the method used in this study is supposed to be beneficial for the selection of field-based PV sites, especially in regions with harsh environment and poor electrical infrastructure.

2. Methodology

The incoming of solar radiation is the dominant factor determining the output of the PV module, and is therefore is an essential input for PV site selection. High spatial-temporal resolution time-series of solar radiation at ground level can be retrieved from satellite measurements. Geographic information science (GIS) analysis is a helpful tool to map the spatial distribution of potential PV stations. GIS overlay can eliminate regions with undesired geographic conditions. To evaluate the difficulty of connecting PV generations to electric grid, the spatial distance to nearest substations should also be considered.

2.1. Satellite measurements of solar radiation

Satellite measurements of downward solar radiation (DSR, same definition as Global Horizontal Irradiance, GHI) is based on the established relationships between the extraterrestrial radiation (ETR) and the sensor observed radiance. The satellite retrieval methods of DSR can be roughly divided into two main categories: albedo-based models and reflectance-based models.

2.1.1. Albedo-based models

The surface albedo is the reflected proportion of the total DSR by the ground. Fig. 1 shows the procedure of sunshine illumination, atmosphere absorption, surface reflection and satellite observation. The albedo-based models are developed on the following principle:

$$G_{ext} = G_r + G_a + G_g \tag{1}$$

$$DSR = \frac{1}{1-\rho}(G_{ext} - G_r - G_a) \tag{2}$$

ETR (G_{ext}) comprises reflected (G_r), atmosphere absorption (G_a) and ground absorption (G_g) components, and ρ is the surface albedo (Paulescu et al., 2012). While G_{ext} and G_r are measured directly by the satellite sensors, the models differ in their estimation of G_a and ρ. For example, the Heliosat-3 model (Mueller et al., 2004) uses the