Energy Policy 58 (2013) 248–259

Contents lists available at SciVerse ScienceDirect

Energy Policy

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

GIS-based approach for potential analysis of solar PV generation at the regional scale: A case study of Fujian Province

Yan-wei Sun [a], Angela Hof [b], Run Wang [a,*], Jian Liu [a], Yan-jie Lin [a], De-wei Yang [a]

[a] Key Lab of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, 1799 Jimei Road, Xiamen 361021, China
[b] Landscape Ecology/Biogeography, Geography Department, Building NA 5/128, Ruhr University Bochum, Universitaetsstrasse 150, 44780 Bochum, Germany

HIGHLIGHTS

- We developed a grid-based comprehensive potential analysis framework of solar energy at the regional scale.
- We evaluated the technical potential of solar PV generation.
- We calculated the cost of PV generation and got the geospatial supply curve (GSC) of Fujian Province.
- PV technology provides high potential for roof-top application and large-scale PV stations.
- Determining a reasonable feed-in tariff is essential for expanding the application of solar PV energy.

ARTICLE INFO

Article history:
Received 29 October 2011
Accepted 4 March 2013
Available online 30 March 2013

Keywords:
Solar energy
GIS-based approach
Potential assessment

ABSTRACT

Spatial variation of solar energy is crucial for the estimation of the regional potential and selection of construction location. This paper presents a case study of using high resolution grid map of solar radiation combined with the other restriction factors to evaluate the comprehensive potential analysis of solar PV generation at the regional scale, in order to present a framework of decision support tool for solar energy management in a regional area. The cost of PV generation is calculated based on the geographical distribution of technical potential. Moreover, geospatial supply curve (GSC) is employed to portray the evolution of available potential of photovoltaics (PV) generation with the increase of the generation cost. By integrating the economic evaluation variables of net present value and simple payback period, grid-based economic feasibility of PV generation project is then carried out under two feed-in-tariff scenarios. Finally, total CO_2 reduction potential and its spatial distribution in the study area are calculated. The results confirm that PV technology provides high potential for roof-top application and large-scale PV stations. Additionally, determining a reasonable feed-in tariff is essential for expanding the application of solar PV energy. The findings improve understanding of regional renewable energy strategies and the supply/demand assessment.

1. Introduction

Most Chinese cities currently experience rapid urbanization and economic growth. Therefore, improvement in energy efficiency and promotion of clean and renewable energy development might play the most important role in energy conservation and greenhouse gas (GHG) reduction (Lin et al., 2010; Xiao et al., 2011). Solar power is the conversion of sunlight into electricity, directly using PV, or indirectly using concentrated solar power (CSP). PV electricity is one of the best options for sustainable future energy requirements of the world. At present, the PV market is growing globally at an annual rate of 35–40%, with PV production around 10.66 GW in 2009 (Razykov et al., 2011). In the same year, China has newly installed PV capacity of 160 MW, and with the total installed capacity of 300 MW. China is about to raise its 2015 goal for solar photovoltaic (PV) power to 10 GW in the newly submitted “Development Plan for Renewable Energy during the 12th Five-Year Period” (Xu, 2011). If it is realized, China′ PV market will usher in an era of speeding up development.

The market development of solar energy is strongly dependent on the policy, technology development and transfer, economics of solar energy products, and the local solar energy resource. It is necessary to integrate all these influencing factors to analyze the potential of solar energy as a source for producing electricity and plan the exploitation of solar energy in a given area. Spatial information technologies, particularly Geographical Information

* Corresponding author. Tel.: +86 592 6190784; fax: +86 592 6190977.
E-mail address: rwang@iue.ac.cn (R. Wang).

0301-4215/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2013.03.002

Systems (GIS), have been widely used in evaluating the feasibility of solar power stations in a given region and identifying optimizing locations. During the last decade, considerable effort has been expended to obtain Decisions Support Systems (DSS) tools in order to facilitate renewable energy at a regional scale (Domínguez and Amador, 2007). The main objectives of such studies were to evaluate the potential of renewable energy resources through integrating data of various constraints factors. For example, Hoogwijk (2004) presented a comprehensive analysis using a grid cell approach to assess the geographical, technical and economic potential of renewable energies at the regional and global scales. Clifton and Boruff (2010) integrated the local environmental variables and electricity infrastructure on a high resolution grid to identify the potential for CSP to generate electricity in a rural region of Western Australia. Charabi and Gastli (2011) assessed the land suitability for large PV farms implementation in Oman using GIS-based spatial fuzzy multi-criteria evaluation. Janke (2010) identified areas that are suitable for wind and solar farms using multi-criteria GIS modeling techniques in Colorado. Additionally, rooftop PV is a main application form of distributed solar generation in built-up area. In order to estimate the rooftop PV potential for a large-scale geographical region, various modeling technologies have been developed in recent studies. Wiginton et al. (2010) demonstrated techniques to merge the capabilities of GIS analysis and object-specific image recognition to determine the available rooftop area for PV deployment. Kabir et al. (2010) identified and calculated bright roof-tops of Dhaka Megacity from Quickbird high-resolution optical satellite imagery in order to assess power generation potential through solar photovoltaic applications. Liu et al. (2010) built a model with taking both natural and social restriction factors of solar resources into consideration to evaluate the available roof-mounted solar energy resource in Jiangsu Province.

Due to the higher development cost of solar energy, economic feasibility is very critical for implementing regional solar energy projects. Sun et al. (2011) studied the economic and environmental benefits of the grid-connected PV power generation system in China' 34 province capital cities using the net present value and the single factor sensitivity analysis tools. Ramadhan and Naseeb (2011) determined the economic feasibility and viability of implementing PV solar energy in the State of Kuwait. The cost analysis showed that when the value of saved energy resources was used in producing traditional electricity, and the cost of lowering CO_2 emissions were accounted for, the true economic cost of the levelized cost of electricity (LCOE) of a PV system would decline significantly. Poullikkas (2009) carried out a feasibility study in order to investigate whether the installation of a parabolic trough solar thermal technology for power generation in the Mediterranean region was economically feasible. His case study took into account the available solar potential for Cyprus, as well as all available data concerning current renewable energy sources policy of the Cyprus Government. However, the study did not take the spatial variability of solar radiation into account.

GIS is a power tool to perform spatial multi-criteria decision analysis integrating geographical spatial data for a comprehensive feasibility assessment of solar energy potential at the regional scale. The solar energy potential evaluation and economical feasibility analysis need to be evaluated together to identify the areas that have economically competitive renewable resources. Spatial explicit assessment of solar radiation is a key element of improved feasibility methodology framework present here. To integrate the potential evaluation and economical analysis for solar energy, this study developed a grid-based comprehensive potential analysis framework of solar energy at the regional scale for technical users and economic decision-makers. A case study of the approach is implemented for Fujian Province, China.

2. Study area

The study area of this research is Fujian Province, which lies in the southeast coast of China facing Taiwan across the Taiwan Straits, and is divided into nine prefecture-level divisions. The province covers an area of over 139,000 square kilometers and has a population of 36.89 million (2010). The province capital is Fuzhou. Fujian has a mild and humid climate and its mean temperature in the coldest month of January is 5 °C (41 °F) in the northwest and 12 °C (53.6 °F) in the southeast. In the hottest month of July, it has an average temperature of 25–30 °C (77 –86 °F). Over the past three decades of "Reform and Opening", Fujian has experienced spectacular economic growth. Energy consumption in Fujian Province has undergone a dramatic increase in last three decades, with an annual growth rate of 8.46%. Annual energy consumption reached 82.83 million tons of coal equivalents (TCE) in 2008; most of the energy consumed comes from fossil fuels (84%) and hydroelectric power (15.8%). Wind power and other forms of renewable energy are at a very early stage of development and provided only 0.2% of the whole energy consumption (Statistics Bureau of Fujian Province, 2009). About 60% of energy consumed comes from outside Fujian. This percentage is expected to grow in the future, indicating a serious threat to Fujian's energy security and economic growth (Wang et al., 2011). In this context, the large-scale application of renewable energy is taken as main measures to address the current challenges of supply shortage of primary energy and to achieve the target of carbon emission reduction.

3. Methodology

This study presents a GIS-based approach to facilitate the feasibility analysis of investments for policymakers, investors and energy planner in a given region. The procedure is comprised of two steps: the first step is to evaluate the potential for exploiting solar energy sources, including geographical and technical potential in suitable areas with the aid of GIS spatial analysis functions. The second step is to assess economic feasibility for PV generation. Continuous cost surface for PV generation is calculated based on the technical potential in the study area. Next, a solar geospatial supply curve is developed following a GIS method of the National Renewable Energy Laboratory (NREL) (Kline et al., 2008). To analyze the returns and risks on PV investment, the financial analysis of investments is conducted in this study with a cash flow analysis based on the following economic parameters: net present value (NPV) and simple payback period (SPP), according to the expected energy outputs, and energy costs. The framework of the methodology is illustrated in Fig. 1.

3.1. Estimation of solar radiation

To exactly estimate the solar radiation for the study area, a high resolution solar radiation map for Fujian Province was calculated by using the solar radiation analyst module of ArcGIS 9.3, which has been used in published literatures (Clifton and Boruff, 2010; Gastli and Charabi, 2010). The module accounts for atmospheric effects, site latitude and elevation, steepness (slope) and compass direction (aspect), daily and seasonal shifts of the sun angle, and effects of shadows cast by surrounding topography, and it allows to modify the coefficient of the atmospheric transmissivity (Charabi and Gastli, 2011). The model estimates the total amount of radiation as the sum of direct and diffuse radiation of all sunmap and skymap sectors. The main input parameters to the model were a 90 m × 90 m digital elevation model (DEM) derived from the Shuttle Radar Topography Mission (SRTM) and coefficient of the atmospheric transmissivity. The DEM data set is provided by International Scientific & Technical Data Mirror Site, Computer Network Information Center, Chinese