Energy Conversion and Management 151 (2017) 240–258

Contents lists available at ScienceDirect

Energy Conversion and Management

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

A novel framework for the potential assessment of utility-scale photovoltaic solar energy, application to eastern Iran

Hamed Hafeznia*, Hossein Yousefi*, Fatemeh Razi Astaraei

Department of Renewable Energies and Environment, Faculty of New Sciences and Technologies, University of Tehran, Tehran, Iran

ARTICLE INFO

Keywords:
Spatial planning
Solar photovoltaic power plants
Geographic information systems
Electricity production capacity
Birjand

ABSTRACT

This paper presents a framework to assess the potential of photovoltaic solar energy for utility-scale installations. In order to achieve this purpose, the framework incorporates spatial planning and performance simulation of photovoltaic power systems into the potential assessment process. Birjand County where is a suitable region for the deployment of photovoltaic technologies because of its climatic conditions was selected as a case study. The installation of solar power plants as a subset of infrastructure facilities should have the conformity to the standards of land-use planning. At the first step, the set of factors (27 criteria) influencing on the site selection of photovoltaic power plants was defined. After the detection of unsuitable areas, they were excluded from the county map by Boolean logic. Remaining areas were rated based on the technical, socio-economic, environmental criteria by using different fuzzy membership functions. Then, these rated areas were mapped. To determine the optimal sites for the grid-connected installations of photovoltaic, the fuzzified maps were overlaid by fuzzy gamma operator. Then, the pixels of final map were classified into five groups regarding to their fuzzy value. The results show that optimal places for the installation of photovoltaic power plants account for 0.5 percent (2005 hectares) of Birjand's territory. The results of geo-spatial modeling of this thesis were verified by using satellite images. To estimate the capacity of electricity production from photovoltaic power plants, a 46.2 kW- photovoltaic installation was designed and its performance and energy output was simulated under climatic and geographical conditions of Birjand. The estimated energy output of photovoltaic power plants in optimal sites of Birjand County (1781.6 GW h/year) not only can supply the electrical demand of Southern Khorasan Province but also, the excess generated electricity can export to other provinces and neighboring countries such as Pakistan and Afghanistan.

1. Introduction

Population growth, as well as economic and industrial development in countries around the world led to greater use of energy resources. According to statistical data from the International Energy Agency (IEA), the total primary energy supply of the world increased from 10,359 Million tons of oil equivalent (Mtoe) in 2002 to 13,699 Mtoe in 2014 [19].

Exploiting cheap, stable, and reliable energy resources is required to maintain the rate of socio-economic development. Fossil fuels are used as main energy source in the world. Increasing concerns about environmental pollution and global warming made the international community to determine requirements in the energy sector to mitigate the effects of climate change through achieving climate agreements. Renewable energies are the appropriate choices to replace fossil-based energy resources [27]. However, the development of renewable energies faces many obstacles including financial, technical, political, legal, social and environmental barriers [25].

Iran is located inside the world's Sun Belt, and this geographical position has made this country to enjoy high potential of solar energy [23]. Iran, where more than two-thirds of its area is sunny for 300 days a year and with an average radiation of 4.5–5.5 (kW h/m^2/day), is one of the countries known to be suitable for solar energy technologies [44]. Among Iran's Provinces, South Khorasan Province is known as one of the provinces with high priority of deploying renewable energies due to high cost and low reliability of energy transfer since it is placed at the endpoint of energy transmission lines. Regarding climatic and geographical conditions of South Khorasan Province, solar energy is one of the best options among renewable energy sources [16]. This study tries to provide an innovative framework for assessing the feasible potential of solar energy for utility-scale photovoltaic facilities in Birjand County.

The research studies so far conducted to assess solar photovoltaic potential can be classified into two categories. The first class studies are

* Corresponding author.
E-mail addresses: h.hafeznia@yahoo.com, h.hafeznia@ut.ac.ir (H. Hafeznia), hosseinyousefi@ut.ac.ir (H. Yousefi).

http://dx.doi.org/10.1016/j.enconman.2017.08.076
Received 15 May 2017; Received in revised form 24 August 2017; Accepted 27 August 2017
0196-8904/

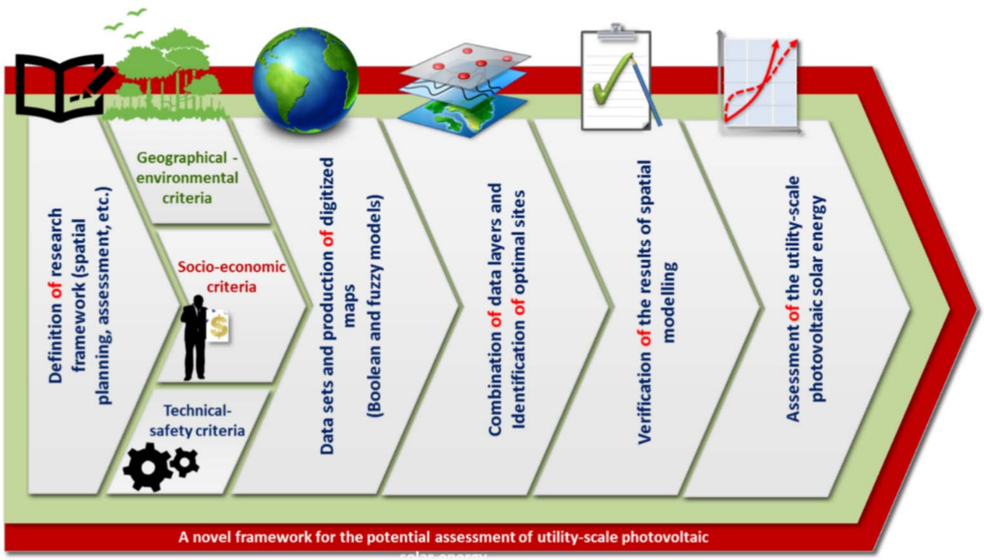

Fig. 1. The steps of this research paper.

for small-scale applying solar PV panels on the facade and roof of urban buildings; and the second-class studies estimate the potential for utility-scale.

Singh and Banerjee [37] estimated rooftop solar photovoltaic potential of Mumbai in India by using PVSyst software and GIS tools for analyzing satellite images. Wiginton et al. [46] determined the available area for deploying PV panels on the rooftop of buildings in south eastern Ontario. Jakubiec and Reinhart [22] utilized GIS, LiDAR data and DAYSIM simulations for the potential assessment of rooftop photovoltaic for Cambridge City of Massachusetts in USA. Assouline et al. [2] used a combination of GIS and support vector machines (SVMs), as a supervised learning algorithm, for estimating rooftop PV potential of the urban areas in Switzerland.

To assess the solar photovoltaic potential in utility scale, several research studies have been done for different regions of the world. These studies used different methodologies to estimate the potential of solar energy for electricity generation. Bulut and Buyukalaca [6] provided a model for generating data of solar radiation in Turkey. Some of them predicted the solar radiation in different countries using estimating models and climatic data [34,43]. Polo et al. [29] produced the solar resources and power potential maps of Vietnam using GIS and satellite imagery. Fadare [12] conducted a research study to model the solar energy potential in Nigeria by applying artificial neural network (ANN). Pan et al. [28] estimated the daily global solar radiation for the Tibetan Plateau in China. Gastli and Charabi [14] created solar radiation maps of Oman using GIS tools and also, they calculated the potential of electrical energy generation. Solar radiation in Iran have been predicted by a number of researchers. Samimi [33] presented an altitude-dependent model. Various parameters such as cloudiness coefficient, sunshine hours, Sun-Earth correction and altitude were used to estimate daily radiation in Iran. Besarati et al. [5] generated solar radiation maps for five different cases; the three cases of them are generally used for photovoltaic power plants and others are applicable to concentrating solar power (CSP) plants. They also simulated a 5 MW PV power plant for 50 cities of Iran. Capacity factor, GHG emission reduction and annual generated electricity are the results of this simulation. The results suggest a great solar potential for central and southern parts of Iran. Alamdari et al. [1] investigated the solar energy potentials for different parts of Iran by calculating maximum, minimum and average values of annual horizontal radiation for 63 stations. They produced GIS maps of horizontal radiation for each month of the year. They indicated Southern Khorasan and Khuzestan provinces are the most suitable regions for deploying solar systems in Iran economically.

Yeo and Yee [47] proposed a new model for site location planning of urban energy supply plants for a planned city in the Republic of Korea using GIS database and an artificial neural network (ANN). They presented a technical methodology and also, produced energy potential maps as supportive materials for urban energy supply planning. Carrion et al. [7] selected the suitable sites for using solar energy in Andalusia, Spain and then, estimated the electricity production capacity of PV power plants from this region.

Although all the articles mentioned above estimate solar energy potential through different methodologies, few studies estimated the capacity of the power generation with high precision. Often the potential of electrical energy produced from photovoltaic power plants is calculated through multiplying solar radiation by the amount of land available (based on the average land required for each MW), which is expected to be inaccurate. The purpose of this research paper is to examine the hypothesis whether incorporating spatial planning and performance simulation of photovoltaic power plants into the potential assessment process leads to a higher precision and accuracy results. In this study, a new framework is proposed to estimate the electricity production capacity through photovoltaic power plants in a region. It is important to note that not all land available in an area is suitable for the deployment of photovoltaic power plant.

Solar power plants are known as a country's infrastructure; and it is recommended that its construction and site selection follow sustainable development model. At the first step, to assess the potential of solar energy, land suitability assessment is conducted for the establishment of photovoltaic power plant in Birjand County, which is one of the regions receiving significant solar radiation [1], to identify optimal locations to get benefit of solar energy; and then, by designing and simulating the performance of a 46.2-kilowatt power plant under climatic and geographical conditions of the study area, which is carried out in PVsyst software [30], the electrical energy potential is calculated. Sharma and Chandel [36] reported that the estimation results of PVsyst software have 1.4% uncertainty with the actual measured results when measured solar data is applied as the input of the software. Generalizing the results of the PV power plant to optimal sites, the potential of utility-scale photovoltaic solar energy in Birjand is estimated. Fig. 1 simply represents the steps of the research.

2. Materials and methods

The aim of this research paper is the potential assessment of utility-scale PV solar energy. To estimate the solar potential, at the first level, it is required to identify suitable locations for establishing PV power plants. Then, the electrical energy producible within the optimal