Energy Conversion and Management 118 (2016) 295–305

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Evaluation of wind power generation potential using a three hybrid approach for households in Ardebil Province, Iran

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ARTICLE INFO

Article history:
Received 22 September 2015
Received in revised form 31 March 2016
Accepted 1 April 2016
Available online 6 April 2016

Keywords:
Economic evaluation
Wind energy
Household
Ranking
Hybrid approach
Hybrid Optimization of Multiple Energy Resources (HOMER) software

ABSTRACT

The objective of the present paper is to conduct a thorough technical–economic evaluation for the construction of small wind turbines in six areas within Ardabil province of Iran using the Hybrid Optimization of Multiple Energy Resources software, and also to rank these areas by a hybrid approach composed of Data Envelopment Analysis, Balanced Scorecard, and Game Theory methodologies. Higher accuracy of the proposed hybrid approach and its ability to properly detect the relationships between the decision-making components make it preferable over the simple Data Envelopment Analysis method. Technical–economic feasibility study is conducted by analyzing wind speed data for period from 2008 to 2014 using Hybrid Optimization of Multiple Energy Resources software. In the next step, the type of equipment used in the design, benefit, costs, total net costs, depreciation and amount of generated electricity are obtained separately for each location. The results show that; Airport, Nir, Namin, Bilasavar, Firozabad and Ardabil were rank first to last respectively.

1. Introduction

In today's world, growing unbalance in energy supply and demand has caused the urgency to develop new energy sources to be felt more than ever. In the past 30 years, the global economy has had an annual growth of about 33 per cent, while electricity consumption has increased by 36% [1]. In recent years solar and wind energy technologies have seen much progress and countries have often turned to one of these two energies (whichever that is most efficient for their geography). This tendency is so that in some parts of the world, a large percentage of required electricity is supplied by these energies [2]. The high profitability, economically efficient production, renewability and low emissions of wind power have elevated the status of this energy [3]. Moreover, global developments in the field of environmental protection and the perishable nature of fossil resources have accelerated the tendency to develop and use renewable energies [4]. Many areas of Iran have been studied for the construction of wind power plants and some power plants have been constructed. Several measures have been taken to evaluate Iran's wind power generation potential; these include preparing Iran's wind atlas which has been developed by Iran's Renewable Energy Organization [5]. The motivation for conducting this study is to perform a thorough technical–economic evaluation for the construction of small wind turbines in six areas within Ardabil province of Iran using the Hybrid Optimization of Multiple Energy Resources software (HOMER), and also to rank these areas by a hybrid approach composed of Data Envelopment Analysis (DEA), Balanced Scorecard (BS), and Game Theory (GT) methodologies.

There has been numerous research works in the past related to evaluation of wind power generation potential in different parts of Iran. The wind energy potential was investigated in Manjil in north of Iran and it was acknowledged as one of the world's windiest location [6]. Several studies have been done on feasibility and potential of wind energy in Iran's provinces. For example, in the assessment of wind energy potential in Semnan province, Damghan city has been determined as the best location for the installation of wind power plants [7]. In another research, economic evaluation of wind turbines in Aligoodarz of Iran was investigated which was promising [8]. The feasibility study of wind energy potential in Zahedan province has shown that wind power is equal

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http://dx.doi.org/10.1016/j.enconman.2016.04.007
0196-8904/

Nomenclature

x_{ij}	input of *i*-th member of *j*-th unit
y_{rj}	output of *i*-th member of the *j*-th unit in the first stage
y_{sj}	output of *s*-th member of the *j*-th unit in the second stage
y_{pj}	output of *p*-th member of the *j*-th unit in the first stage
z_{rj}	weight given to *r*-th output of *j*-th unit
u_r	weight given to *r*-th output
v_i	weight given to *i*-th output
b_i	*i*-th member of the vector b
E_{qi}	efficiency of *i*-th unit
$\bar{E}_J$	cross-efficiency score of *j*-th unit
s_i	output of the first stage
t_k	Total weight given to *k*-th stage

Greek symbols

θ^a	breakpoint of the first model
θ^b	breakpoint of the second model
θ^c	breakpoint of the third model
θ_{cross}	cross efficiency
γ_i	weight given to *i*-th member
μ^a_{jr}	weight given to *r*-th output of *j*-th unit in first stage

Indices

N	the number of studied areas
b	breakpoints vector
r	index of second stage input
n	the number of studied units
P	index of second stage output
i	index of members of units in the first stage
m	the number of first stage inputs
j	index of units
u	result vector
S	feasible subset of solution space
k	number of stage

to 89.2 kW h per square meter and wind power density is equal to 781.2 kW h per square meter [9]. There are few feasibility study works carried out for other regions of Iran such as: the feasibility study of wind potential in the provinces of North Khorasan, and South Khorasan [10], the feasibility study of wind energy in Shahrbabak using Weibull function [11], the economic evaluation of using small wind turbines in Kerman [12], and assessment of wind and solar energy potential in Salafchegan, Kish and Chabahar using Weibull distribution function [13]. The value and importance of wind energy and the economic value of wind power along with the simplicity of its production and use has led to improved methods for its production, distribution and consumption [14].

Research has shown that the emergence and application of wind power energy have created a promising development in the use of sustainable energy resources. These studies have also provided researchers with more suitable, profitable and economic wind energy development options which have enabled them to come up with more desirable and efficient ways of harnessing this energy [13]. Favorable areas for the construction of wind power plants are still being identified in Iran. However, due to the lack of material and equipment and economic crisis in the country, only some very efficient and more economical sites such as Manjil and Binalud have become operational and currently generate electricity [15]. Thus, the value and the outstanding features of renewable energies, especially wind power and its cost-effectiveness, necessitates new research aimed at facilitating and accelerating their development.

There are different softwares which analyze hybrid energy power systems such as HOMER, ARES, INSEL, iHOGA, Hybrid2, and SOMES [16]. For this study, the software of HOMER was used. HOMER stands for Hybrid Optimization Model for Electric Renewable which was developed in the USA in 1993 by the National Renewable Energy Laboratory (NREL). This software is designed to do a general analysis for electric power systems [17]. This software has been applied by many researchers which is able to simulate, optimize and perform sensibility analysis of renewable energies. It is also to analyze hybrid systems of renewables with diesel generators and fuel cells too. An important function of HOMER is its ability to do economic evaluations of the energy power systems including optimization of components considering different sizes [18]. In literature, there have been many research works which HOMER software was used to perform economic evaluation and hybrid energy power systems. HOMER software simulation is able to carry out using hourly meteorological and load demand data. The input load data by the users must be on monthly basis. It is also able to do the economic and sensitivity analysis for different scenarios and projects [19].

Sinha and Chandel [20] applied HOMER software to analyze the hybrid system including fixed tilt and sun tracking photovoltaic based micro with wind systems along with determining the optimum configurations for a 6 kW roof mounted micro wind based hybrid system using fixed and tracking photovoltaic in a location in India with low wind speed. It was concluded that horizontal axis with monthly adjustment, horizontal axis with daily adjustment, horizontal axis with continuous adjustment and two axis tracking system are more efficient than the fixed tilt angle system.

Bhattacharjee and Acharya [21] performed economic evaluation of using wind-solar energy for a small scale application in an educational building in a north-east Indian state Tripura with low wind energy potential. The HOMER results showed that solar energy could provide majority of electricity need for the region, but wind energy could be useful for half of the year when average PV power production is comparatively less.

Azimoh et al. [22] investigated the feasibility study of a hybrid mini-grid for two locations at the Thlatlaganya village in Polokwane municipality of Limpopo province in South African rural area. They showed that a village of 300 household needs about 2.4 kW h/household/day of electricity, but the solar home system was not provide this amount of electricity. It was found that hydro electric system could be used together with mini grid system in order to be efficient.

Al-Sharafi et al. [23] used HOMER software in order to optimize sizes of a battery bank and PV modules of a hybrid PV–wind power generation system for city of Dhahran in Saudi Arabia. They used two different cases of 1 wind turbine, and 2 wind turbines. They also repeated simulations cover wide range of batteries too. They concluded that overall performance index (OPI) can be a useful tool that is able to mix the effects of different system indicator performances which could result in the best hybrid configuration.

Edwin and Sekhar [24] investigated feasibility of combining renewable energy sources like biomass (BM), gobar gas (GG) and biogas (BG) to meet the cooling load of milk preservation in the rubber cultivated regions and paddy regions in India. It was concluded that They analyzed combinations of renewable energy sources on the Net Present Worth (NPW), Payback Period (PBP), and Coefficient of Performance (COP) for total cooling. It was concluded that the COP and payback period of their hybrid energy system based milk cooling system were 0.16–0.23 and 4–6 years respectively which was economically viable.