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Economic analysis of small wind turbines in residential energy sector in Iran

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ABSTRACT

The residential energy sector, as one of the biggest energy users in Iran, is potentially appropriate for the utilization of renewables. This study provides a comprehensive and integrated feasibility analysis of small wind turbines as one of the most economic renewables in 88 regions of Iran to identify the most affordable conditions for investing and comparing the effects of different parameters, using the HOMER Software. For this reason, climate and economic conditions have been considered. Furthermore, we have tried to discuss the effect of FIT and grid power price on economic efficiency; in addition, the minimum feasible capacity for cost-effective use of wind turbines and the minimum suitable average wind speed have been detected. The results show that small wind turbines are cost-effective approximately in 30% of the studied regions; in most of these regions wind speed is higher than 5 m/s, and 3 kW is the best capacity for wind turbines. In addition, it has been demonstrated that FIT is one of the most effective factors for the cost-effective use of wind turbines. Besides, capital cost, wind features and interest rate have been identified as the other important factors which must be considered.

Introduction

In recent years, due to the value of non-energy uses of fossil fuel products in industries (e.g. petrochemical industries that produce various and valuable products by reforming methane and propane) along with high prices of crude oil and global environmental problems, the emergence of new energy resources is on the increase across the globe [1]. Also, the costs of renewable technologies are declining progressively, and are projected to drop even more. These factors have fostered investments in and researches on renewable energy, particularly wind and solar energies [2]. Iran has a large amount of fossil energy resources. Iran has the fourth-largest proved crude oil reserves (158 Billion barrels) and the second-largest natural gas reserves (33,500 billion cubic meter) [3]. These resources are exhaustible and their prices are influenced by various factors such as economic conditions. However, due to the growing Electricity demand (6.6% the average growth rate During the past decade) [4] and also the economic dependence on fossil fuel in Iran, the application of Renewable resources seems necessary. Among the renewables, wind energy technologies are one of the most established technologies. Due to technological improvements and the implementation scale, wind power makes up for the largest share of RES electricity production today, apart from large hydroelectric power plants [5]. The application of wind energy for electricity production in Iran started in 1994 and it is the second renewable resource for power generation in the country [6]. Recently, regarding the development of renewable energies, related activities and policy makings have increased. As an example, the Feed-in tariffs for wind energy have specifically been determined and adjusted annually in Iran. These tariffs for wind energy in 2015 are shown in Table 1. Therefore, this study provides an economic analysis of small wind turbines by considering the current situation of Iran. The purpose of this study was to perform an economic evaluation and identify the most economically effective factors in the residential energy sector of Iran. Hence, a feasibility study of these turbines was performed. Thereafter, the impact of important parameters was examined.

In the recent past years, several researches have been carried out on renewable energy with different purposes; for instance, Heagle et al. [8] have examined the social barriers, policies and incentive programs for residential and small wind projects. Alishahi et al. [9] have presented a framework to study the impacts of different regulatory interventions, in order to promote wind power investments in generation expansion planning. The suitability of Feed-in tariff for wind energy is another study which carried

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Table 1
Wind energy Feed-in tariff in Iran [7].

Capacity	Guaranteed FIT for wind power plant (Rials per kWh)
More than 50 MW	3400
1–50 MW	4200
Less than 1 MW	5700

out in New Zealand [10]. The evaluation of Feed-in tariff regulation for onshore wind energy is another similar study in Turkey [11]. a broad range of data is gathered by Shahmohammadi et al. [12] to develop a comprehensive system dynamics model to evaluate the impacts of Feed in Tariff mechanism on the generation mix of Malaysia during a 20-year period between 2011 and 2030. Gómez et al. [13] conducted a study on the effects of a new set of rules on the levelized cost of electricity for different power generation solutions in Amazon; Black et al. [14] have focused on fiscal and economic impacts of state incentives for wind energy development in the Western United States; Zachar and Daoutidis [15] have studied the impacts of location and load shape selection on micro-grid optimal design. Wind analysis and economic analysis are proposed to assess the wind energy potential for installation of wind turbines in Thailand by Quan [16]. The Algerian wind resource assessment has been done using statistical analysis based on the measured wind speed data in the last decade from 63 meteorological stations distributed over the Algerian territory and 24 in the neighboring countries close boundaries by Boudia et al. [17]. Furthermore, Abdelhady [18] provides an overview of the wind power potential at different regions in Egypt. A large number of studies have focused on the feasibility study of renewable energies for instance, Technical simulations and economic models for grid-connected photovoltaic (PV) systems supplying a rural home electricity load in parallel with the electricity network in Western Australia have been studied by McHenry [19]. Liu et al. [20] have analyzed the impact of climate change on the techno-economic performance of solar PV power systems. Also, a similar study has been done by Hdidouan [21]. Thomas et al. [22] have examined the possibility of utilizing a RES-hybrid system for a small Greek island by exploring three different case scenarios. The first two scenarios have included system configurations with gradual conventional fossil-fuel power reduction while the third one investigates if a nearly 100% renewable system is feasible. Haghighat et al. [23] have analyzed the application of photovoltaic panels, wind turbines and diesel generators in a standalone hybrid power generation system for rural electrification in three off-grid villages in Colombia with different climatic characteristics. Studying of techno-economical parameters of a hybrid diesel/PV/wind/battery power generation system for a non-residential large electricity consumer in the south of Iran have been carried out by Baneshi and Hadianfard [24]. Another study examines the overall status of wind energy in India's different states with a GIS-based approach [25]. This study represents an analysis of the technical and economic potential of wind power. This study has been surveyed economic scope of wind power development and assessed the viability of wind farms by estimating the production cost. Also, a similar study has been carried out for Africa [26]. Alamdari et al. [27] analyzed statistically measuring wind speed data for year 2007 at 10 m, 30 m and 40 m heights for 68 sites in Iran; The objective was to evaluate the most important characteristics of wind energy in the studied sites. Qolipour et al. [28] conduct a thorough technical–economic evaluation for the construction of small wind turbines in six areas within Ardabil province of Iran and rank these areas by a hybrid approach composed of Data Envelopment Analysis, Balanced Scorecard, and Game Theory methodologies. Rojas-Zerpa and Yusta [29] propose the combined application of two multi-criteria decision-making methods, namely, AHP and VIKOR, to facilitate the selection of the best solution for electrical supply of remote rural locations, involving technical, economic, environmental and social criteria in Venezuela. Review of some other studies are presented in Table 2.

Various types of approaches were applied in order to study the renewables. Linear programming [46], mixed integer nonlinear programming [47,48], Multi criteria decision making [49–52], artificial intelligence [53–55] and engineering economics [56] are the most commonly applied methods of system selection and optimization. On the other hand, HOMER [36,57–59], TRNSYS [60,61], RETScreen [40], WindHyGen [62], WAsP [63], Simulink [34,64], LABVIEW [65], LINGO [66] and MATLAB [1,67,68] are some software used for the evaluation of renewable energy systems.

Statement of the objectives

The aim of this study is to cover the weaknesses of existing studies. Other researches in Iran have been focused on the feasibility studies of one station or eventually one province of the country and did not evaluate Iran's wind energy through a comprehensive view and also they have not studied the effects of wind turbine capacity and wind condition on the feasibility of wind energy. But in this research, it has been tried to investigate the wind energy usage in residential energy sector in Iran by means of gathering the data of anemometer stations in different parts of the country and considering geographical and climate conditions. As a result of this study and according to incentives (like Feed-in tariff), it will be identified the most affordable regions of the country in order to take in priority for investing. Moreover, different manageable variables and indicators like electricity selling price and FIT for developing wind energy have been studied. Finally, according to different uncertainties for financial and economic indicators and natural indicators like wind speed, various sensitivity analysis have been carried out and as a result of these analysis, the minimum feasible capacity for cost-effective use of wind turbines and the minimum suitable average wind speed in different regions have been determined. The minimum suitable average wind speed can be used as a reference for selecting the regions. As well as, the most economic capacity of wind turbine can be considered as an indicator for selecting and developing suitable capacity of wind turbine technology. Finally, the amount of FIT for economic use of wind turbines has been investigated in different regions.

Applied methodology

The annual statistical wind data have been extracted from SUNA (Renewable energy organization of Iran); these data were refined by a program in MATLAB and qualified regions based on accuracy and adequacy of information have been selected. The data of 88 regions were available and sufficient for this study. Using the simulation software, HOMER Energy, analyses of this study was conducted. This modeling tool, developed by the National Renewable Energy Laboratory of the United States, is based on energy balance calculus. Once electrical and thermal loads are specified, the model searches for a combination of generation resources, including RES, in order to supply such loads at a minimum cost [69]. This software evaluates the design options for both off-grid and grid-connected power systems. HOMER's optimization and sensitivity analysis algorithms allow evaluation of the economic and technical feasibility of various technology options and takes into account, change in technology costs and energy resource availability [70]. HOMER evaluates the technical feasibility of a system to examine if it can meet the loads (electrical and thermal). Then, it determines the total net present cost (NPC) of the system as follows [71]