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Assessment of solar and wind energy potentials for three free economic and industrial zones of Iran

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ABSTRACT

This paper aims to evaluate the potential of renewable energy sources of solar and wind in three free economic and industrial zones of Chabahar, Kish and Salafchegan in Iran. Feasibility of harnessing solar energy was investigated by using key solar parameters like monthly mean global, beam and diffuse solar radiation as well as clearness index. It was found that all locations had great potentials for utilizing different solar energy systems. Additionally, the monthly, seasonal, semi-yearly and yearly optimum tilt angles of south-facing solar surfaces were determined. For all zones, adjusting the tilt angle twice a year or in other words, the semi-yearly tilt adjustment for two periods of warm (April–September) and cold (October–March) were highly recommended, since it offers almost the same level of annual solar energy gain (SEG) as those of monthly and seasonal adjustments. Weibull Distribution Function (WDF) was performed for analyzing the wind potentials at different heights. It was found that Chabahar was not suitable for wind energy development, but Kish and Salafchegan with yearly wind powers of 111.28 W/m^2 and 114.34 W/m^2, respectively ranked in class 2 which are considered marginal for wind power development. Three different wind turbine models were proposed for Kish and Salafchegan.

1. Introduction

Due to negative environmental effects of fossil fuel consumption along with significant vagueness about the future of energy supplies, it is expected that renewable energy sources will be utilized intensively in the future. Global consumption of fossil fuel created serious challenges such as global warming, environmental pollution and global climate change during past few decades. On the other hand, fossil fuel price is increasing rapidly too. Governments and researchers attempt to use different renewable energy sources in order to reduce fossil fuel consumption. Iran as well as many other countries has high rate of energy consumption [1]. It is widely recognized that a reasonable and an effective policy toward renewable system can lay the solid foundation for the development of renewable energy in many countries [2]. Modern renewable energy sources like hydropower, wind, solar, geothermal, biofuels and modern biomass provided 8.2% of the world's electricity demand in 2010 [3].

There is also an attempt to limit emission of carbon dioxide to the level of 450 ppm. Harnessing power from renewable energies is one of the most sustainable and cleanest ways for generating electricity as they release no direct emission and harmful gasses such as carbon dioxide. Two major renewable energy sources are solar and wind which could be utilized alone or together to meet electricity demand in many countries. Currently, solar energy systems are widely employed in different applications such as spaces heating and cooling, cooking, and providing hot water. Solar and wind energies have rapid growth across the world in terms of total installed capacity more than other sources. Solar photovoltaic ranked first with total installed capacity of 70 GW, about 74% increase in one year from 2010 to 2011, followed by solar thermal power wind turbines and solar hot water/heating systems [3]. The annual average of global solar radiation for the entire of Iran is about 5.24 kWh/m^2 and even is higher in central parts of the country. A survey shows that average amount of sunshine duration in the whole year is approximately more than 2800 h [4]. In terms of wind energy, studies regarding the wind potential estimation in more than 45 suitable locations showed that Iran's wind potential is at least 6500 MW [5]. It is highly recommended that before any decision for harnessing solar and wind energy, further

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investigations should be conducted based on a more detailed analysis.

Recently, many studies have been conducted related to solar and wind energy resource utilizations in different parts of the world. Besarati et al. [6] investigated the potential of harnessing solar radiation in different areas of Iran, also provided solar radiation maps for five different cases of fixed and tilted surfaces. The most important result of their study showed a great potential of solar energy in central and southern parts of Iran. El Ouderni et al. [7] assessed availability of the global solar radiation in terms of hourly, daily, monthly and seasonal scales for the site of Borj-Cedria in the gulf of Tunis, Tunisia. They also utilized a conventional model to calculate the hourly horizontal solar radiation. By validating the performance of the model with experimental measurements, they showed that the model was in good agreement with the measured data during the clear sky conditions. Gastli and Charabi [8] presented a study on solar power prospects in Oman by generating solar radiation maps using GIS software. Furthermore, they estimated the yearly electricity generation potential for different Concentrated Solar Power (CSP). Their results indicated great solar energy potential and solar electricity generation on most of the lands of Oman during the whole year. Gopinathan et al. [9] estimated the monthly and annual mean global solar radiation at various slopes and orientations for three locations in the Southern African region using the anisotropic model proposed by Hay. They calculated the optimum tilt and azimuth angels for winter, summer and the whole year in order to receive maximum solar radiation on the surfaces. Benghanem [10] performed a study on the optimum slope angle of solar panels to receive maximum solar radiation for city of Madinah in Saudi Arabia. The results showed that yearly optimal tilt angle was around latitude of the location. Moreover, by using annual optimum tilt angle, the surface looses 8% radiation compared with the monthly optimum tilt angle. Kaldellis and Zafirakis [11] performed an experimental study to determine the optimum angle of PV panels during the summer period for Athens in Greece. On the basis of their results, the angle of 15° (±2.5°) was introduced as optimal for almost the entire summer period. Islam et al. [12] determined the characteristics and potential of wind power for Kudat and Labuan located in Malaysia using a 10 m height measured wind speed data. They found highest monthly mean wind speeds were 4.8 m/s and 4.3 m/s at Kudat and Labuan, respectively. Moreover, the maximum wind power densities were 67.40 W/m^2 and 50.81 W/m^2 for Kudat and Labuan, respectively. They concluded that the locations were suitable only for small-scale wind energy applications. Keyhani et al. [13] assessed the potential of wind energy exploitation in Tehran, the capital city of Iran, using long term measured wind speed data at 10 m height. Their results revealed that the annual average wind power densities in different years were between 74.00 and 122.48 W/m^2 and wind energy potential in Tehran was suitable only for applications such as battery charging, and water pumping. Abbes and Belhadj [14] investigated the possibility of constructing a wind farm in the El-Kef region in Tunisia. They analyzed the characteristics of wind speed using Weibull distribution function (WDF) and estimated the capacity factor of 0.26 for different wind turbine configurations. They conducted a technical economic analysis to examine the feasibility of the project. Mohammadi and Mostafaeipour [15] studied possibility of wind energy utilization for Zarrineh city in Kurdistan province based on hourly, monthly, seasonal, and yearly analysis of wind data. Their results illustrated that the site was marginal location for wind energy harnessing. They also assessed the standard deviation and power density method to determine best method for evaluation of wind power, therefore found more precision for using power density method. Akpınar [16] evaluated the potential of wind energy for some coastal locations at the North Eastern of Turkey. The obtained results demonstrated that the monthly mean wind speed in the region varied between 1.53 m/s and 4.06 m/s. Also, the maximum annual mean wind power density and wind energy density were 59.96 W/m^2 and 525.25 kWh/m^2, respectively.

Purpose of this study is to evaluate the potential of solar and wind energy recourses in three free economic and industrial zones of Iran, named Chabahar, Kish and Salafchegan. On this account, the potentials and characteristics of solar energy were analyzed using key solar parameters such as monthly and yearly global solar radiation and clearness index as well as monthly mean daily beam (direct) and diffuse radiation. The optimum tilt angle of the south-facing solar surfaces was determined. Likewise, the potential and characteristics of wind energy were investigated based on hourly, monthly and yearly analysis of the wind data. After assessing the wind energy potential, some appropriate wind turbines were introduced and evaluated in order to be installed in the cities. These three free economic and industrial zones are very important, because most of the merchants are doing their businesses there. Clearly, there is not any custom fee on imported goods like solar equipments and wind turbines. The next Section offers geographical description of three cities. The analysis methodology is presented in Section 3. Results and discussions are brought forward in Section 4. Finally concluding remarks are presented in Section 5.

2. Geographical description

There are eight free economic industrial zones in Iran, but three major free zones of Chabahar, Kish Island, and Salafchegan (Fig. 1) will be discussed in this research work. Salafchegan is located near major industrial zones like Arak, Tehran, and Isfahan. Port of Chabahar is situated in southeastern part which has access to the Oman Sea and Indian Ocean. Kish is a major free zone Island which is located in the Persian Gulf.

2.1. Chabahar port

Port of Chabahar is located in southeastern part of Iran in Sistan-Baluchestan province which is along the Oman Sea and Indian Ocean and also located at 25°20′N (latitude) and 60°37′E (longitude) with elevation of 7 m above the sea level. Its population is 70,710 and is the warmest part of the country in winter and the coldest southern port of the country in the summer. The average temperature and relative humidity throughout the year are 26 °C and 72%, respectively. Also, annual average rainfall is less than 200 mm. Due to strategic location of this port which has nearest road access from the land locked countries of Central Asia (Afghanistan, Turkmenistan, Uzbekistan, Tajikistan, Kyrgyzstan and Kazakhstan) to the free waters, Chabahar is considered to be a major strategic location in Iran [17].

2.2. Kish Island

Kish Island is one of the Persian Gulf islands in the southern part of Iran and also located at 26°30′N (latitude) and 53°59′E (longitude) with highest elevation of 35 m above the sea level. Kish Island with a length of about 15.45 km and a width of about 7.5 km has an area of 90 km^2. The total population of this island is about 20,667, and the average temperature and average relative humidity throughout the year are 26.6 °C and 67%, respectively. Annual average rainfall is 145 mm. It is a major location in recent years due to tourist attraction. Today, due to the economic growths, many investments are done in this zone [18].