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Evaluation of hydrogen production from harvesting wind energy at high altitudes in Iran by three extrapolating Weibull methods

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ABSTRACT

One of the most appropriate ways for energy storage is producing hydrogen from renewable resources. Wind energy is recognized as one of the widely used renewable energy resources. This paper investigates the use of wind energy for producing hydrogen in Iran. To achieve this, the country is divided into five major regions: center, north, south, east and west. The performance of three large-scale commercial wind turbines, ranging from 1500 kW to 3000 kW at hub height of 80 m and four large-scale wind turbine ranging from 2000 kW to 4500 kW at hub height of 120 m are evaluated for producing hydrogen in 150 wind stations in Iran. All wind data were recorded based on 10-min time intervals for more than one year at different wind mast heights. For estimating Weibull parameters, the Standard Deviation Method (SDM), Empirical Method of Lysen (EML) and Power Density Method (PDM) are used. An extrapolation method is used to determine the shape and the scale parameters of the Weibull distribution at the high attitudes of 80 m and 120 m. Then, power law and surface roughness exponents, capacity factor, annual energy production and annual hydrogen production for the wind sites are determined. The results indicate that rated power is not the only determinative parameter and the highest hydrogen production is from the GW-109/2500 wind turbine at the hub height of 80 m and from E112/4500 at the hub height of 120 m. For better assessment, the amount of hydrogen production is depicted in Geographic Information Science (GIS) maps using power production of the seven wind turbine models. Next by analyzing these GIS maps, it is found that there are significant potentials in north, north-west, east and south of Iran for producing hydrogen from wind energy.

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Introduction

Global warming, reduction in fossil fuel supplies and an increasing demand for energy production persuade policy makers to look for renewable energy resources [1–5]. Among different sources of renewable energies wind energy is an attractive one available in different parts of the world [6,7]. Sustainability, ubiquity and zero fuel cost are the advantages of wind energy [8,9]. On contrast, its disadvantages are volatility, low density and high start-up costs [10,11].

Recently, hydrogen production from renewable sources such as wind is considered as an attractive goal to decrease utilization of fossil fuels supplies. By electrolyzing the water, it is possible to produce hydrogen without carbon dioxide or other toxic gases emissions [12–14]. Iran is among the countries suffering from energy crisis and it is essential to find new ways of energy generation [15,16]. By using technology, the energy in wind can be used for practical purposes like electricity generation, hydrogen or ammonia production, battery charging, pumping water and grinding grain [17].

In recent years, lots of research have been performed for evaluating wind power potential of different areas [18–20]. In 2011, Islam et al. [21] calculated wind characteristics and potential for Kudat and Labuan in Malaysia at height of 10 m. Wind Power densities for Labuan and Kudat were 50.81 and 67.40 W/m^2 respectively. It was concluded that this ranges of wind power densities is very low and is only appropriate for battery charging and water pumping. In 2012, Mpholo et al. [22] obtained wind power potential of Masitise and Sani in Lesotho and the average wind power densities were 121.6 and 221.3 W/m^2 respectively. According to PNL classifications these size fall in class 2 and 3 respectively and are appropriate for medium-size wind turbines. In 2013, Diaf et al. [23] studied the potential of 13 regions for wind energy applications in Algeria by using recorded data at height of 10 m. Technical and economic aspects for six different large-size wind turbines installation was studied. The Authors concluded that the Suzlon S82-1500 wind turbine model was an appropriate option for installation. In 2013, Mostafaeipour et al. [24] determined the potential of wind energy in Binalud area after statistical evaluation of four-year data. The results indicated that wind power density was high and suitable for construction of grid connection plant. In 2014, Fazelpour et al. [25] studied the wind energy resource in the city of Ardebil, Iran. The six-year measured data based on 3-h time interval was used at height of 10 m. The results revealed that the monthly variation of mean wind speed is high and the months of October and September had higher wind power densities. However, it was found that Ardebil wind site is inappropriate for grid-connection applications. In 2015, Pishgar-Komleh et al. [26] studied the wind energy resource in Firuzkuh, Iran. They concluded that based on PNL classification, wind power density is nearly 203 W/m^2 and is suitable for installing medium size wind turbines. In 2016, Ozay et al. [27] statistically analyzed wind characteristics in Alaçatı area of Turkey. The data was recorded at heights of 30, 50 and 70 m based on 10-min time intervals for about five years. Wind speed frequency distributions, wind directions, mean wind speeds and parameters of Weibull distribution function were determined.

Many studies have been conducted using Pearson, Johnson, Log-normal, Weibull, Rayleigh and Gaussian distributions and among them Weibull distribution has advantages such as flexibility, accuracy and simplicity [28–30]. Evaluating the available numerical methods to compute more suitable one for determination of Weibull parameters is significant. In 2012, Saleh et al. [31] compared the different methods to estimate Weibull distribution parameters in Zafarana, Egypt. The 10-min data was used to assess the efficiency of mean wind speed method, the maximum likelihood method, the modified maximum likelihood method, graphical method and energy pattern method. It was found that mean wind speed method and maximum likelihood method are the most appropriate methods for computing wind power density. In 2013, Mohammadi et al. [32] compared the results of two well-known methods, empirical method of Justus and energy pattern factor at height of 10 m for determining Weibull parameters in Zarrineh wind station. The results demonstrated that energy pattern factor method is more accurate in this wind site. Furthermore, the Weibull parameters were used for estimating wind speed and wind power potential at height of 30 and 50 m. In 2014, George et al. [33] computed the accuracy of five methods for determining Weibull distribution function parameters. After analyzing the results, it was concluded that maximum likelihood method outperforms other methods at the studied areas for calculating wind speed distribution. At the same year, Petkovic et al. [34] used two different methods for calculating scale and shape parameters of Weibull distribution function. The aim of their investigation was to minimize error band, observed training error and support vector regression. The results revealed that it was possible to predict accuracy and generalize capability by support vector machine method. In 2015, the effectiveness of these six methods for computing shape and scale parameters was determined by Kidmo et al. [35] in Garoua, Nigeria. The results revealed that the energy pattern factor outperforms other methods in terms of representing wind speed distribution. The less accurate method was graphical method for calculating wind speed distribution. Two and three-parameter Weibull distribution were compared with Wais [36] in 2016. The results indicated that in areas with high frequency of low wind speed, three-parameter Weibull distribution had a better accuracy. Jiang et al. [37] compared the numerical methods and metaheuristic optimization algorithms for determining parameters for wind energy potential evaluation in areas with low wind speeds. For this aim, Weibull, Rayleigh, Gamma and Lognormal probability distributions were studied. The results revealed that Weibull distribution function outperforms all of the other distributions with only a slight difference. Besides, the efficacy of empirical method of Justus, Maximum Likelihood method and Least Squares method for estimating scale and shape parameters were evaluated. In 2017, Katinas et al. [38] found that geographical location of the area and height from the ground level influence the amount of power density by using statistical analysis of eight different methods for estimating Weibull parameters. Furthermore, in each wind station the estimation method based on the location feature can be different.

Although there are several works related to evaluating wind power density and estimation methods, lack of research