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Evaluation of wind energy potential in Morocco's coastal regions

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A R T I C L E I N F O

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A B S T R A C T

This paper evaluates the potential of wind energy in six coastal locations in the Kingdom of Morocco, namely Al Hoceima, Tetouane, Assila, Essouira, Laayoune and Dakhla. First, a literature review of recent wind energy potential studies in different locations worldwide has been conducted. Thereafter, the status of wind energy development in Morocco along with its achievements and challenges has been reported. A comprehensive literature review of the mathematical distributions used to fit wind data and procedures employed to estimate the shape and scale parameters of the Weibull distribution is as well presented. The second part of this paper investigated the statistical analysis of wind data based on hourly wind speeds and directions considered for a period of five years between 2011 and 2015. The analysis has shown that the Weibull model independently of the used algorithms for estimation scale and shape parameters, presented an accurate description of the frequencies of actual wind data. By the end, annual energy outputs and capacity factors were derived for wind turbines of various sizes between 225 and 900 kW. The results showed that Dakhla is the most suitable location for harnessing the wind power, while Laayoune has been identified as the second most suitable site. Both Dakhla and Laayoune were found to be suitable for the grid-connected wind energy conversion system while Assila and Essouira have been categorized to be appropriate for the stand-alone wind power applications.

1. Introduction

Combustion of fossil fuels is undoubtedly one of the prime factors contributing to global warming and GHG emissions. In order to reduce reliance on fossil fuels and limit their environmental impact, increasingly governments have taken initiatives to promote and generalize the use of renewable energies [1,2]. Renewable sources, including solar [3], biomass [4], wind [5], and geothermal [6] are developing fast and becoming more economically competitive [7].

The extraction of wind power with modern turbines has become a well established global technique. Wind energy is renewable, sustainable, cost-effective and eco-friendly [8,9]. Moreover, wind energy consumes no water making it more attractive than thermal power plants that necessitate an extensive use of fresh water for cooling, especially in hot or dry regions [10].

For all the preceding reasons, it is believed that wind energy would be the second most widespread source for electricity generation after hydropower [11,12]. As revealed by Fig. 1 [13], a rapid growth of wind installed capacity after 2000 is observed. During 2015, 63,013 MW of wind power was established worldwide, which is 1.8% more than that in the previous year.

The wind turbine constitutes the core of a wind energy plant. It converts the kinetic energy associated with wind into mechanical energy that will be next converted into electrical energy [14]. Recently, various new wind energy conversion technologies have emerged, aiming at reducing cost, improving efficiency and reliability [15]. Knowledge of the behavior of the wind is critically essential for understanding and assessing the performance of wind turbines. Wind speed and frequency depend greatly on the location. Hence, wind farms are only located in certain regions of the world. The statistical characteristics of wind speeds at a given site are required for the evaluation its suitability for the design and management of wind energy plants [16].

This work introduces an in-depth statistical evaluation of wind characteristics and energy potential at six coastal sites in Morocco. Variations of mean wind speeds, Weibull parameters and wind power density are presented. Moreover, the performance of different wind turbines is reported in the considered regions. This preliminary analysis will serve as a decision making model for optimal and cost-effective investment in wind power in Morocco.

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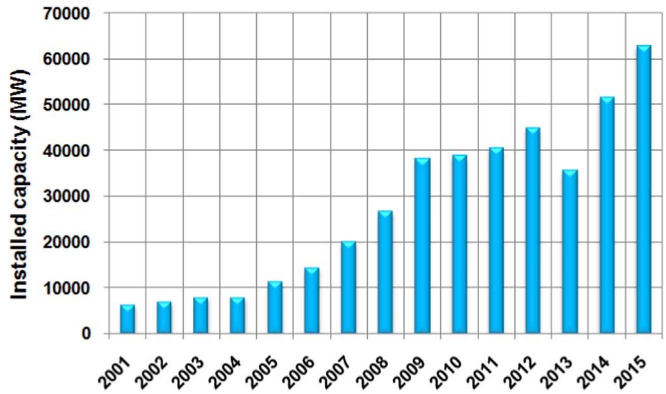

Fig. 1. Global annual installed wind capacity (2000–2015) [13].

The rest of this paper is structured as follows: Section 2 is dedicated to an updated and extensive literature review, including a summary of the most recent wind energy potential studies performed worldwide, a state of the art of the most used distributions in the statistical analysis of wind data. Moreover, Section 2 introduces the present status of wind energy development in Morocco together with its achievements and challenges. As the Weibull analysis is used in the current study, a comprehensive review of methods used to estimate the shape and scale parameters is also presented. Section 3 explains the methodology followed in this study, starting from a brief description of the studied sites, to the statistical methodology used for the analysis of wind data and finalized by a specification of the selected turbines used for the performance evaluation. Section 4 presents the mathematical formulations of the used performance indicators comprising the power density, net capacity factor and energy output generated by the turbines. Finally, Section 5 reports and discusses the obtained results.

2. Literature review

2.1. Recent studies in wind energy potential

To date, many works associated with wind power potential and characteristics have been carried out in several countries around the world. In Iran, Dabbaghiyan et al. [17] studied the wind energy potential for four sites at various heights in Bushehr province using Weibull distribution to assess the wind power density. It was reported that the average wind power density in the studied region is approximately 265 W/m^2 at the height of 40 m.

Ayodele and Ogunjuyigbe [18] presented the wind energy potential of Vesleskarvet (Antarctica) utilizing daily average wind speed measured during a period of 11 years. In their study, the average wind speed and wind power density were 10.9 m/s and 1650 W/m^2, respectively.

Dong et al. [19] conducted a statistical study in Chuuk State (Micronesia) using Weibull and Rayleigh distribution in order to represent the wind speed data during 2013. Their results indicate that a 20 kW turbine was proper for electricity generation producing about 36,841.73 kW h/year.

Belabes et al. [20] conducted a technical and economical potential evaluation in six Algerian cities using Weibull distribution. According to the reported results, Tiaret and Oran showed the most important wind power density with 238 W/m^2 and 171 W/m^2, respectively.

Baseer et al. [21] analyzed the wind potential of an industrial base in Saudi Arabia utilizing hourly wind speed data from 2008 to 2012. The frequent wind speed was 3.5 m/s while the annual average wind power density was found to be 168.46 W/m^2.

Irwanto et al. [22] examined the daily, monthly and yearly wind speed data in order to assess the wind potential at Chuping and Kangar in Perlis (Malaysia), these data were analyzed using Weibull distribution during five years. It was shown that the windy period was from January to April. Moreover, it was shown that Kangar was the suitable location with a wind speed and power density of 2.5 m/s and 19.69 W/m^2, respectively.

Khahro et al. [23] assessed the wind energy potential at Gharo (Sindh, Pakistan) using wind data measured from 2003 to 2007 at 30 m height. The authors estimated the most frequent wind speed as 9.356 m/s and the power density as 260 W/m^2 based on the Weibull distribution.

Hernández-Escobedo et al. [24] studied the wind resources in northern Mexico using daily measures. They concluded that Tamaulipas was the windiest state in September and October with a wind power density of 1000 W/m^2.

Sharma and Ahmed [25] investigated the wind energy capacity of two sites in the Fiji Islands. They reported 3.88 m/s in the island of Kadavu and 6.38 m/s in Suva Peninsula as average wind speed at 34 m height using WAsP software.

Karthikeya et al. [26] analyzed wind data obtained by a LIDAR device during 2 years in 3 sites in Singapore. The results showed that Pandan Gardens was the best site with a maximum wind power density of 45 W/m^2.

Sobchenko and Khomenko [27] presented an assessment of wind resources for seven sites in Ukraine over a period of eleven years in order to identify the site with a poor wind potential (Lviv with a density power of 70 W/m^2) and the site with a good one (Simferopol with a density power of 180 W/m^2).

Al Zohbi et al. [28] compared the wind characteristics of five sites in Lebanon. The maximum value of wind speed was recorded in Daher El Bayder while the minimum one was recorded in Cedars.

Shu et al. [29] evaluated wind speed data that were recorded in five stations in Hong Kong during six years. The highest average wind speed was found at TMS (Tai Mo Shan weather station) with a value of 9.04 m/s while the lower one was at HKO (Hong Kong Observatory station) with a value of 2.55 m/s.

Chandel et al. [30] conducted a statistical study in order to evaluate the wind potential for a location in western Himalayan using 1 min, 10 min, hourly and daily data. The analysis of statistical data indicated that this location can be considered as a fairly windy site. Therefore, the available wind potential can be suitable for some specific applications like water pumping and solar– wind hybrid systems for decentralized power generation.

2.2. Wind energy potential in Morocco

Since the past decade, energy demand has ramped-up very rapidly in the Middle East and North Africa (MENA) region, prompted by economic and population growth, and improved living standards [31]. However, the trend is considered not sustainable in the long term, especially for net energy importing countries. Hence, this zone has become the center of interest of huge investments in sustainable energy projects, principally by virtue of excellent availability and abundance of renewable resources such as solar and wind [32]. In fact, numerous countries across the MENA region have fixed renewable energy targets in order to variegate their energy mix. Morocco is a pioneer among MENA countries in building a regulatory framework for developing renewable energy sources and energy efficiency. Compared to other Arab countries, Morocco's program of installing 42% capacity of renewable energy by 2020 and 52% by 2030 stands out as the most challenging target in the Arab region [33].

This ambitious target was set up by Morocco for several reasons. First, the country presently imports what is more than 96% of its energy. Secondly, according to recent statistics, energy demand in Morocco is rapidly growing and is expected to triple by 2030 [34,35]. This strong dependency on imports (that are mostly fossil fuels) has placed Morocco in a very precarious energy and financial situation and has made it more vulnerable to the effect of global climate change [36].