CHEMICAL ENGINEERING TRANSACTIONS
VOL. 76, 2019

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Petar S. Varbanov, Timothy G. Walmsley, Jiří J. Klemeš, Panos Seferlis

ISBN 978-88-95608-73-0; **ISSN** 2283-9216

DOI: 10.3303/CET1976168

Wind Resource Assessment using Weibull Function for Different Periods of the Day in the Yucatan Peninsula

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One of the most important variables in wind assessment as resource is Wind Power Density (WPD) which is finally the parameter that gives information about the site analyzed. To calculated WPD is strongly recommended to determine the two parameters of Weibull function, shape factor (*k*) and scale factor (*c*) to have a preliminary idea of how the wind resource is on the evaluated site. In this study has been analyzed wind speed as resource with Modern-Era Retrospective analysis for Research and Applications version 2 (MERRA-2) data, these are re-analysis hourly data from 1980-2016 at 50m height, over the Yucatan Peninsula. An algorithm was designed to separate data in four periods of time for an average day (00:00-05:00; 06:00-11:00; 12:00-17:00; 18:00-23:00) in order to obtain a more accurate wind description according to the Weibull function, its parameters *k* and *c*, as well as the prevailing direction on every site. The aim of this study is comparing WPD to energy demand curve in the Yucatan Peninsula, according to the different periods of the day.

1. Introduction

As energy demand increases driven not only by population growth but also by consumption patterns, renewable energies play a more important role in the supply of electric power, thus high quality resource availability estimates are needed since they are the principal requirements for modelling renewable energy generation plants (REGP). One of these resources is wind which constitutes an essential part in renewable sector, with an increasing annual market that reached 487,279 MW over 2016 (GWEC, 2018). In fact, on that year, wind power (onshore and offshore energy systems) accounted for about a quarter (487 GW, of which over 90% consisted of onshore systems) of the total renewable capacity (second place after the hydro-power sector, which totals almost 1,100 GW capacity) and supplied ~16% of renewable power which is 4% of total global electricity production (REN21, 2017), subsequently reaching an overall capacity of 600 GW for wind turbines installed worldwide by the end of 2018, according to preliminary statistics published (WWEA, 2019).

In the case of Mexico in 2017 the total electricity consumption was 260,052 GWh, renewables contributed around 77,907 GWh which represents 30% of electric generation, out of which wind energy contributed with 10,378 GWh (4% of generation) (SIE, 2019) generated by 46 wind farms across the country. In 2015 Mexico reformed its Transition Energetic Law and established a minimum share of clean energy in the generation of electric power of 25% by 2018, 30% by 2021 and 35% by 2024 (LTE, 2015).

Assessing wind resource for electricity generation implies knowledge of its behavior such as the climate or Wind Power Density (WPD) (Ahmed, 2019). In fact, the crucial step in wind assessment is to determine wind resource provided an accurate wind speed modelling (Mazzeo et al., 2018), as can be the probability density function (PDF) that focuses on wind speed distribution parameters which allow to determine Weibull parameters (Gugliani et al., 2018); and is that if wind speed follows the Weibull distribution with scale parameter which has the same units as wind speed (*c*) and dimensionless shape parameter (*k*), load and power density also follow

Paper Received: 16/03/2019; Revised: 20/05/2019; Accepted: 02/06/2019
Please cite this article as: Alcala G., Perea-Moreno A.J., Hernandez-Escobedo Q., 2019, Wind Resource Assessment using Weibull Function for Different Periods of the Day in the Yucatan Peninsula, Chemical Engineering Transactions, 76, 1003-1008 DOI:10.3303/CET1976168

the same distribution with shape parameter $k/2$ and $k/3$ respectively, and scale parameters c^2 and c^3 respectively (Chang, 2013). Thus, given its importance, some studies have used WPD to determine the viability of the wind in a zone; a research assessed the distribution and intensity of onshore wind resources on global, continental and national scales, based on recently released global high resolution climate data to geographically analyze the distribution and intensity of onshore wind resources (assessed using the wind power density parameter) globally, continentally and nationally (Bandoc et al., 2018); in China, there is a study where Weibull distribution function is verified to be a reliable model for wind speed prediction and determine wind power density (Li et al., 2018). An analysis of WPD showed that offshore sites will produce at least 1.7 times more energy than the onshore and nearshore sites when using the same commercial wind turbine (Li and Yu, 2018); in Mexico WPD has been assessed for small urban communities in the Baja California Peninsula and found out that in this territory WPD is above 400 W/m^2 (Hernandez-Escobedo et al., 2016); there are several studies about wind assessment in the Yucatan Peninsula; a study of a ultrasonic anemometers at northern Yucatan were wind energy was calculated (Soler-Bientz, 2011); wind speed patterns have been found in the Yucatan Peninsula (Soler-Bientz et al., 2009) and Figueroa-Espinoza et al. (2014) determined that mesoscale data could be useful for wind assessment.
The aim in this study is to propose a novel methodology to assess wind speed as resource of energy and provide more accurate information about WPD and compare it to the energy demand curve in the zone of Yucatan Peninsula, an average day was separated in four periods of time, Early Morning, Morning, Afternoon and Night (00:00-05:00, 06:00-11:00, 12:00-17:00, 18:00-23:00 h respectively). Several works, as referred, have assessed wind speed, however, there is no information about WPD compared with the energy demand curve.

2. Data and wind power density

Modern-Era Retrospective analysis for Research and Applications version 2 (MERRA- 2) data from NASA were used, this are re-analysis data with hourly records since 1980 until 2016 (MERRA, 2019) and covered the complete Yucatan Peninsula which are composed by the states of Campeche (C), Yucatan (Y) and Quintana Roo (Q). In Figure 1 the states and the position of MERRA locations can be observed.

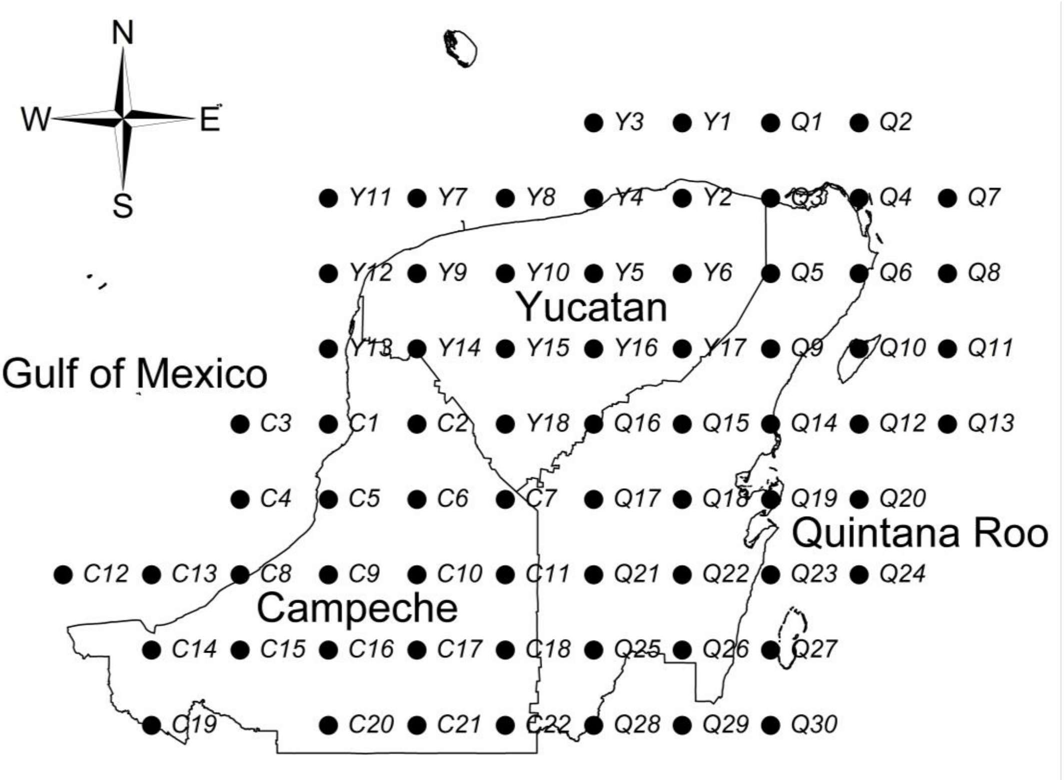

Figure 1: The Yucatan Peninsula and MERRA data. The Campeche, Yucatan and Quintana Roo locations are represented as C, Y and Q respectively.

Weibull distribution has been used in the most of wind assessment because provides information about frequency and distribution of the wind respecting time. It has two parameters, scale factor (c) with the same units as wind speed and shape factor (k) dimensionless (Montgomery et al., 2014). Weibull distribution is given by Eq(1).

$$f(v)=\frac{k}{c}\left(\frac{v}{c}\right)^{k\text{-}1} e^{-\left(\frac{v}{c}\right)^{k}} \tag{1}$$

where $f(v)$ is the probability density function (PDF); v is the wind speed (m/s). To calculate c and k, Eq(2a, 2b) is showed.

$$k=\left(\frac{\sum_{i=1}^{n} v_i^k ln(v_i)}{\sum_{i=1}^{N} v_i^k}-\frac{\sum_{i=1}^{N} ln(v_i)}{n}\right)^{-1},\ c=\left(\frac{1}{n}\sum_{i=1}^{n} v_i^k\right)^{\frac{1}{k}} \tag{2a, 2b}$$

where v_i is the mean wind speed starting in i until n which is the number of nonzero wind speed data.
In wind assessment, WPD is the variable who considers its the kinetic energy and determine the viability of the studied site. The most used equation to obtain WPD is based in Weibull parameters see Eq(3).

$$p(v)=\int_0^{\infty}\frac{P(v)}{A}f(v)dv=\frac{1}{2}\rho c^3\Gamma\left(\frac{k+3}{k}\right) \tag{3}$$

$p(v)$ is the wind power density (W/m^2); A is the rotor area in m^2; $f(v)$ is PDF; ρ is air density at the site; $P(v)$ is the mass flux and Γ is the gamma function and is calculated as follow in Eq(4).

$$\Gamma(x)=\int_0^{\infty} e^{-u}u^{x-1}du \tag{4}$$

2.1 Data processing

Data processing was performed by implementing a self-written code, on the R free software environment and language, which consists on an integrated suite of software facilities for statistical computing and graphical display (R Core Team, 2018).
Energy pattern consumption is determined according to records on energy demand, and are compared to WPD, for the studied locations. In order to do this, an iterative process was run through the 74 sites, which are distributed on a grid shaped arrangement across the Yucatán Peninsula (see Figure 1), using as input data MERRA-2 files. These files contain complete time series of surface pressure (kPa), air temperature (ºC) at 2m and 10m above the ground level, wind speed (m/s) at 50m above ground level and wind direction (º) at 60m above ground level; all these variables have hourly records dating from 1980 to 2016.
An initial pre-processing for data included summer times corrections by assigning the corresponding UTM zone (-6 hours for Mexico), for separating data on 4 periods of time which correspond to Early Morning (00:00-05:00 h), Morning (06:00-11:00 h), Afternoon (12:00-17:00 h) and Night (18:00-23:00 h).
Subsequently, geolocated Weibull parameters were calculated for each period of time via the Weibull PDF and cumulative distribution function (CDF). In addition, for every site location a prevailing wind direction was determined; this is done by grouping data on 30° bins (for a total of 12 sectors), considering the sector with the highest cumulative WPD as the prevailing direction.

3. Results

The Federal Electricity Commission divided Mexico in 7 electric regions and keeps energy consumption records for each one (CENACE, 2009). For the Yucatan Peninsula region, its energy demand curve is presented in Figure 2 as well as the averaged demand of every time period, in this case Afternoon and Night have the highest consumptions rates, which are the time periods to prioritize on energy generation.

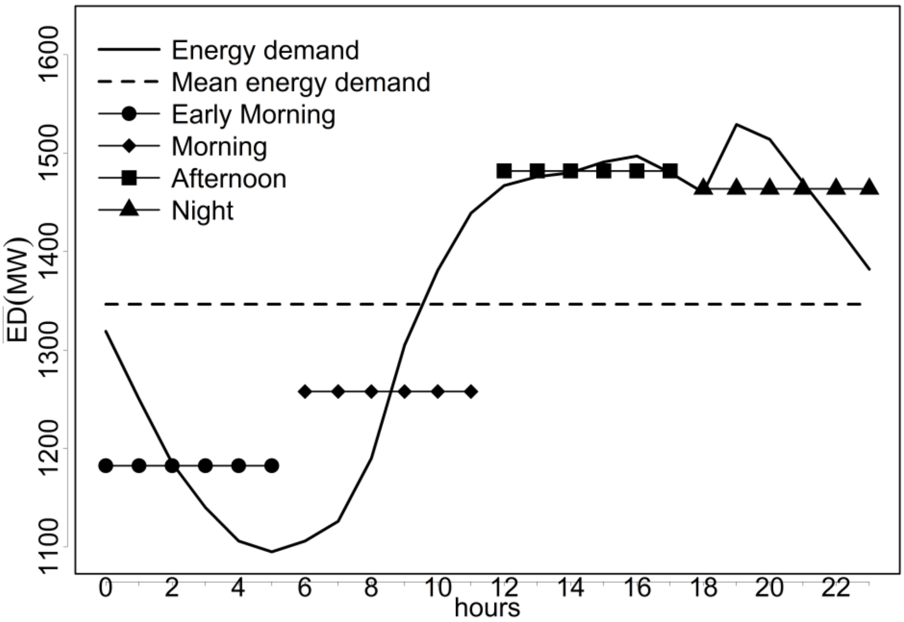

Figure 2: Demand load curve and mean WPD

3.1 WPD and prevailing direction

Wind power density and its prevailing wind direction was calculated for the all Yucatan Peninsula, an average day was separated in four periods of time, a) Early Morning, b) Morning, c) Afternoon and d) Night, see Figure 3.

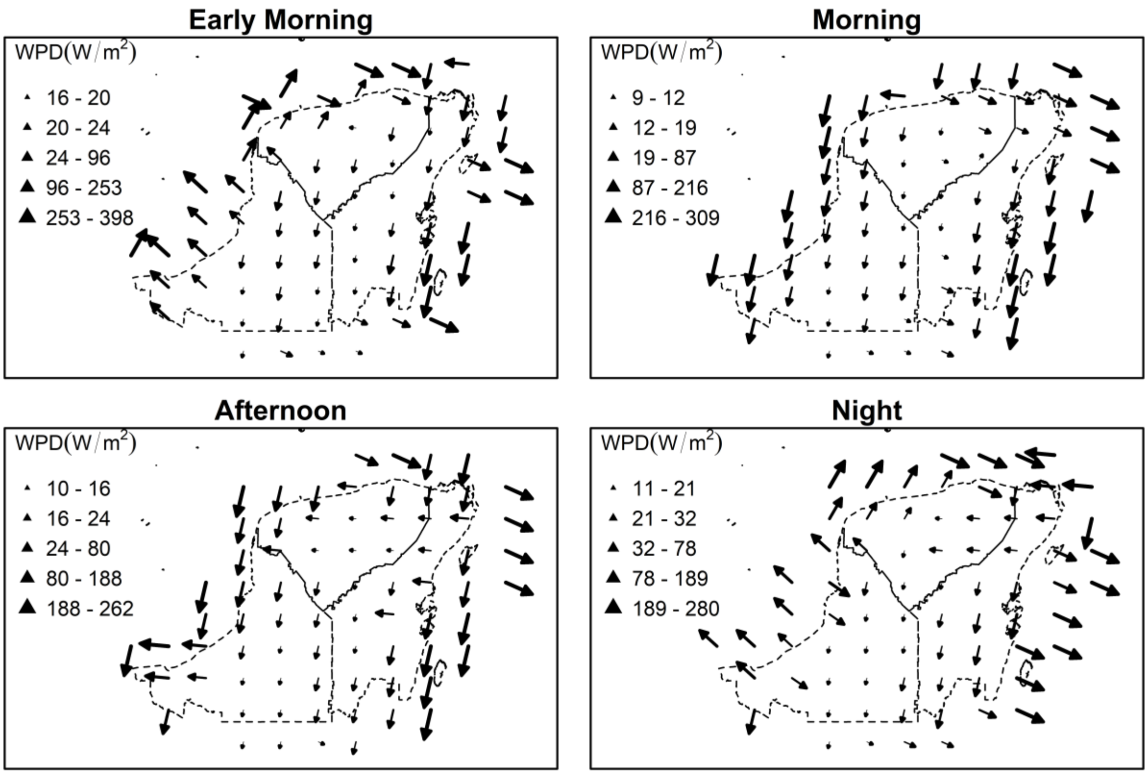

Figure 3: WPD and prevailing wind direction for the Yucatan Peninsula

As result of wind characterization, Figure 3 shows a southeast prevailing direction with values ranging on WPD between 10 – 269 W/m^2 during an average day, presenting the highest values for most of the sites at Early Morning, nevertheless electric demand curve at this time has the lowest energy demand. The locations that present the highest WPD at Night or Afternoon, have in general lower WPD values compared with the other sites with highest WPD at Early Morning or Morning. Furthermore, highest WPD values are for offshore sites, in exception for locations Q19 and Q10 (Cozumel Island).
The scale and shape factors behaviour can be observed on Figures 4 and 5.

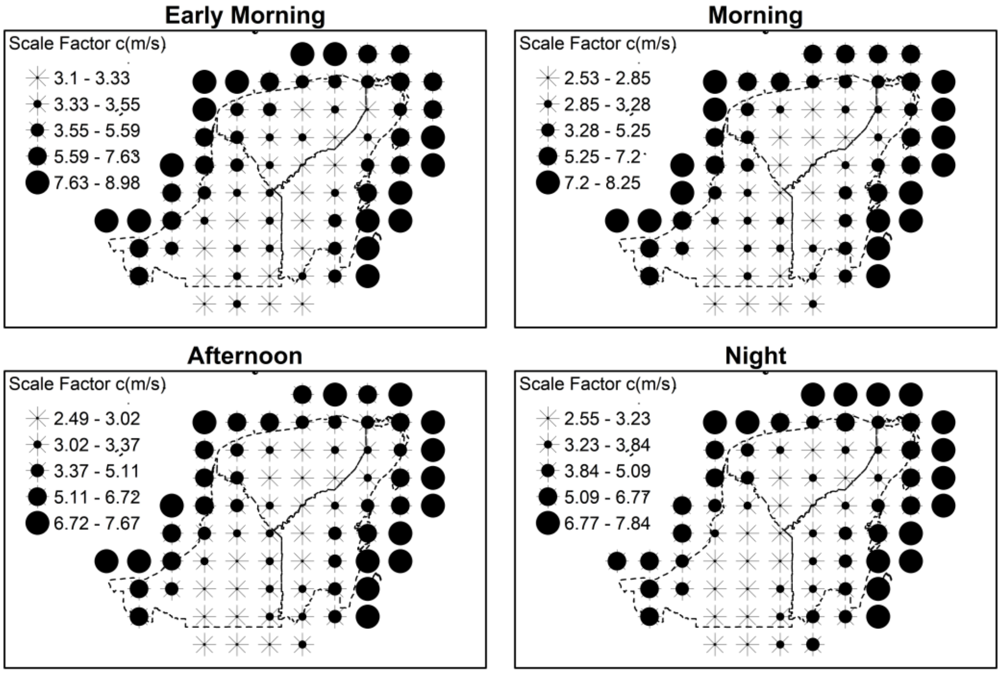

Figure 4: Scale factor for the Yucatan Peninsula

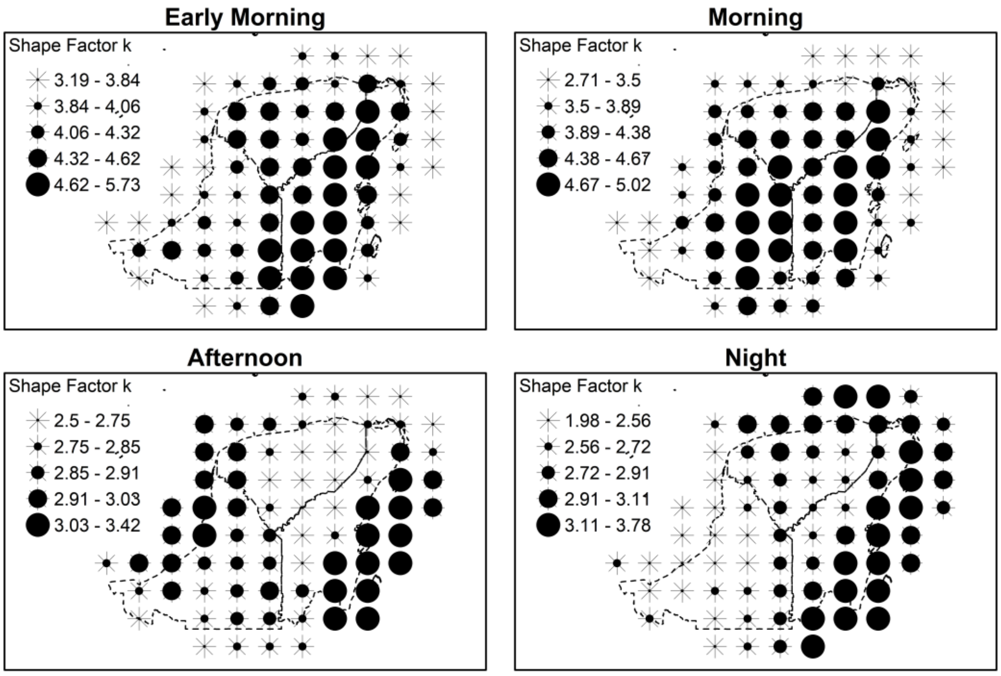

Figure 5: Shape factor for the Yucatan Peninsula

The analysis of *c* can provide information about the prevailing magnitude of wind speed in a particular zone, in fact, Figure 4 shows the highest values of *c* are presented at Early Morning and Night, the states of Campeche and Quintana Roo have more sites onshore with values between 6.72 m/s to 8.98 m/s, however, the sites with most wind speed are offshore. Shape factor, as observed on Figure 5 shows an interesting feature giving a lowest value of k 1.98, at Night, which indicate that wind speed along the Yucatan Peninsula presents a frequency in most of the cases above its mean.

4. Conclusions

The present work has proposed a methodology to assess wind speed and wind direction considering the different periods of time for an average day in accordance to the hourly variable energy demand curve. It was observed that the higher energy demand takes place at the Afternoon and Night, however it was found that WPD has the higher values at Early Morning and Morning. In general, sites with the highest WPD are offshore locations, nevertheless locations with values of WPD of 400 and 139 W/m^2 could be found onshore with suitable characteristics to supply electric power demand on and could be suitable for supplying electric power on priority periods of the day. In situ information was also found for both parameters k and c, which in fact could improve wind assessment to place wind farms. The limitation of this works is the lack of meteorological stations, and re-analysis data has been used. The next step of this work, is to determine power and energy generation.

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