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EVALUATION OF THE WIND POTENTIAL IN UNIÓN HIDALGO, OAXACA FOR THE SIZING OF LOW POWER WIND TURBINES.

EVALUATION OF THE WIND POTENTIAL IN UNIÓN HIDALGO, OAXACA FOR THE SIZING OF LOW POWER WIND TURBINES

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Abstract -- In the Isthmus of Tehuantepec region of the state of Oaxaca there is a large wind resource. However, there are several localities where this resource has not been characterized in detail, which leads to not being able to generalize it for the implementation of wind turbines. Therefore, the objective of this study is to evaluate the wind potential in the municipality of Unión Hidalgo, Oaxaca, and thus to size different models of wind turbines that can supply the electricity demand of a house in the municipality, based mainly on the available power, the usable power and the bimonthly energy consumption. First, the monthly and annual wind speeds at 10 m and 50 m height were analyzed, finding that the highest speeds occur in the months of November, December and January, with winds exceeding 7.82 m/s (10 m height) and 9.81 m/s 50 m height). , the annual average values of power density at 10 m and 50 m were determined using two methods of analysis, the Empirical Justus Method (EMJ) and the Density Method (MDP). Subsequently, a sample of 130 households was made to determine the average bimonthly electricity consumption in the municipality of Unión Hidalgo, which was approximately 282.13 kWh. Based on the results, three wind turbines were proposed, of which AIR 19/100 was determined to be the best candidate for implementation, obtaining that the annual power per hour is equal to 11 269.75 kWh (occupying the values of 50m in height). The above is favorable for both the use of wind potential and the supply of homes in the region.

Keywords: Weibull probability distribution, Shape and scale factor, Power density, Wind energy.

Abstract -- The Isthmus of Tehuantepec region of the state of Oaxaca has a large wind resource. However, there are several localities where this resource has not been characterized in detail, which leads to not being able to generalize if the wind resource of the municipalities that comprise it, if it is of interest for the implementation of wind turbines. Therefore, the objective of this study is to characterize the wind resource in the municipality of Unión Hidalgo, Oaxaca, in order to analyze different models of wind turbines that can supply the electricity demand of a house in the municipality, based mainly on the available power, the usable power and the bimonthly energy consumption. First, the monthly and annual wind speeds at 10 m and 50 m height were studied, finding higher wind speeds in the months of November, December and January, with winds exceeding 7.82 m/s (10 m height) and 9.81 m/s (50 m height). As a second point, the annual average values of power density at 10 m and 50 m were determined using two methods of analysis, the Empirical Justus Method (EMJ) and the Density Method (MDP). Finally, a sample of 130 households was taken to determine the average residential consumption in the municipality of Unión Hidalgo, which was 282.13 kWh (bimonthly), and based on the results, three wind turbines were proposed, of which AIR 19/100 was determined to be the best candidate for implementation, obtaining that the annual power per hour is equal to 11
269.75 kWh (occupying the values of 50m height), which is favorable for both the use of the wind potential and the supply of homes in the region....

Key words - Weibull Probability, Distribution, Shape and scale, Potential density, Wind power.

INTRODUCTION

The world's energy demand is increasing every day due to population growth and industrialization. The worrying thing is that most of the energy is obtained from fossil fuels, which are non-renewable resources and are also considered to be the cause of environmental problems, such as global warming [1]. In order to contribute to the solution of this problem, in the last decades renewable energies have been of great importance as efficient and environmentally friendly alternatives for energy production [2].

Among the different types of renewable energy, wind energy has become popular in recent years worldwide [3]. In 2022, of the renewable energy produced in Mexico, 2.4% was obtained from wind energy [4] highlighting that the state of Oaxaca produces more than 55.8% of the national wind energy [5]. Especially, in the Isthmus of Tehuantepec region of the state of Oaxaca, which due to its geographic particularities presents wind gusts above 10 m/s [6]. In the world

6.5 m/s winds for energy generation [7], so that the use of this resource
wind power could generate conditions sufficient for combat the needs energy and problems
environmental issues of today [8].

To date, there are several studies on the characterization of the wind resource of the Isthmus region.
of Tehuantepec, highlighting the research of Jaramillo & Borja in 2004 [9] who conducted an analysis of wind in the region of La Ventosa. In another study, Barrera [10] presented the study of wind energy in the Isthmus of Tehuantepec with two study areas: La Ventosa and San Dionisio del Mar. Likewise, Cadenas and Rivera [11] presented the wind speed forecast in the southern coast of Oaxaca, Mexico, focusing on the aforementioned municipalities.

Despite the studies conducted, there are municipalities in the Isthmus of Tehuantepec region that do not have detailed wind assessments, such as Unión Hidalgo,
which currently has only a preliminary study by Dorrego et al [12]. ,
the purpose of this study is to characterize the wind resource in the municipality of Unión Hidalgo and of
According to the available and usable wind resource, analyze different models of wind turbines that can supply the demand for electricity in a given area.
housing in the municipality.

DEVELOPMENT

Study site

Unión Hidalgo is a municipality in the state of Oaxaca located in the Isthmus of Tehuantepec region, at the coordinates 94° 50' west longitude and 16° 29' north latitude, at an altitude of 20 m above sea level. Union Hidalgo borders the municipalities of Juchitán de Zaragoza, Santo Domingo Ingenio, Laguna Superior, Niltepec and San Dionisio del Mar [13].

Data collection

NASA data [14], at latitude and longitude 16.449256°, -94.850121° respectively, were used to evaluate the wind resource of Unión Hidalgo. The data
The data obtained were at an altitude of 10, 50, 100 and 200 m, with a data collection period of 2010-2021.
For this case, only data at two heights, 10 m and 50 m, were studied, since the height of the bushing does not exceed these measurements in its estimation; although for different studies, data at 100 m and 200 m can be taken, which are obtained from the same database.

Statistical analysis of data

The average velocity (v_{prom}), standard deviation (σ) and turbulence intensity (I_t) were obtained by the following equations, respectively:

$$v_{prom}=\frac{1}{N}\sum_{i=1}^{N} v_i \qquad \text{Eq. (1)}$$

$$\sigma=\sqrt{\frac{1}{N}\sum_{i=1}^{N}(v_i-v_{average})^2} \qquad \text{Eq. (2)}$$

$$I_t=\frac{\sigma}{v_{Prom}} \qquad \text{Eq. (3)}$$

Where v_i represents the sum of the pooled data.

Weibull distribution function

For this study, the Weibull probability function was used, which is a distribution function, characterized by the shape and scale factor. The former defines the dispersion of the distribution and the latter the shape of the distribution [15]. The Weibull density is represented by the following equation:

$$f(v)=\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^{k}\right] \qquad \text{Eq. (4)}$$

and the cumulative distribution function is:

$$F(v)= 1-exp\left[-\left(\frac{v}{c}\right)^{k}\right] \qquad \text{Eq. (5)}$$

Where v represents the wind speed in (m/s), c is the scale factor with units of (m/s) and k is the shape factor, the same dimensionless. The estimation of c and k was performed using the following methods:

Empirical Justus Method (EMJ)

The parameters of c and k can be calculated Eq. (6) and (7), respectively [16].

$$k=\left(\frac{\sigma}{v_{prom}}\right)^{-1.086} \quad \text{Eq. (6)}$$

$$c=\frac{v_{prom}}{\Gamma\left(1+\frac{1}{k}\right)} \quad \text{Eq. (7)}$$

Where Γ represents the gamma function.

Method 2. Power density method (MDP)
The parameters k and c can be calculated by Eq. (8), (9) and (10), respectively [17][18].

$$k=1+\left(\frac{3.69}{F_{e}^{2}}\right) \quad \text{Eq. (8)}$$

$$F_e=\frac{\frac{1}{n}\sum_{i=1}^{n} v_1^3}{v_{prom}^3} \quad \text{Eq. (9)}$$

$$c=\left(\frac{1}{n}\sum_{i=1}^{n} v_{l}^{k}\right)^{\frac{1}{k}} \quad \text{Eq. (10)}$$

Where: Fe energy pattern factor, v_1 is the wind speed at time 1.
To estimate the cumulative frequency of velocities that are greater than or equal to a certain value V, the cumulative distribution F' [19] was used.

$$F'(v\geq V)= 1 - F\,(v\leq V)= e^{-\left(\frac{v}{c}\right)^{k}} = Pr \quad \text{Eq. (11)}$$

Extrapolation of wind speed and Weibull parameters at different heights.
Most of the time, the measured wind speed distributions are made at a height different from the height of the wind turbine nacelle. In this situation, the wind speeds and the parameters of the wind turbine nacelle are
Weibull's are generally extrapolated to the height of the wind turbine hub, this extrapolation is performed by means of the power law expression [20] [21].

$$v=v_0\left(\frac{z}{z_0}\right)^{a} \quad \text{Eq. (12)}$$

Where v is the wind speed at the desired height z, v_0 is the wind speed at the reference height $z0$ and is the power law exponent (coefficient) is defined by the following equation.

$$\alpha=\frac{0.37-0.088\ln(v_0)}{1-0.088\ln\left(\frac{z_0}{10}\right)} \quad \text{Eq. (13)}$$

The Weibull parameters k_z and c_z at the desired height z are related to k_0 and c_0 measured at a height of 50 m and are given by the following equations:

$$k_z=\frac{k_0\left(1-0.088\ln\left(\frac{z_0}{10}\right)\right)}{1-0.088\ln\frac{z}{10}} \quad \text{Eq. (14)}$$

$$C_z=C_0\left(\frac{z}{z_0}\right)^{\alpha} \quad \text{Eq. (15)}$$

Wind direction estimation
For this study, annual and monthly wind directions were used, obtained from NASA database [22], from which data for 12 years (2010- 2021) were extracted and interpreted by means of a wind rose.

Estimated wind power output
The wind power ($p(v)$) was calculated directly from the wind speed using the following equation [23].

$$p(v)=\frac{1}{2}\rho A v^3 \quad \text{Eq. (16)}$$

And the wind energy per unit area is given by:

$$P=\frac{p(v)}{A}\,f(v)=\frac{1}{2}\rho v^3\,\frac{1}{2}\rho A v^3 \quad \text{Eq. (17)}$$

By integrating Eq. (18) over a period of time the average wind power density is given by the following expression:

$$P=\frac{1}{2}\rho\int_0^{\infty} v^3 f(v)\,dv=\frac{1}{2}\rho c^3\,\Gamma\left(1+\frac{3}{k}\right) \quad \text{Eq. (18)}$$

k and c, which were determined by the regression functions, were introduced in the power expression to calculate the wind energy density (Eq. (18)), which is a productivity indicator to predict wind energy.
The wind energy density is expressed as:

$$E=\frac{1}{2}\rho c^3\left(1+\frac{3}{k}\right)\Delta_t \quad \text{Eq. (19)}$$

Where Δ_t is the time period.

Wind turbine productivity evaluation
The wind turbine productivity evaluation is carried out by
is measured using the capacity factor C_f and is expressed by Equation 20. The above when the wind turbine is operating at 100% of its rated power [24].

$$C_f=\frac{P_{OUT}}{P_r} \quad \text{Eq. (20)}$$

P_{OUT}, is defined by the turbine power curve and varies according to wind conditions [25] and Pr the rated power.
The energy extracted from the wind turbine, E_{OUT} is calculated based on the power output which varies depending on the
wind speeds v_i and is calculated using the following equation [26]:

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$$E_{OUT}=\sum_{i=1}^{n} P_{OUT}(v)_i \Delta_t \quad \text{Eq. (21)}$$

Calculation of the energy consumption of a residential house

The calculation of the sample to determine the energy requirement of a house in the population of Unión Hidalgo was based on data from INEGI in the last population and housing census of 2020 [13]. This census mentions that the municipality of Unión Hidalgo has 4,266 dwellings. Knowing this data, the sample was calculated using the following equations [27].

$$n=\frac{N*Z^2*S}{e^2(N-1)+Z*S} \quad \text{Eq. (22)}$$

$$S^2=\sum\frac{(X-\bar{X})^2}{N} \quad \text{Eq. (23)}$$

Where:

n is the sample size, *N* the population size, *Z* the critical *Z* value, *S* the variance of the population under study, *e* the absolute precision level or margin of error referring to the width of the desired confidence interval in the determination of the mean value of the variable under study.

DISCUSSION AND ANALYSIS OF RESULTS

Wind speed analysis

Annual Vprom at altitudes of 10 m and 50 m

The annual distributions of wind speed in Unión Hidalgo are represented in **Figure 1.** These data correspond to the heights of 10 m and 50 with one analysis per year.

It is estimated that the annual V_{prom} in Unión Hidalgo at 10 m altitude is 5.76 m/s, observing that there is an important variation in the years 2014, 2015 and 2016 **(Figure 1a)**, since the V_{prom} exceeded 6 m/s and in the following year (2017), the velocity decreased to 5.57 m/s, remaining in that margin in the remaining years.

For the particular case of a height of 50 m, the velocity increased considerably with respect to lower heights, obtaining the behavior shown in **Figure 1b**. Similarity is observed in the annual variations with respect to the 10 m analysis height. Estimating that the annual V_{prom} in Unión Hidalgo is 7.39 m/s at a height of 50 m.

These results are similar to research carried out in other states of the country, where Hernández-Escobedo et al [28] reported wind speeds of 5.45 m/s at an altitude of 50 m; however, in Union Hidalgo similar velocities were recorded at 10 m, i.e. a lower altitude.

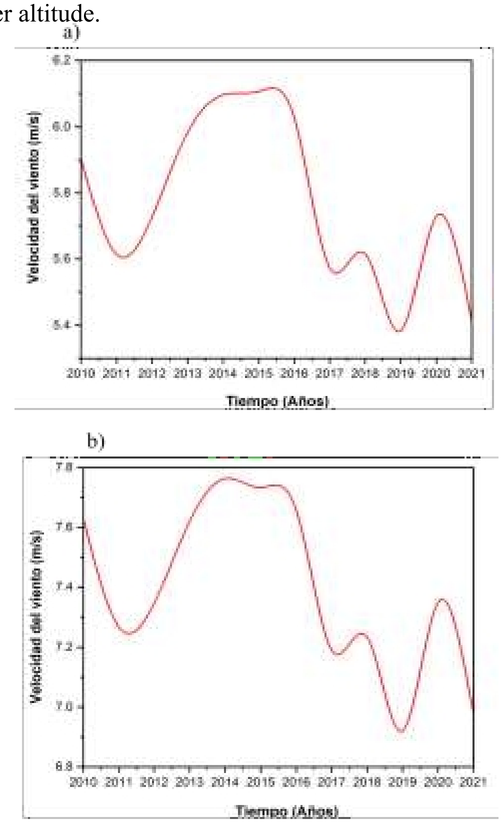


Figure 1. Annual V_{prom} at heights of a) 10 m and b) 50 m.

Monthly V_{prom} at heights of 10 m and 50 m.

The monthly wind speed distributions are plotted **in Figure 2.**

It is observed that for heights of 10 m the highest speeds in each year are found in the months of January, November and December with values of 7.82 m/s, 7.54 m/s and 7.19 m/s, respectively. It is also observed that the lowest wind speed values occur in the months of June, September and August with wind gusts of 3.89 m/s, 3.90 m/s and 4.16 m/s, respectively **(Figure 2a).**

In the case of the 50 m height, the distributions of higher and lower monthly velocities are concentrated in the same months as the 10 m height (**Figure 2b**) where the highest average velocities are 9.81 m/s, 9.69 m/s and 9.19 m/s, respectively, and in the opposite case, the lowest wind speeds are 5.16 m/s, 5.31 m/s and 5.64 m/s, respectively.

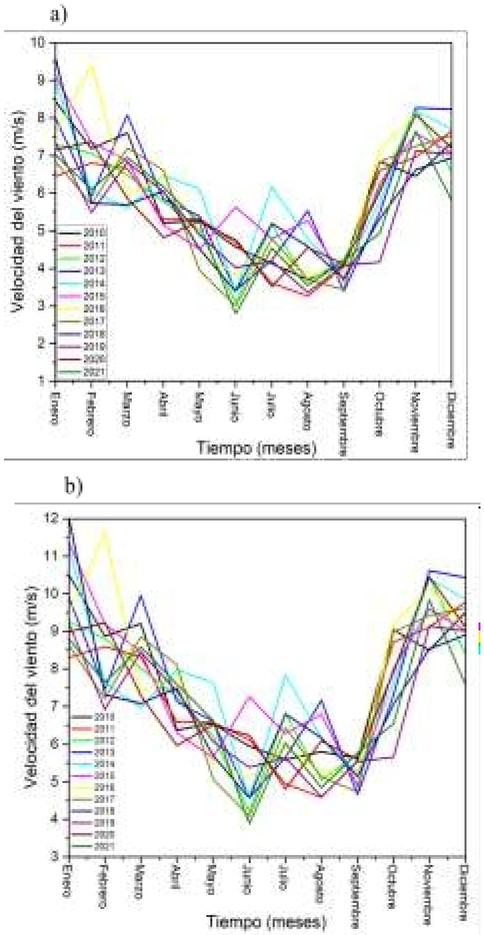


Figure 2. Monthly v_{prom} for each year of study.
a) height of 10 m and b) height of 50 m.

Wind data settings
The *k* and *c* adjustments are shown in **Table 1,** where it is observed that for each method the factors do not vary considerably, since, for *k* at 10 m and 50 m, the percentage of variation is only 11.72% and 4.05%, with respect to the MDP and EMJ method.
For the specific case of *c* at 10 m and 50 m, the percentage variation is only 0.78% and 0.24% with respect to the EMJ and MDP methods. The above shows that there no significant variation in each analysis method and the same behavior is predicted when integrating the calculation adjustment for the power densities.

Table 1. Calculations k and c using the empirical Justus method (EMJ) and power density method (MDP).

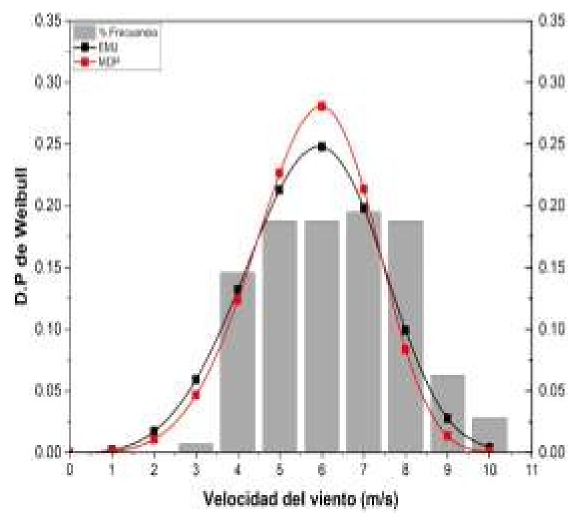
Site	Method	*k*	*c*
Unión Hidalgo (10 m)	EMJ MDP	4.14 4.69	6.35 6.30
Unión Hidalgo (50 m)	EMJ MDP	4.50 4.69	8.09 8.07

Wind power density
The wind power density at 10 m and 50 m are presented in **Table 2**, where the power densities do not vary significantly, finding that, at a height of 10 m, the method (EMJ) varies only 5.31 W/m^2 with respect to the method (MDP) and in the case of the study at 50 m height, the behavior is the same with a variation of 3.41 W/m(2).
These results confirm the wind potential of the municipality of Unión Hidalgo, since the power density at the heights studied is relatively higher than that reported by Fajardo-Díaz et al. [29], who carried out a study similar to the one in this research in the state of Zacatecas, obtaining a power density of 49.35 W/m^2 for an average annual wind speed of 4.6 m/s.

Table 2. Power density obtained from the methods determined for evaluation.

Site	Method	Power density (W/m²)
Unión Hidalgo (10 m)	EMJ MDP	142.94 137.63
Unión Hidalgo (50 m)	EMJ MDP	293.13 289.72

Probability trend Weibull distribution
The wind frequency over a given speed range is shown in **Figure 3.**



Weibull probability distribution, for different velocity ranges, compared to the percentage of frequency obtained (analysis at 10 m height).

It is observed that the probabilistic frequency at 10 meters height is concentrated in 25% in the speed range of 6.0 to 6.9 m/s for the case of the method

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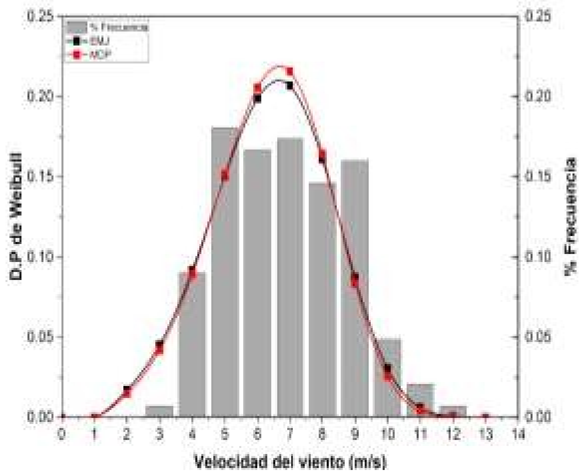
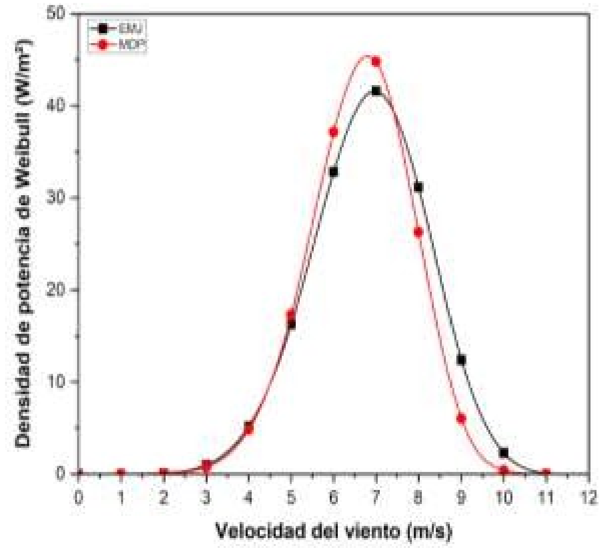
(EMJ); and for the (MDP) method the concentration remains at 28% in the same velocity range, being the highest value in the distribution.
In the case of the second study height (50 m) (**Figure 4**) the primary concentration is in the range of 8.0 to 8.9 m/s, with 21% concentration for the (EMJ) method and 22% for the (MDP) method.
As the results showed, the maximum concentrations obtained are between 20 and 30%, which are higher than those reported in other investigations carried out in Mexico, where maximum concentrations of 14% were found for velocities of 5 m/s [30]. The above once again demonstrates that the wind potential of the municipality of Unión Hidalgo and the Isthmus of Tehuantepec region in general.



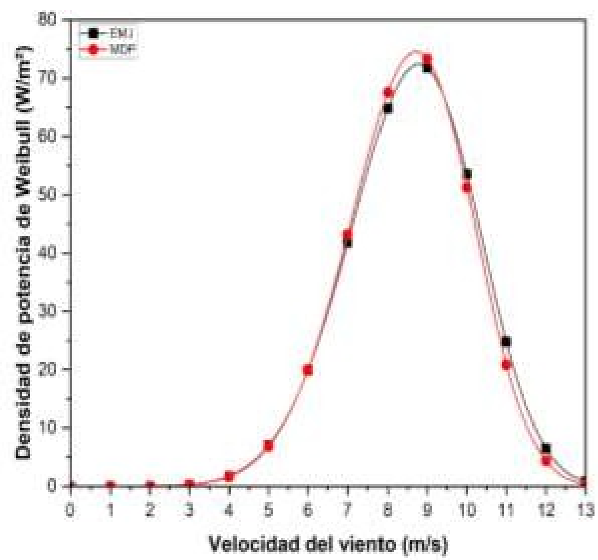
Weibull probability distribution, for different velocity ranges, compared to the percentage of frequency obtained (analysis at 50 m height).

Weibull power density
In this study the first analysis was carried out at 10 m height, obtaining that at speeds between 7.0 and 7.9 the power density is 41.60 W/m² (EMJ) and 44.80 W/m² (MDP), being the highest values in the trend **(Figure 5).**
These higher densities can be obtained in the months of November, December and January, as wind speeds are within the established range.
Based on these results, it is known that the average power density is 143.23 W/m² and for the particular case of the analysis methods (EMJ and MDP) the results shown in **Table 1** were obtained. For the empirical method of Justus (EMJ) a higher power density is obtained and it is much closer to the average power density.



Weibull power density, for different velocity ranges, (analysis at 10 m height).

For the second analysis (**Figure 6**) at a height of 50 m, it was found that at speeds between 9.0 and 9.9 m/s the highest power density can be obtained with values of 71.80 W/m² and 73.33 W/m² for the empirical Justus method (EMJ) and the power density method (MDP), respectively. These higher densities can occur in November, December and January since only in these months wind speeds are in this range.



Weibull power density, for different velocity ranges, (analysis at 50 m height).

Based on the analysis performed, the average density was also 294.01 W/m² and for the case of

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The following results were obtained from the particular analysis methods **Table 2.**
Noting that for the empirical method of Justus (EMJ) a higher power density is obtained and it is much closer to the average power density.

Wind rose diagrams
The graphs represented in **Figures 7** and **8** correspond to the wind directions at two different heights of analysis at 10 m and 50 m, respectively. The winds behave unidirectionally to the northeast, regardless of the variation of speeds at different heights, as well as the representation of the monthly directions are maintained in this same behavior, indicating that their direction is concentrated in the northeast.

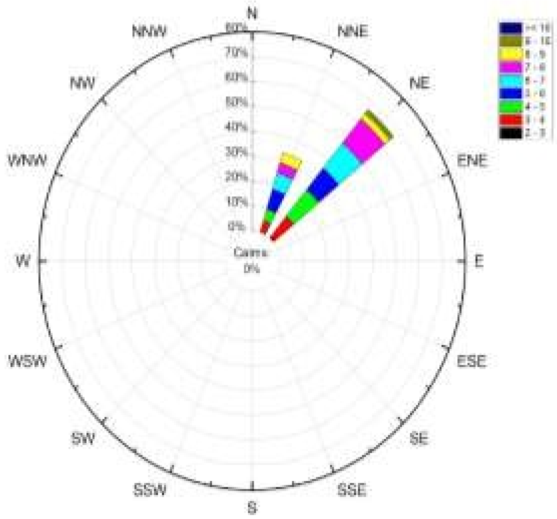

Figure 7. Wind rose, under the analysis at 10 m height.

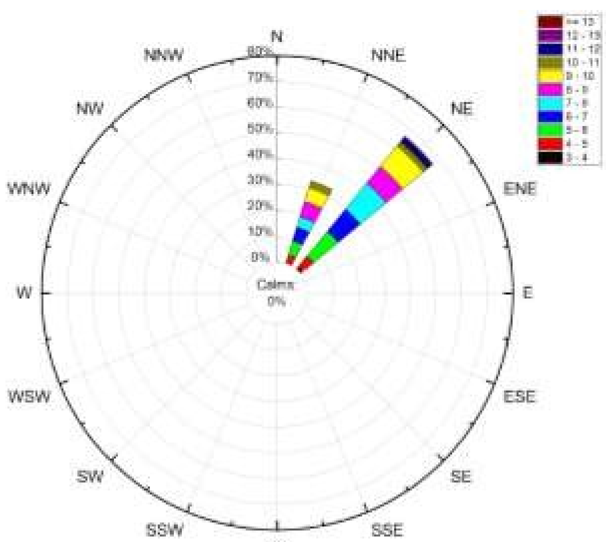

Figure 8. Wind rose, under the analysis at 50 m height.

Average energy consumption in the study area
In this case, for the study of the average energy consumption in the area, a sample of 130 households was taken in the municipality of Unión Hidalgo, Oaxaca, in which a year of consumption was recorded in the periods September-November 2020 and July-September 2021, this on a bimonthly basis, finding the behavior illustrated in **Figure 9.** It is observed that the average electricity consumption per bimonthly does not exceed 300.81 kWh, this being the highest average annual consumption. Based on this estimation, it was obtained that the average bimonthly consumption in homes in this locality is of 282.13 kWh and in terms of annual consumption, a household consumes 1692.78 kW/h.

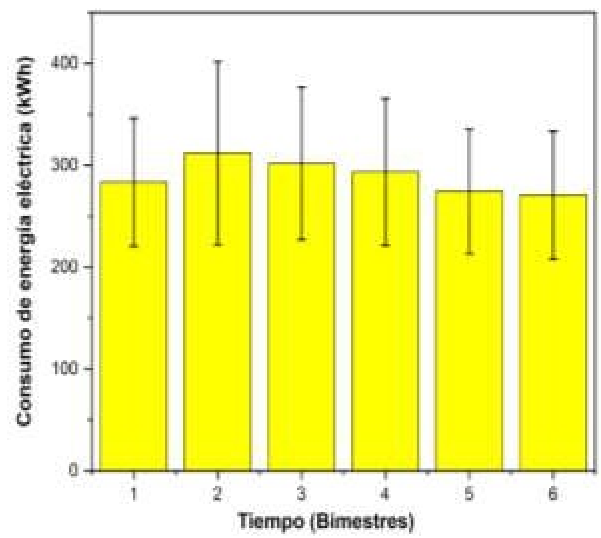

Figure 9. Electricity consumption (kWh) per two-month period in the municipality of Unión Hidalgo.

Power characteristics of selected wind turbines.
For the selection of wind turbines, we compared different data sheets, verifying the power output with the power consumption, as well as comparing the start-up speed and the cut-off speed, in order to select a wind turbine that would satisfy the energy consumption of a house in the region of Unión Hidalgo.
Table 3 shows the characteristics of three selected wind turbine models [27,31,32], these wind turbines are of low power with nominal power of 100 kW and heights from 10 m to 50 m from the hub. Mainly considering the wind characteristics of Unión Hidalgo, for the selection, such as the V_{prom} which is above 5.76 m/s and which is of great importance to know the starting speeds to be considered. These wind turbines were proposed due to their starting speed, which is between 3.5 m/s and 4.5 m/s, as well as their nominal power, which is 100 kW.
The estimated power output for each model of wind turbine is given in **Figure 10**, obtaining that the

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power output in each of the wind turbines is: ADES ADES 100 $_{Pout}$= 1325 kWh, ACSA 120/100 $_{Pout}$= 1525 kWh, and for the AIR 19/100 $_{Pout}$ turbine= 1525 kWh.

Table 3. Selected wind turbines with their technical specifications at hub heights between 10 and 50 m.

Wind turbine	ACSA A20/100	AIR 19/100	ADES ADES 100
Hub height (m)	24	25/45	27.5
Rated power (kW)	100	100	100
Rotor diameter (m)	20	19	29
Nominal speed (m/s)	13	14	10
Speed of start-up (m/s)	4.5	3.5	3.5
Cutting (m/s)	24	24	20

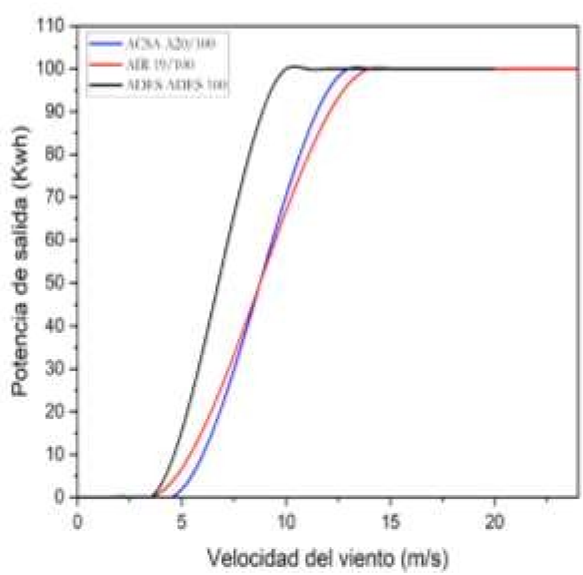

Figure 10. Power output of each turbine studied.

As presented in Table 4, in terms of capacity , the ACSA 120/100 and AIR 19/100 wind turbine have a higher efficiency, having a more cost-effective approach as opposed to the ADES ADES 100 turbine.

Available and usable power provided by each wind turbine.

	ADES ADES 100	ACSA 120/100	AIR 19/100
Cf	13.25	15.25	15.25
Output E (kWh)	9791.7	11269.75	11269.75

Based on the usable output power, it was decided to study the annual output power of the AIR 19/100 wind turbine because the theoretical power of the wind turbine is higher. For this purpose, only the data at a height of 50 m were used, obtaining that the annual power per hour is equal to 11 269.75 kWh.

CONCLUSIONS

In this study, the wind characteristics of Unión Hidalgo Oaxaca were evaluated, as well as the determination of a wind turbine based on the usable power of the area and the average energy consumption, concluding the following:

- The average velocities in the region at 10 m and 50 m altitude were 5.76 m/s and 7.39 m/s, respectively, with the highest velocities concentrated in the months of January, November and December.
- In the case of the adjustments of the shape factor and scale parameters, in the Weibull distribution, the MDP and EMJ methods do not vary considerably, since, for *k* at 10 m and 50 m, the percentage of variation is only 11.72% and 4.05%, with respect to the MDP and EMJ methods.
- The power densities for 10 m with the MDP and EMJ method were 142.94 W/m^2 and 137.63 W/m^2 respectively. At 50 m with the MDP and EMJ methods the power densities were 293.13 W/m^2 and 289.72 W/m^2, respectively.
- Wind behavior based on wind direction behaves unidirectionally to the northeast, regardless of height variability.
- The annual energy consumption of a household based on the sample is 1692.78 kWh.
- Based on the comparison of the three turbines, AIR 19/100 is the one that showed the best adaptability to the wind power output and based on the annual consumption of households in the region, obtaining that the annual power per hour is equal to 11 269.75 kWh.
- Future research should be directed towards the development of low power turbines capable of harnessing wind energy generated at heights of less than 50 meters.

- Further research is needed for the development of batteries with higher capacity and storage efficiency of electrical energy generated by low-power wind turbines.

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