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Direct Measurements of Wind Data over 100 Meters above the Ground in the Site of Lendinara, Italy

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***Abstract*—**The wind resource in the Italian site of Lendinara (RO) is analyzed through a systematic anemometric campaign performed on the top of the bell tower, at an altitude of over 100 m above the ground. Both the average wind speed and the Weibull distribution are computed. The resulting average wind velocity is in accordance with the numerical predictions of the Italian Wind Atlas, confirming the accuracy of the extrapolation of wind data adopted for the evaluation of wind potential at higher altitudes with respect to the commonly placed measurement stations.

***Keywords*—**Anemometric campaign, wind resource, Weibull distribution, wind atlas

I. Introduction And Background

ACCORDING to the European Wind Energy Association 2010 annual report [1], Italy is the third country in Europe for installed wind power, with a total capacity of 5797 MW. The higher portion of Italian wind energy is generated in the southern regions (including Sicily and Sardinia), being northern territories characterized by a quite poor wind resource.

Wind potential studies are generally subdivided into both regional-scale and local-scale [2]. Among the regional-scale analyses, concerning the evaluation of wind potential on spatial scales of the order of 100 km^2, the Italian Wind Atlas, which was developed in the framework of the “Ricerca di Sistema” project in cooperation with CESI [3], can be cited. Among the local-scale studies, several authors have investigated the wind potential of candidate locations for the installation of wind turbines.

Lo Brano et al. [4] investigated the wind speed characteristics in the urban area of Palermo, Sicily (Italy). A numerical procedure was developed, in order to perform a preliminary statistical analysis of the wind resource of the analyzed site. Castellani et al. [5] characterized the wind distribution of the whole region of Umbria (Italy) using a numerical model combined with a collection of field data resulting from an orographic analysis.

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After choosing the best wind prediction model, several numerical simulations were performed, in order to elaborate a Regional Energy Plan.

As far as the analytical representation of wind speed distributions is concerned, Lavagnini et al. [6] adopted a Weibull function to represent the wind speed frequency distribution in 48 Italian sites, also comparing two different methods for calculating the wind distribution parameters. Successively, Fisauli et al. [7] adopted the wind speed frequency distribution of those 48 analyzed sites to calculate the yearly electric energy that could be obtained from the wind resource by two different types of wind turbine generators; the proposed correlation between the available energy and the annual mean wind speed was exploited to estimate the available energy for other 94 sites, based only on the mean wind speed data.

Lavagnini et al. [8] established a wind map of Italy starting from the anemometric data obtained for the already cited 48 anemometric stations. The most promising locations for wind energy production were thus identified, also performing some statistical analysis of the wind resource of the considered geographical locations.

Chiodo et al. [9] analyzed the problem of an efficient estimation of wind probabilistic distribution for the quantitative evaluation of wind power generation statistics. For this purpose, the generally adopted Weibull distribution was examined and compared with the Log logistic model.

As can be clearly inferred from the above mentioned examples, wind maps are usually obtained using anemometers located at moderate heights above the ground and further extrapolated to the desired altitude by means of mathematical procedures, comprising both numerical methods (Computational Fluid Dynamics) and the commonly used logarithmic law. In this work, wind data deriving from a one-year anemometric campaign, conducted on the top of the tower bell of Lendinara (Rovigo, Italy), are presented using the Weibull statistical distribution, obtaining a statistical analysis of real wind data collected by an anemometer located over 100 meters above the ground.

II. Materials and Methods

As can be seen from Fig. 1, Lendinara is a small village near Rovigo, in the north-east of Italy. This site was selected for the proposed anemometric campaign due to the presence of a bell tower which, with its over 100 meters height, represents the forth architecture of this kind in Italy.

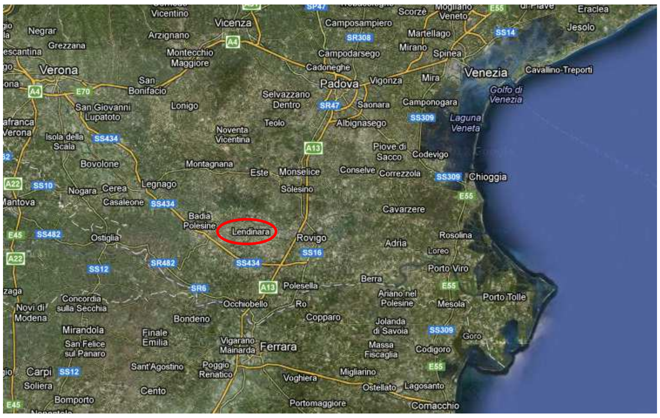

Fig. 2 Aerial view of the measurement site (evidenced by the red circle)

The bell tower of the Santa Sofia dome, visible in Fig. 2, was inaugurated in 1857 and carries at its top a 4 meters high angel as a weather vane, weighting about 700 kilograms.

Fig. 2 The bell tower of Lendinara; the red arrow evidences the location of the anemometer

Fig. 3 View of the weather vane on the top of the bell tower of Lendinara; the red arrow evidences the location of the anemometer

The idea of settling an anemometric station on the top of the bell tower dates back to 2008, with the start of a project whose main aim was to collect direct wind speed data at an altitude of over 100 meters above the ground, in order to investigate the wind potential of the North-East of Italy at high altitude (northern Italy is generally characterized by very low wind potential at the ground level). The University of Padua endowed the project with the necessary instrumentation: the funds, made available by the department of Industrial Engineering, allowed the purchase of a Taco-Gonio anemometer (visible in Fig. 3), an E-Log datalogger (represented in Fig. 4) and a GPRS modem for the transmission of the data to a remote server.

Fig. 4 E-log datalogger placed inside the bell tower of Lendinara

The instrumentation started collecting wind data in September 2010. The anemometer was set to register the maximum, the minimum and the average values of wind velocity every two minutes. The obtained wind data can be freely consulted in the online archive [10]. Due to technical problems, some data are missing: from March 28th to March 31th, from May 24th to June 3rd, from October 12th to October 15th and from October 18th to 19th. Only the periods containing a full record of data were analyzed in this work. The software Microsoft Excel ® provided the statistical elaboration of the data and the calculation of the average wind speed for every day and month during the entire year 2011. Wind data were subsequently re-elaborated in order to determine the Weibull distribution of the wind velocity on the considered site during the year. The probability density function of the Weibull random variable wind speed v is given by:

$$f(v,\alpha,\beta) = \frac{\beta}{\alpha} * \left(\frac{v}{\alpha}\right)^{\beta-1} * \exp\left[-\left(\frac{v}{\alpha}\right)^{\beta}\right] \qquad (1)$$

The function depends on two parameters, the shape parameter β and the scale parameter α. The Weibull distribution is related to a number of other probability distributions: in particular, it interpolates between the exponential distribution (β = 1) and the Rayleigh distribution (β = 2). The value of β is strictly connected with the form of the probability density function of the Weibull distribution. For $0 < \beta < 1$, the probability density function tends to ∞ as v approaches zero from above and is strictly decreasing. For β = 1, the probability density function tends to $1/\alpha$ as v approaches zero from above and is strictly decreasing. For $\beta > 1$, the probability density function tends to zero as v approaches zero from above, increases until its mode and decreases after it. For $\beta = 2$ the probability density function presents a finite positive slope at x=0. As β goes to infinity, the Weibull distribution converges to a Dirac delta distribution.

The parameters of the Weibull distribution can be estimated using several methods. Al-Fawzan [11] compared two graphical methods, the Weibull Probability Plotting (WPP) and the Hazard Plotting Technique (HPT) and three analytic methods, the Maximum Likelihood Estimator (MLE), the Method of Moments (MOM) and the Least Squares Method (LSM). The present analysis estimates the two parameters of the Weibull distribution from the collected wind data using the MLE, in formulas:

$$\frac{\sum_{i=1}^{n} v_i^{\beta} \ln v_i}{\sum_{i=1}^{n} v_i^{\beta}} - \frac{1}{\beta} - \frac{1}{n}\sum_{i=1}^{n} \ln v_i = 0 \quad (2)$$

$$\alpha = \frac{\sum_{i=1}^{n} v_i^{\beta}}{n} \quad (3)$$

where n is the dimension of the sample. The two parameters are obtainable resolving the formulas with an iterative method as Newton's one.

III. Results and Discussion

As shown by the red line in Fig. 5, the average wind speed registered during the year 2011 was 3.97 m/s. This result is in accordance with the predictions of the Italian Wind Atlas, as can be seen from Fig. 6.

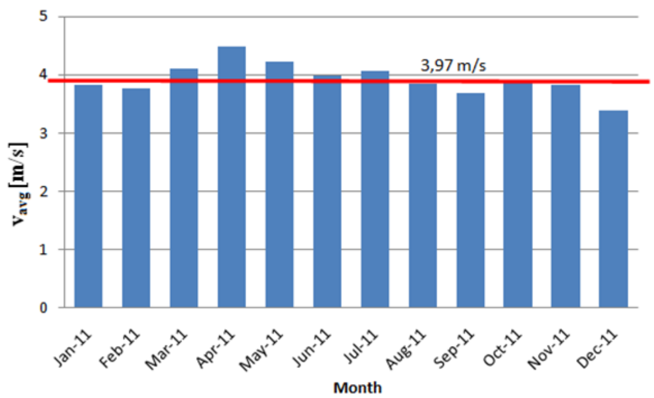

Fig. 5 Monthly evolution of the average wind speed during 2011

The absolute peak of average wind speed was reached in April (4.49 m/s), while the second value was registered in May (4.21 m/s). The months with lower average wind speeds were December (3.37 m/s) and September (3.68 m/s): therefore, the spring months confirmed to represent the windiest period of the year.

A trend in the evolution of the average wind speed can be clearly noticed from Fig. 5: the average wind speeds tend to increase from February to April, when a decrease is registered till September.

In October the velocities increase again and then decline till December.

Fig. 6 Average wind speed at 100 m above the ground for the site of Lendinara (from: [12])

Figs. from 7 to 18 show the day by day trend of the average wind speed during 2011. The windiest days are the first days of March and the first days of November: in these periods the average wind speed reaches about 12 m/s.

A clear trend, in which the wind velocity rises up to the relative maximum value and then decreases, can be registered during each considered month; this trend is registered about four of five times in every month. The red asterisks identify the missing data.

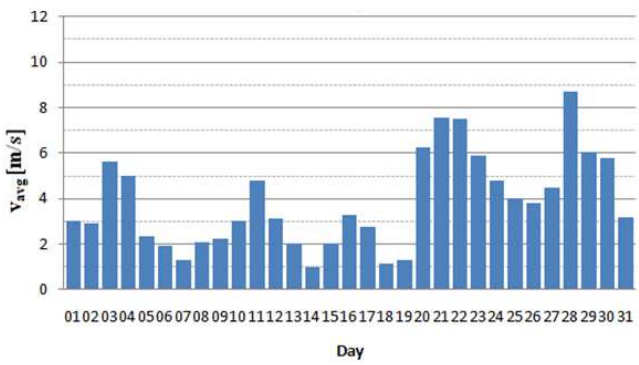

Fig. 7 Daily evolution of the average wind speed during January 2011

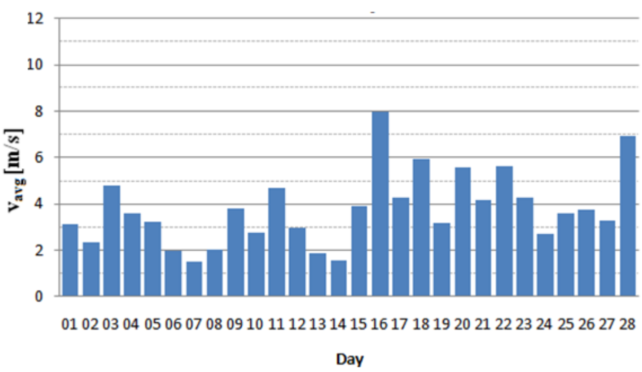

Fig. 8 Daily evolution of the average wind speed during February 2011

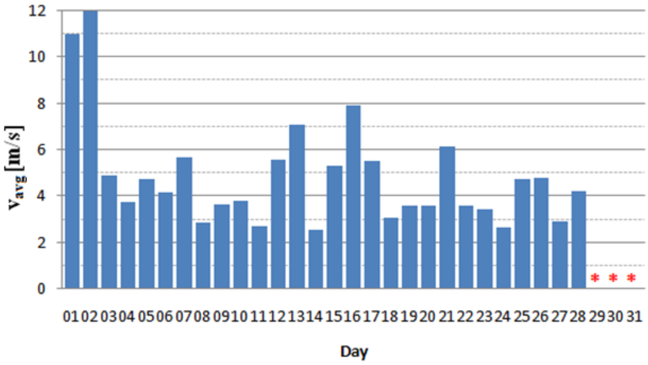

Fig. 9 Daily evolution of the average wind speed during March 2011

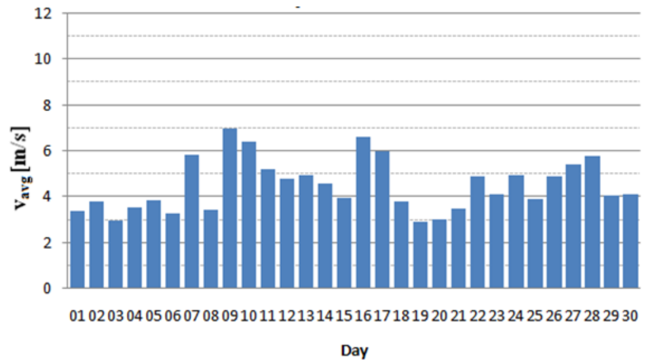

Fig. 10 Daily evolution of the average wind speed during April 2011

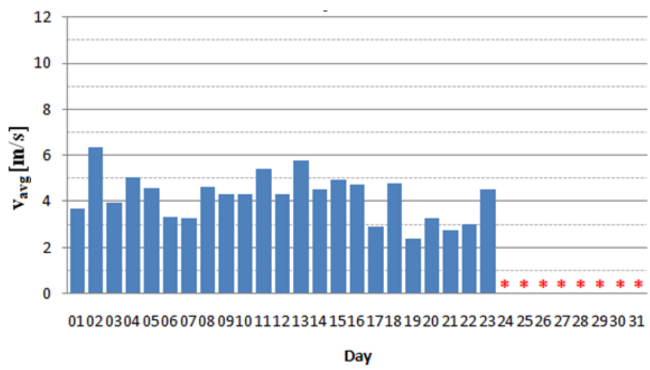

Fig. 11 Daily evolution of the average wind speed during May 2011

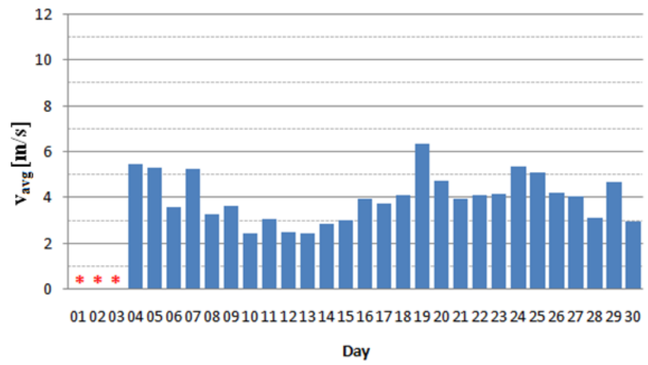

Fig. 12 Daily evolution of the average wind speed during June 2011

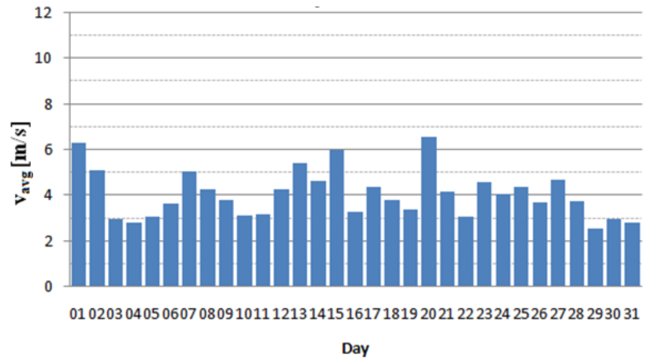

Fig. 13 Daily evolution of the average wind speed during July 2011

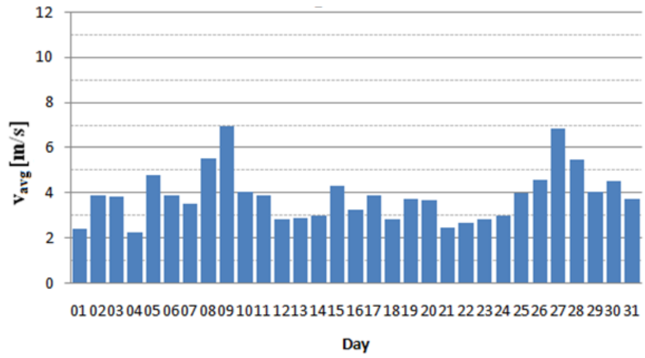

Fig. 14 Daily evolution of the average wind speed during August 2011

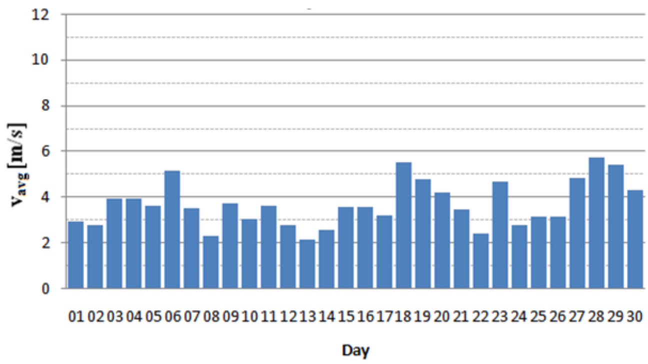

Fig. 15 Daily evolution of the average wind speed during September 2011

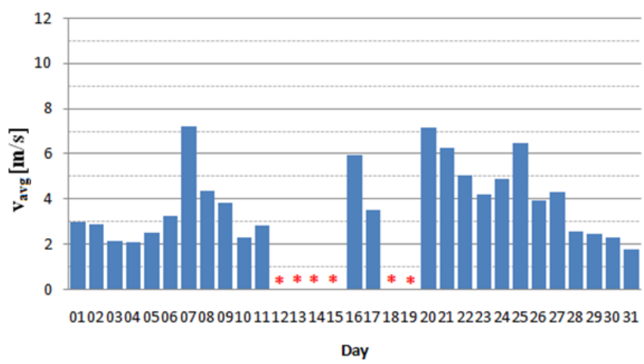

Fig. 16 Daily evolution of the average wind speed during October 2011

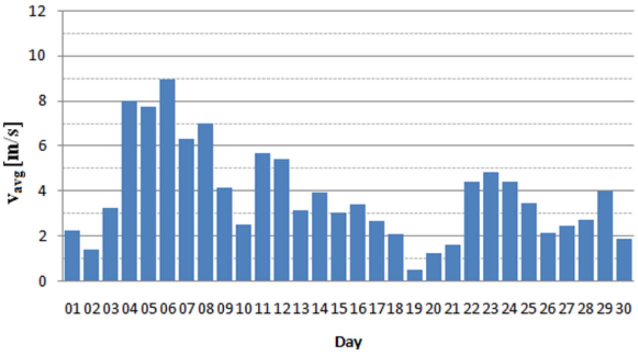

Fig. 17 Daily evolution of the average wind speed during November 2011

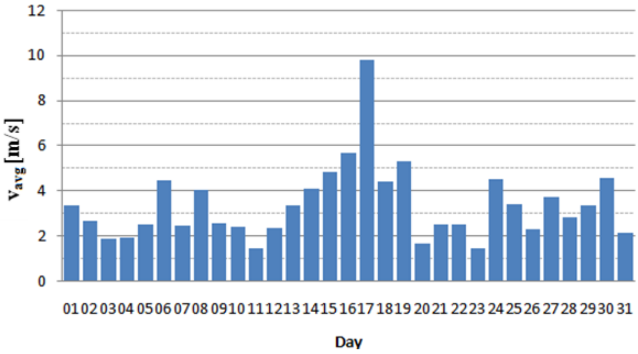

Fig. 18 Daily evolution of the average wind speed during December 2011

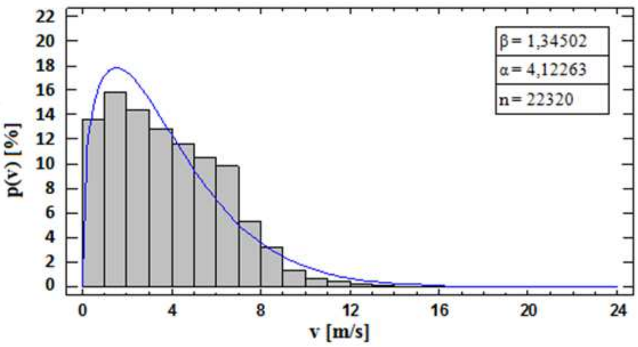

Fig. 19 Weibull distribution of the average wind speed during January 2011

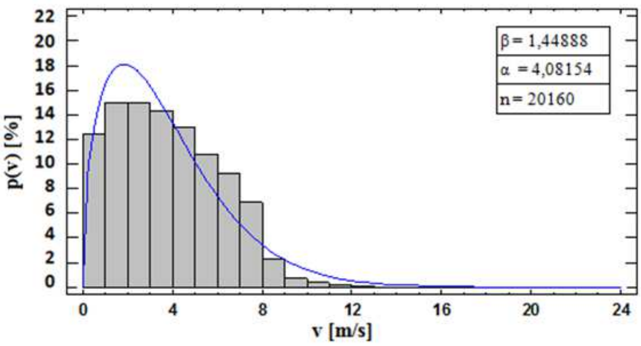

Fig. 20 Weibull distribution of the average wind speed during February 2011

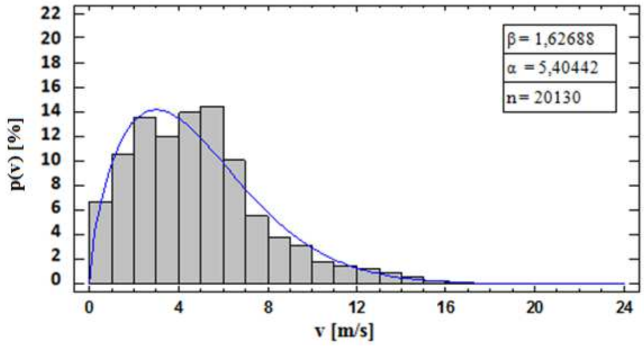

Fig. 21 Weibull distribution of the average wind speed during March 2011

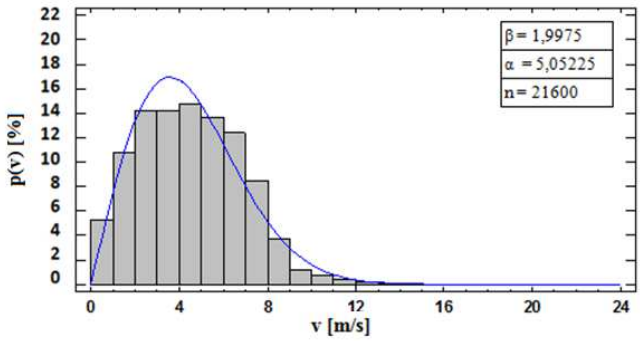

Fig. 22 Weibull distribution of the average wind speed during April 2011

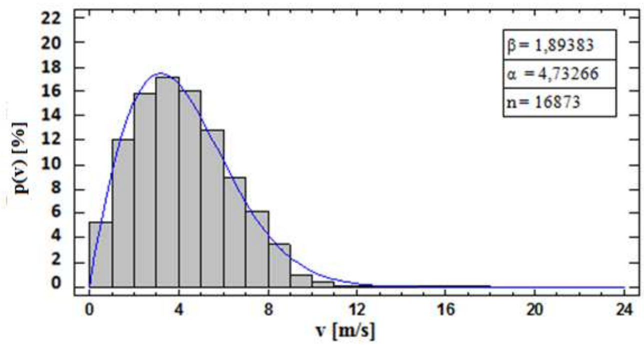

Fig. 23 Weibull distribution of the average wind speed during May 2011

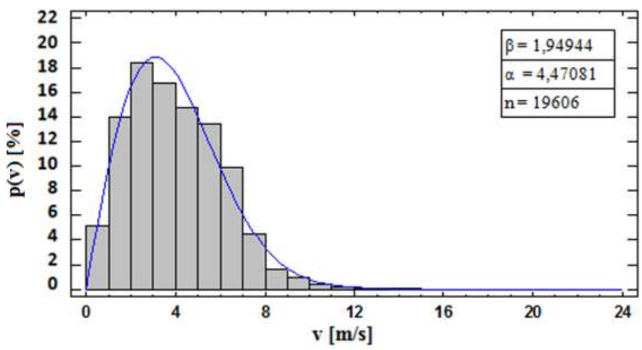

Fig. 24 Weibull distribution of the average wind speed during June 2011

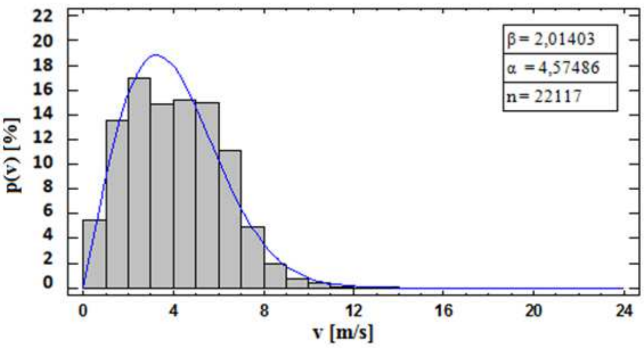

Fig. 25 Weibull distribution of the average wind speed during July 2011

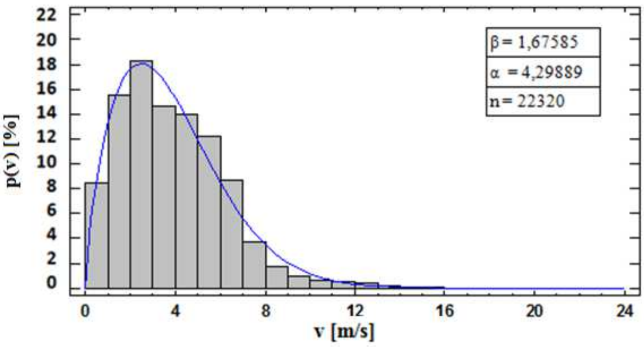

Fig. 26 Weibull distribution of the average wind speed during August 2011

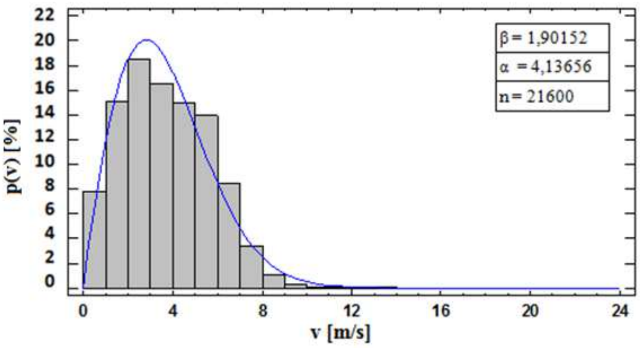

Fig. 27 Weibull distribution of the average wind speed during September 2011

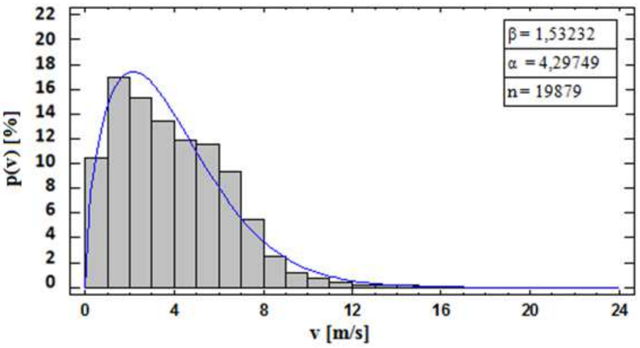

Fig. 28 Weibull distribution of the average wind speed during October 2011

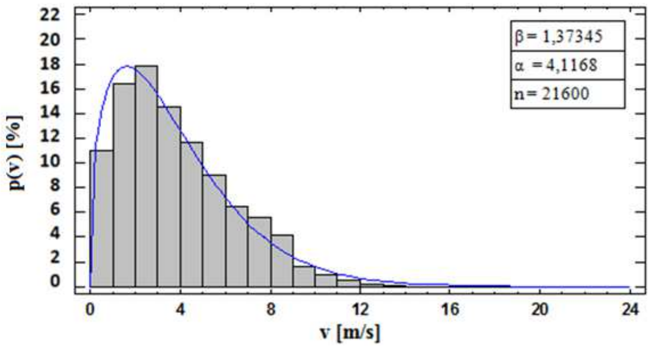

Fig. 29 Weibull distribution of the average wind speed during November 2011

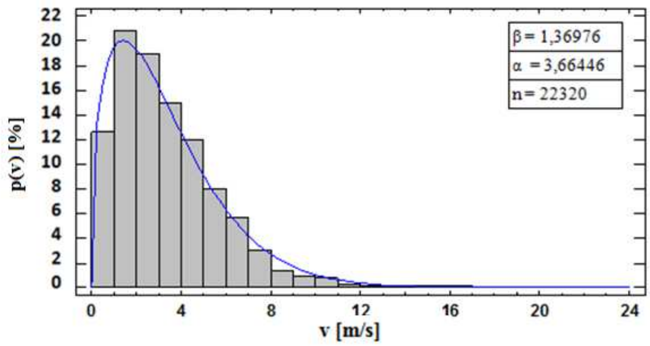

Fig. 30 Weibull distribution of the average wind speed during December 2011

Figs. from 19 to 30 evidence the monthly evolution of the Weibull distribution of the average wind velocity, while Fig. 31 summarizes the Weibull distribution of the average wind velocity for the whole 2011.

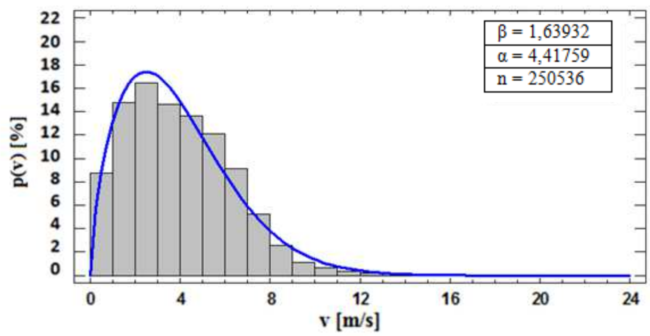

Fig. 31 Weibull distribution of the average wind speed during the whole 2011

IV. Conclusions and Future Works

The wind speed characteristics of the site of Lendinara (northern Italy) have been investigated through a monitoring station installed over 100 m above the ground for a continuative period of 12 months. After a preliminary statistical analysis, in which the wind speed time series have been split and analyzed for each month and season, the probability density function has been computed for each month of the year and also for the whole arc of the investigation.

Shape and scale parameters for each month have been provided using the Maximum Likelihood Estimator method. The resulting average wind velocity is in sharp accordance with the numerical predictions of the Italian Wind Atlas, confirming the accuracy of the extrapolation of wind data adopted for the evaluation of wind potential at higher altitudes with respect to the commonly placed measurement stations, at least for plain areas.

Further work should be performed by placing other measurement stations on the top of adjacent bell towers, in order to perform a full campaign of measurements based on a network of high level installed anemometers, thus determining measured data of high altitude winds, to be compared with the numerical predictions methods for the estimation of wind potential on which the Italian Wind Atlas is based.

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NOMENCLATURE

$f(v,\alpha,\beta)$ [-]	probability density funcion
α [-]	Weibull scale parameter
β [-]	Weibull shape parameter
v [m/s]	average wind velocity of the considered interval
v_{avg} [m/s]	average velocity during a day or month
n [-]	dimension of the sample
$p(v)$ [%]	frequency of Weibull distribution

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