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Evaluation of the Solar and Wind Energy Potential of the Paraguayan Chaco, "La Patria" Case

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Abstract: *This paper aims to analyze and evaluate the existing solar and wind energy potential in the Paraguayan Chaco, for which a Davis weather station was installed in La Patria for a three months period, which sent every 30 minutes data of wind speed at 10m height and global solar radiation. The measuring instruments were calibrated according to international standards, field experience and scientific literature independently. For the elaboration of this paper four aspects were taken into account: 1) the experimental method of data treatment, 2) adjustments based on data from scientific literature, 3) discussion of the results and 4) the conclusions, which allow us to have an overview more comprehensive about the potential of renewable energy resources existing in the region. Regarding the use of mathematical models, adjustments were made using regression curves and statistical models representing the focus of analysis of this research.*
Keywords : *Davis weather station, solar energy potential, wind energy potential, Weibull distribution.*

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I. Introduction

More countries are developing the use of technologies based on the use of renewable energy resources, focusing their efforts on mitigating the problems associated with climate change, since currently only 19% of the final energy consumption worldwide comes from renewable sources [8]. In the zone of South America, Brazil stands out as one of the countries with the greatest innovation in technologies associated with renewable energies, followed by Argentina and Uruguay. Latin American countries together invested US $ 15.5 billion in renewable energy in 2013, which compared to the US, China and Europe with US $ 35.8, 56.3 and 48.4 billion respectively, is a low amount.

The power energy of Paraguay is characterized by a high primary supply of renewable and local origin, specifically hydroenergy and biomass. According to the 2014 Energy Balance, 53% of this offer corresponds to hydroelectricity, 29% to biomass and the remaining 18% to hydrocarbons, the latter imported in its entirety. This shows that the largest percentage of supply is centralized in electricity generation through conventional hydroelectric power [9]. However, recent pre-feasibility studies have shown that Paraguay's energy matrix can be diversified towards other methods of generating electricity, and decentralized and distributed generation can be viable from a perspective of reducing losses in the transmission process. The energy mainly due to the fact that this type of generation would be closer to the load demand sites [5]. One of the viable alternatives is the wind systems, identifying between the regions of greater potential the north of the Chaco, as well as the northeast, the center-west and the southeast of the Eastern region. However, there is still no reliable assessment of this potential in the form of a wind map based on quality measurements. The national authorities are currently promoting projects to carry out studies for this purpose [5]. One of those projects that is already in its final stage of development is the "Solar and Wind Energy Potential (PESE)", promoted by the Itaipu Technological Park PTI, which published on its website, solar and wind maps of Paraguay [19].

On the other hand, there are considerable limitations for the installation of large-scale wind systems with high profitability in Paraguay due to the lack of energy policies that strengthen the Law N ° 3009/06 "of Independent Electricity Production and Transportation", especially in what refers to the differentiated tariffs for the generated energy. In order to rectify this situation, a renewable energy bill was recently presented to Congress, which should create favorable legal and economic conditions for the development of all types of renewable energies in Paraguay. This law currently has a half sanction from the Chamber of Senators.

The present article proposes a new macro energy scenario inserting innovation on the current energy matrix. In order to promote the decentralization of the load demand, to improve the quality of life of the inhabitants of the Department of Boquerón. This department is located in the northwest of the western region of Paraguay (see Figure 3), a place that has been taken into account for the feasibility study for the insertion of

wind technology. Taking into account the vegetative growth in the Mennonite colonies of the central Chaco, the future implementation of the wind system proposed in this article would present a positive alternative for the Paraguayan Electric System, as regards the load relief in the equipment of power of the Stations and in the Transmission Lines of the North System [4].

II. Solar Potential In Paraguay

Despite its rather humid climate, global solar radiation in Paraguay is relatively high. However, there is no reliable data from terrestrial measurements over a sufficiently long period due to the lack of appropriate measuring stations in our country [8], [17]. In recent years, DINAC's Directorate of Meteorology and Hydrology have installed a series of new automatic meteorological stations throughout the national territory, which also measure global solar radiation. Then, in a few more years, it will be possible to create a solar map based on terrestrial measurements with data of 5 or more years of duration.

Practically the only source of data currently available with sufficiently long series for the whole country is the "Atmospheric Science Data Center" of NASA. These data of monthly averages of global solar radiation were obtained through satellite measurements over a period of more than 20 years. The territorial distribution of the data with a resolution of 1 ° of longitude by 1 ° of latitude is quite homogeneous (see Figure 1). The annual averages of the global horizontal radiation range between 4.7 kWh / (m2d) in the south and 5.1 kWh / (m2d) in the north of the country [17]. In view of the results obtained by the analysis of the solar data, it is very interesting to take benefit of this source of energy, not only from a sustainability perspective, but also commercial.

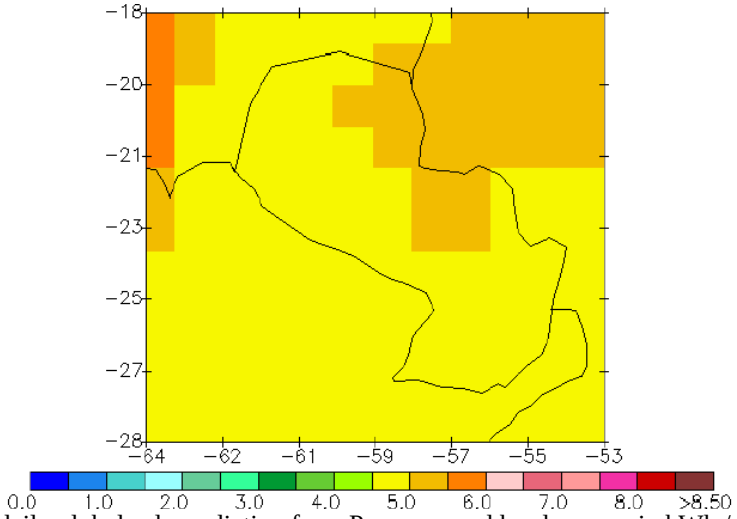

Figure 1. Average daily global solar radiation from Paraguay and border areas in kWh / m2. Source. NASA (1983-2005).

The insolation evaluated together with the climatic and geographical conditions of the area show excellent conditions for the use of this resource with the technologies known today. It is the objective of this article to analyze from a realistic perspective, sustainable and technically viable, the different options that could be postulated with the perspective of proposing a hybrid system of electrical generation in order to correct future energy problems. Attending to the ultimate purpose of this project, which aims to try to assess the solar potential in the area of La Patria, Department of Boquerón gather information from different stations in order to understand and modernize the radiation that can be exploited. This research work seeks to know the power and energy transmitted by the sun in the area of La Patria. For this, it is essential to evaluate the global, direct and diffuse radiations on an annual, monthly and daily basis together with their hourly behavior for each month, always seeking to have the highest possible range and variety of data, both satellite and fixed land stations.

III. Wind Potential In Paraguay

In Paraguay, the winds are characterized by three main climatic phenomena: i) circulation towards the high pressure centres with the western end controlled by the Pacific anticyclone and the east by the Atlantic anticyclone, ii) the Andes mountain range and the Altiplano acting as a barrier and suppressing westerly winds throughout the territory; and iii) the wind generated depending on the intensity of the quasi-stationary low pressure center in the Chaco [16].

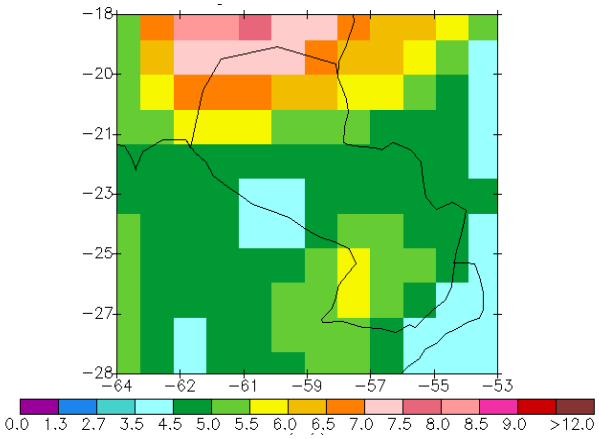

Figure 2. Average wind speed at a height of 50 m above the surface in m / s. Source. NASA (1983-1993).

As a result, generally low speeds are expected throughout the year in the eastern part of Paraguay, belonging to the high pressure zone. On the Paraguayan and Argentine Chaco and the Pampean lands and pockets, a system of low pressure is almost stationary. In winter, when the low pressure zone is located on the Chaco, east winds are produced that rotate towards the Northwest in the center of Paraguay. In summer, the southernmost location of the depression centered on the Pampean mountainous areas leads to winds from the North and Northwest in the Paraguayan Chaco. Figure 2 shows the average annual speeds at 50 m height according to NASA satellite measurements [13]. The seasonal variation of the wind is great in this area, expecting maximums from August to December due to the rapid warming of the region. There are previous works in which the wind potential of Paraguay is valued with the objective of using wind energy power for rural electrification. In a 1997 paper, average speeds were estimated in different parts of the country with the intention of generating a preliminary wind map of Paraguay [13].

IV. Meteorology Station Of La Patria

The meteorological station of La Patria was assemble in 2012 and operated by the Federation of Cooperatives of Production FECOPROD. It is located at latitude 21º 21 '59 "south and longitude 61º 29'16" west in the western region of Paraguay, specifically in the Department of Boquerón, at a distance of approximately 100 km north of the city of Mariscal Estigarribia and at a distance of approximately 500 km from the capital city of Asunción (see Figure 3).

Figure 3. Map with the 3 meteorological stations considered in the Western region. Source. DINAC, Google Earth (2013).

The area where the meteorological station is located is densely forested. The average annual ambient temperature is 26 ° C with average maximum in December of 43 °C and average minimum in June of 13 ° C and an average relative humidity of 44%. In the area, only about 350 mm/year of atmospheric precipitation is observed on average [17].

During the night, the ambient temperature drops considerably [1]. The measuring equipment assembled at the La Patria weather station is a Davis brand equipment of the Wireless Vantage Pro 2 type, which was installed by personnel from the National Directorate of Civil Aeronautics (DINAC). It is powered by a solar panel with a power of 0.5 W and a battery with an autonomy of 8 months without sunlight. It is equipped with

automatic sensors for rain, temperature, humidity, solar radiation and wind (speed and direction). The equipment allows to measure and process instantaneous, daily, monthly and annual data and transmit them every 10 min. [18]

The wind speed and direction data obtained by the anemometer were collected on an electronic chip of a small computer, which can run on battery for a long period of time. The measurement equipment was programmed to send data via a GPRS modem from the La Patria weather station to the facilities of the FECOPROD in the city of Asunción [12]. The wind vane and the anemometer were calibrated and synchronized for an operation range of average speed calculation and mean wind direction of 30 minutes. The 3 meteorological stations of the Department of Boquerón, whose data were used to evaluate the renewable resources are included in the map of Figure 3. This study supposes the critical analysis of the data measured exclusively in the meteorological station of La Patria. After the discovery of several measurement errors and problems with the equipment, we included an extensive discussion of the data treatment and the conclusions obtained about its validity [11].

Table 1. Periods of wind data considered and height of the anemometer of the meteorological stations of Boquerón. Source. DINAC (2013).

STATION	HEIGHT	MEASUREMENT PERIOD	FREQUENCY
Loma Plata	80 m	26/09 - 02/12/2008	30 min
15 de Agosto	80 m	24/10 - 02/12/2008	30 min
La Patria	10 m	16/11/2012 - 16/02/2013	30 min

The meteorological station of La Patria, in which the anemometer and wind vane were installed at a height of 10m above the ground, presents problems in the sensitivity, providing measurements in intervals of 0.5 m/s. This results in the original data without further treatment showing non-Gaussian, biased type behaviors. This could cause wind behaviors analogous to other stations, but these differ in a scale factor. Most stations in the Chaco area are in the installation phase. For this reason, we were only able to access the data from the Loma Plata and August 15 stations (see Table 1), for which wind speed measurements at 80 m height were made in 2008 with the purpose of Evaluate the wind potential of that area. To be able to compare these measurements with the values of La Patria, they were extrapolated to that same height using equation (1) obtained from [2].

$$v_{80} = v_{ref} \frac{\ln(z_{80}/z_0)}{\ln(z_{ref}/z_0)}$$

v80: wind speed at a height of 80 m above ground level (m / s).
vref: wind speed at a height of 10 m above ground level (m / s).
z80: height above ground level where the wind speed (80 m) will be studied.
zref: height of the measuring equipment above ground level (10 m).
z0: roughness length in the wind direction (m).

With regard to the length of roughness in the wind direction z0 that we took for our study it should be emphasized that this value depends on the type of terrain and the wind speed varies with the height due to the shear produced by the friction of the air with itself and the roughness of the land. It indicates the height above ground level where the wind speed is theoretically zero. It has to be pointed that the forests and big cities slow down the wind, while the concrete runways of the airports only slow it down slightly. For our research work we take the value of 0.28m, class of terrain 3 [2].

Treatment And Discussion Of Data Measured In La Patria

According to the results counted, processed and measured in the weather station of La Patria during the period from November 2012 to February 2013, we found average wind speeds of 6.98 m/s to 10 m above ground level and 11.2 m / s to 80 m Tall. The values obtained are relatively high taking into account that in the meteorological station located on August 15 for the same months there is an average of only 5.65 m / s to 80 m above the ground level, which suggests a viability of the initial objective of this research work [8].

The relative frequency histogram was designed in intervals of 1 m/s measured from 0.5 m/s onwards up to the maximum recorded speeds. The data recorded by the La Patria sensor have an accuracy of only 1.5 km/h that translates into a range of 0.416 m/s. This causes that the curve of frequencies of speed presents intervals of 1 m/s, reason why it shows an atypical statistical behavior. Its frequency distribution shows non-consecutive values of wind speeds (see Figure 4).

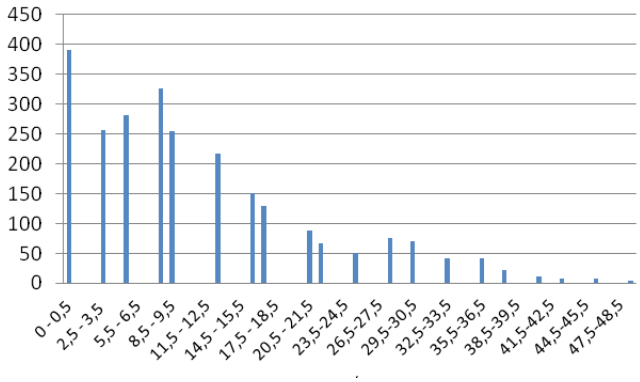

Figure 4. Frequency distribution of wind speeds at 80 m height above ground level in La Patria in m / s. Source. Own Elaboration (2012-2013).

Figure 5 shows the curve of duration of speeds, in which the speed is represented as a function of the accumulated hours (complementary cumulative frequency by the hours measured). We note that for the data of La Patria the speed is greater than 3 m/s for more than 2100 h, the equivalent to 70% of the measurements made, this value is of utmost importance, since most variable pitch wind turbines they start operating at a starting speed of 3 m/s [8], [11].

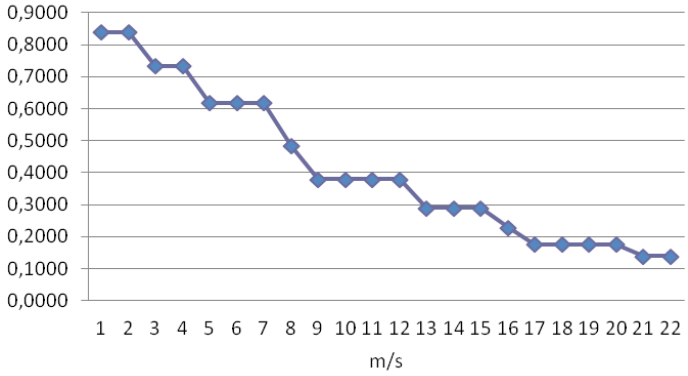

Figure 5. Complementary frequency distribution of wind speeds at 80 m height above ground level in La Patria. Source. Own Elaboration (2012-2013).

In Figure 6, it can be seen that the prevailing wind in the area of La Patria is from the Northeast (NE) and Northeast East (ENE) during the daytime with a weight of 20 and 25% respectively of all the measurements processed during the 3 months measured. In a lower percentage, the measurements in the south-southwest direction (SSW) follow at night, due to the sudden decrease in wind speed at night and the difference in pressure that exists for both cases.

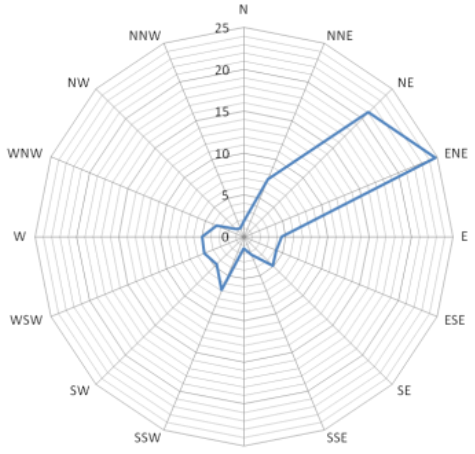

Figure 6. Wind direction rose and relative weight of speeds in La Patria. Source. Own Elaboration (2012-2013).

In Figure 7, it is observed that the average daily wind speed increases during the day reaching its maximum value of 16 m/s after noon and decreasing sharply during the night reaching a minimum value of 7 m/s. It can be seen that the speeds are higher than those estimated. This correspond to the months of lower wind speed so that in the months of August, September, October would have the highest wind speeds and would have greater wind potential [13]. The abrupt change of wind speeds is due to the change in atmospheric pressure and the difference in temperature during the day and night forming ridges in the distribution of the frequencies of the wind speeds.

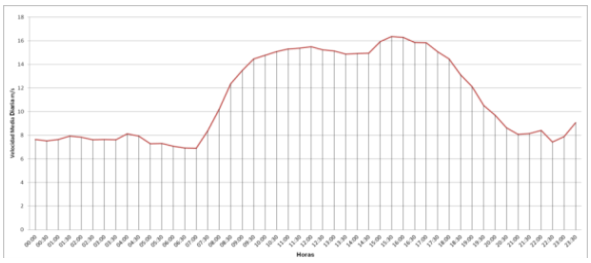

Figure 7. Mean wind speeds over the course of the day in the months of November to February in La Patria. Source. Own preparation (2012-2013).

In order to elaborate a mathematical model that allows estimating the non-linear behavior of the average speed, the monthly data of the La Patria weather station, measured between November 16, 2012 and February 16, 2013, have been processed. The months that were not computed to complete a year were not measured due to failures in the measurement equipment. However, the results obtained with the mathematical and statistical model help confirm that the average value of the measured months of the wind speed at a height of 80m above the ground is about 11.2 m/s, representing a real available power of 740 W/m2.

Figure 8 represents the global solar irradiation curves during the course of the day during the measurement period of 3 months and the same parameter but only on clear days. The average daily global solar radiation obtained from these measurements is 5.6 kWh / (m2d). For clear days the value is 7.7 kWh / (m2d). It is worth mentioning that these values are somewhat lower than those published by NASA for this site and the same period of the year [17]. The difference between both values coming from the 27% measurements is due to cloudiness. It can be observed that clouds appear practically throughout the day, but with greater intensity during the afternoon hours, a phenomenon that is due to the decrease in atmospheric pressure.

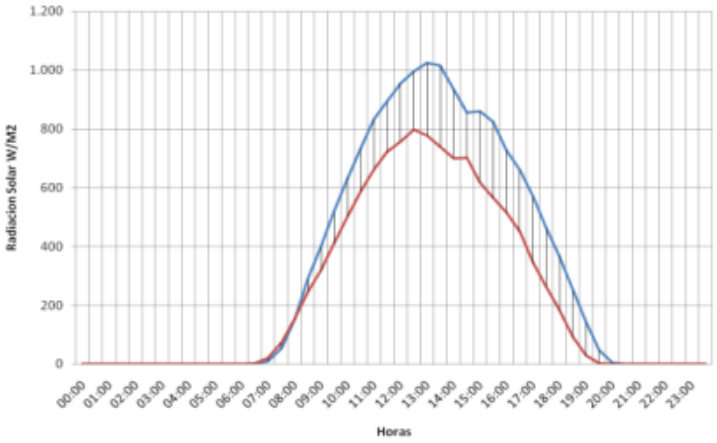

Figure 8. Total average of global solar irradiation (red) and clear sky (celestial) in La Patria in W / m2. Source. Own Elaboration (2012-2013).

The average daily temperature is increasing during the day from 7:00 h reaching its maximum values at 4:00 p.m. and then decreasing slowly during night time. The relationship between the average daily speed and the daily average temperature results in a correlation of 80%, showing an almost ideal thermal cycle due to thermal inertia. It can be observed in the same that increasing the ambient temperature during daytime increases the wind speed. On the other hand, at night time, when the ambient temperature decreases, the wind speed decreases. Both phenomena were analyzed at the same time (see Figure 9).

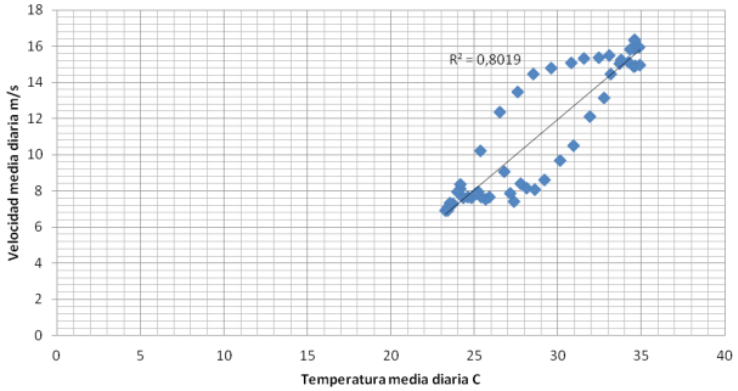

Figure 9. Average daily speed versus average daily temperature in La Patria. Source. Own Elaboration (2012-2013).

As regards the thermal balance, when the environment temperature increases, the humidity decreases during the daytime, reaching minimum humidity values of the order of 50% after half a day, and later in the night time it will be increased up to a maximum of 85%. A similar behavior can be observed between the humidity of the air and the wind speed.

The relationship between the daily average temperature and the daily average pressure results in an almost ideal thermal cycle. It can be observed that when decreasing the atmospheric pressure in daytime increases the daily average temperature, inverse case in nighttime when increasing the atmospheric pressure decreases the wind speed (see figure 10).

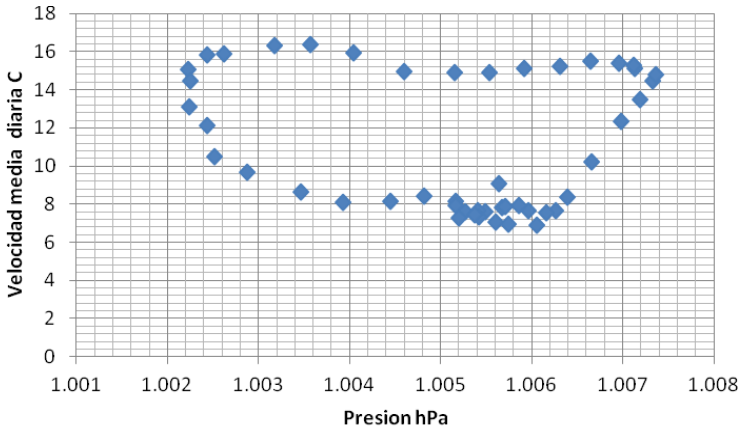

Figure 10. Daily average speed and daily average pressure in La Patria. Source. Own Elaboration (2012-2013).

According to the analysis of the different meteorological parameters and their correlation for the measurements that were processed in the short period of time that the measurements were made. We observed that a system of electricity generation of the hybrid wind-solar type could be viable. It should be noted that the physical phenomenon observed as a result of the processing and evaluation of the data is the effect of thermal inertia. It is a point to take into account for the selection of the most appropriate solar technology.

V. Conclusions And Recommendations

In this article we have evaluated the existing wind and solar resources in the Paraguayan Chaco territory, specifically in the area of La Patria. For a period of 3 months, corresponding to the months of lower wind speed. It has been obtained a projected average speed a height of 80m above ground level of 11.2 m/s, equivalent to an average power of 740 W/m2. Regarding the horizontal daily global solar radiation, an average is obtained during the measurement period of 5.6 kWh/(m2d), which represents a considerable amount for generation systems based on photovoltaic solar energy. These values are considered sufficient to think about the installation of an economically viable pilot plant. We consider that this potential is perfectly usable in places with isolated populations. In the western region of the country there are still many communities without connection to the electricity grid.

To have a more complete picture of the wind and solar potential of the Paraguayan Chaco, it is essential to carry out more measurements at different points in that region and with a duration of at least one full year. The wind speed should be measured on one side at a height of 10 m above the ground to allow comparison with the existing values of other sites and on the other hand at a height of at least 50 m to have data directly to a level where wind generators are normally placed.

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