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Determination of Wind potential in the municipality of Guasca and its viability in power generation

Determinación del potencial eólico en el municipio de Guasca, Cundinamarca y su viabilidad en la generación de energía

Duban Estiven Gantiva-Rodríguez[1], Juan Antonio Aragón-Moreno[2*]

[1]*Estudiante de Ingeniería, Universidad Libre Seccional Bogotá, Sede El Bosque, dubane-gantivar@unilibre.edu.co, 000-0001-9695-0018, Bogotá, Colombia.*

[2]*M.Sc. Meteorología. Universidad Nacional de Colombia, jaaragonm@unal.edu.co, 0000-0003-2768-9082, Bogotá, Colombia.*

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Keywords:

Wind potential, Guasca, Windographer, Power density, ArcGIS.

ABSRACT

Debido a la reducida cantidad de estudios de energía eólico al interior de Colombia, el objetivo de este estudio es determinar el potencial eólico del municipio de Guasca así como su viabilidad en la generación de energía, para ello se recolectaron los datos correspondientes a los años de 2017, 2018 y 2019 de las estaciones meteorológicas que pudiesen medir datos de velocidad de viento tanto dentro del municipio como en los alrededores del mismo (Páramo Chingaza, PNN Chingaza y PTAR Tocancipá) para luego analizar los datos con ayuda del software Windographer. La información generada a partir del análisis muestra que los valores más altos en velocidad de viento proceden del sur del municipio los cuales alcanzan los 4 m/s, así mismo se observa que el flujo del viento en el municipio proviene principalmente desde el este y atraviesa el municipio en dirección oeste. Los análisis de densidad de potencia mostraron que la mayor oferta energética se encuentra al sur del municipio, donde los valores de densidad de potencia alcanzan los 40 W/m2, para evaluar esta oferta eólica se realizó una búsqueda de turbinas eólicas que pudiesen aprovechar las condiciones del municipio, mostrando una generación energética que oscila entre 19,669.02 KWh y 42,711.59 KWh lo que puede considerarse útil para la autosuficiencia a nivel residencial.

Palabras Clave:

Potencial eólico, Guasca, Windographer, Densidad de potencia, ArcGIS.

RESUMEN

Due to the reduced number of wind energy studies in the interior of Colombia, the objective of this study is to determine the wind potential of the municipality of Guasca as well as its viability in energy generation, for this the data corresponding to the years of 2017, 2018 and 2019 of the meteorological stations that could measure wind speed data both within the municipality and in its surroundings was gathered (Páramo Chingaza, PNN Chingaza and PTAR Tocancipá) and then data was analyzed with the help of the Windographer software. The information generated from the analysis shows that the highest values in wind speed come from the south of the municipality, which reach 4 m/s, likewise it is observed that the wind flow in the municipality comes mainly from the east and crosses the municipality to the west. The power density analyzes showed that the greatest energy supply is located in the south of the municipality, where the power density values reach 40 W/m2, to evaluate this wind supply a search was carried out for wind turbines that could take advantage of the conditions of the municipality, showing an energy generation that ranges between 19,669.02 KWh and 42,711.59 KWh, which can be considered useful for self-sufficiency at the residential level.

***Corresponding author.**
E-mail Address: *jaaragonm@unal.edu.co* (Juan Antonio Aragón-Moreno)

Introduction

Energy constitutes a fundamental part of human daily life and for the development of society, an immaterial and fundamental component of the universe as well as something vital for civilization [1] [2]. Wolfgang Bauer and Gary Westfall state the importance of energy as follows: "No physical quantity is more important in our daily life than energy". [3] For decades this growing need for energy was covered mainly by fossil fuels such as oil, coal and natural gas, which generated social, environmental and social problems such as problems of air pollution resulting from the waste of these fuels known as greenhouse gases. [4] [5] The international contribution of fossil fuels, although it has decreased since in 2011 oil accounted for 40% of the energy consumed in the world, five percent less than in 2001, while coal and natural gas accounted for 25% and 21% respectively, still maintains these energy sources as the main and most important in the world. [6] This is in large part because various political and social actors justify the dependence on these fuels for their economic and geopolitical interests. [6]

Due to the increasing demand for energy worldwide, the growing interest in the effects of climate change, and the desire to reduce greenhouse gas emissions, renewable energies, such as wind energy, are growing rapidly [7] Renewable energies -in this case, wind energy- as described by the Institute of Meteorology, Hydrology, and Environmental Studies -IDEAM-, are nowadays valuable resources, cleaner than those originated in fossil sources, these resources are increasingly competitive, especially if we take into consideration that they allow auguring a more sustainable development on Earth. [8] Wind energy is the electrical energy obtained from the wind. i.e. from a certain point of view, wind energy can be understood as an indirect form of solar energy since it is the heat produced by the sun that causes the air masses to move by causing variations in pressure, wind energy varies greatly from one place to another due to the irregularities of the terrain. [9] [10] Wind power has commonly been used to pump groundwater to the surface or to grind grain into flour, but modern wind power plants generate electricity for homes, factories, etc. [11]
To generate wind energy, it is necessary to take into account something fundamental about the wind, and that is that two data are of interest, above all: course and speed. [12] The wind direction changes in time which are connected to the behaviour of the temporal wind flow caused by different geographical and atmospheric factors. [13] Among these are factors such as the Coriolis force which is mainly produced by the rotation of the earth, however, it should be clarified that this force does not generate wind but modifies the direction of the air masses; it should also be noted that in the equatorial zone this force is null. [11] [14] It is also worth mentioning that in the equatorial zone this force is null, in this zone the trade winds are present instead. The Coriolis force together with the influence of high-pressure zones causes the flow of these very constant currents of wind from east to west in the equatorial zone known as the Intertropical Convergence Zone.[11] [12] The wind direction is also affected by different geographical and atmospheric factors: the force produced by the pressure gradient increases the wind speed, which is evident in places with strong winds that in turn evidence high-pressure gradients. [11] [12] On the other hand, friction decreases wind speed, especially during the first 1.5 km of the Earth's atmosphere; this friction is mainly because the air masses are in constant friction with the ground and geographical accidents. [11]

In recent years, significant progress has been made in this field, proof of this is the wind energy studies conducted throughout the world such as China where a wind potential study was conducted in Jiangsu [15] Thailand, where a wind potential study was carried out in the Hat Yai campus of the Prince of Songkla University. [2] Multi-criteria analysis for the offshore wind potential in Egypt [16]. Kaoga et al. [17] conducted a study of wind potential in the far north of Cameroon highlighting the geography of the region which is part of the Mandara Mountains. [17] Nawri et al. [18] carried out a study of wind potential in Iceland. [18] In the region of Baja California, the effects of meteorological phenomena in the area on the wind potential of the region were studied, [19] an evaluation of the wind potential in the state of Veracruz (Mexico) [20] among many other studies found at the international level.

At the national level, however, there are few studies on the subject at least in a more specific way. Besides the Jepirachi wind farm, which is the only wind farm in the country to date, [21] and a small group of wind studies relegated to the department of La Guajira and the Caribbean coast, there are few studies on the subject, at least in a more specific way.

[22] [23] A study of the wind resource in Bogota [24] a statistical analysis of wind distribution in the Aburrá Valley [25] and a study of wind potential in the Chontales páramo. [26] This shows little interest in the subject at the national level, relegating research to the Caribbean coast and specific locations in urban areas, leaving aside other locations that may present suitable conditions for wind power generation, therefore, this study can open a new perspective on the field of wind energy and new points of view in its implementation, likewise, this study can be a starting point for the implementation of wind energy systems on a larger scale in the country, or in mountain areas similar to the study

Methodology

Study Area

The present research was conducted in the municipality of Guasca, located in the department of Cundinamarca, Guasca has an average temperature of 13 °C and is located at an altitude of 2,800 Height above mean sea level. It is located between the cold and paramo thermal floors. [27] To the east, the town is surrounded by the Chingaza National Natural Park, [27] [28] towards the northwest is the Tominé Reservoir. [29] Finally to the west is the Pionono hill in the neighboring municipality of Sopó. [30]

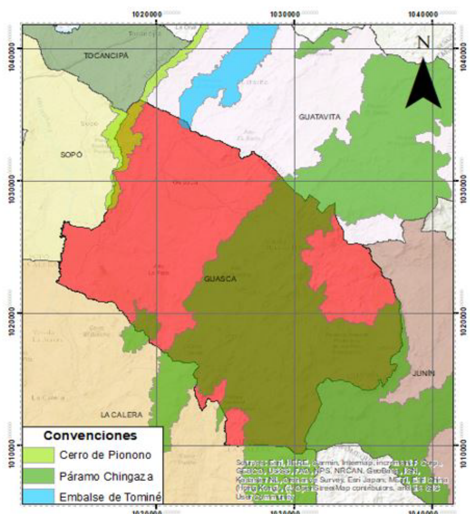


Figure 1. Location of Study Area.

Materials and Methods

Search for meteorological stations: For the present research, the search for meteorological stations that could measure wind speed and direction present in the study area or adjacent to it was carried out, once these stations were located, the request for information was made to the entities that own them (for this case they were the Corporación Autónoma Regional de Cundinamarca - CAR, and the Instituto de Hidrología, Meteorología y Estudios Ambientales - IDEAM) discarding according to the available information those stations that did not have enough data to be used in the subsequent analyses, finally obtaining the following stations (Table I):

Table I. Geographical Location of the Meteorological Stations Selected for the study.

Code	Station Name	Length	Latitude	Altitude (m.a.s.l.)
35025080	Chingaza National Park	-73.83	4.66	3205
35035130	Chingaza Paramo	-73.80	4.71	3863
21205505	Tocancipá WWTP	-73.92	4.97	2572

It should be clarified that a fourth meteorological station located in the municipality of Guatavita was used which, although it does not have data on wind speed or direction, due to its history of having recorded such data in the past and its geographical location was useful to perform the corresponding interpolation work of the subsequent analysis. In that sense, it was also considered a station located within the study area called "Santa Cruz de Siecha", but in the end, it had to be discarded due to lack of data for the year 2019.

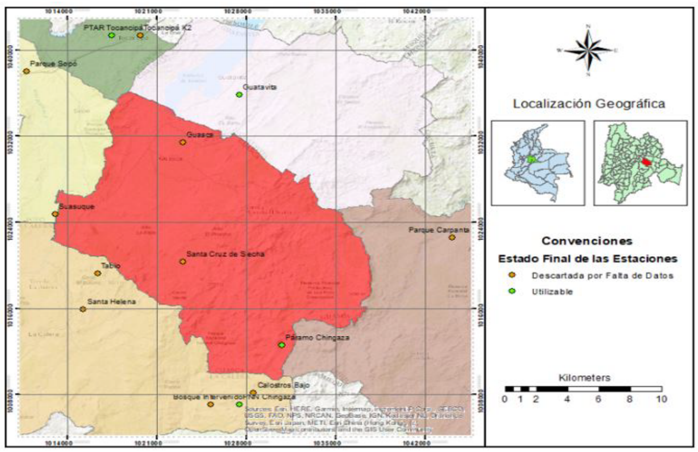


Figure 2. Geographical location of the stations consulted, highlighting the stations that were discarded due to lack of data

Quality Control of Data Obtained: For the present research, daily frequency data series corresponding to the years 2017, 2018 and 2019 were used. To obtain greater reliability of the data, an initial quality control process was carried out, which consisted of eliminating inconsistent data from the series -for example, negative speed data-, and data whose values were three times greater than the standard deviation obtained in the statistical description of the series were also eliminated.

Data Filling: To obtain the total reliability of the data obtained it was also necessary to perform a data filling process which consists of filling any data gaps in the series (Table II) using mathematical methods. For this study, the Windographer program was used, which can perform data filling through a stochastic process known as Markov Chains. [31] This process can be defined as any process in which the probability of a future event can be predicted based only on the immediately preceding events, which implies that the Markov chain and the events that compose it will show identical behavior at any moment in time in which it is observed. [32] [33] [34]

Table II. Percentage of missing data per station.

Station	Percentage (%)
Chingaza National Park	11.5
Chingaza Paramo	9.04
Tocancipá WWTP	1.36

Statistical analysis of the data: Having obtained reliability in the data we proceed to perform the corresponding statistical analysis of the data using the Weibull probability distribution. The probability distributions are mathematical models that serve to determine the probability of occurrence or the behavior of a variable, data or series of data; In the case of wind, a variety of probability distributions can be used to describe the properties of the wind such as direction and speed, as well as the Weibull distribution is widely considered as the probability distribution of occurrence. [35] Likewise, the Weibull distribution is widely considered to be the most suitable probability distribution for analyzing wind speed data given the variety of curves that can result from the use of different parameters related to this wind characteristic.[34][25][36] The Weibull function is characterized by two parameters: a scale parameter and a shape parameter; the scale parameter defines how sparse the distribution is while the shape parameter defines the shape of the distribution [37]

$$\frac{\alpha(x-\gamma)^{\alpha-1}}{\beta^{\alpha}}\, e^{\left(-\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)}, \quad \gamma < x < \infty; de\ otra\ forma\ es\ 0 \qquad (1)$$

Weibull Probability Function. Source. [25]

$$F(x) = 1 - e^{-\left(\frac{x-\gamma}{\beta}\right)^{\alpha}} \qquad (2)$$

Cumulative Weibull function. Source. [25]

For this study we used the statistical function of the Windographer program, which can import and analyze wind resource information from different formats and automatically detect the structure of the same, allowing a quick quality control and statistical analysis. [31][38]

Statistical description of the data: once the data quality control was performed, the corresponding statistical analysis was carried out, which consisted basically in obtaining the measures of central tendency of the data series (mean, standard deviation, variance, box plot). [34][35][36] This was a dominion to study the behavior of the data series and to be able to have more clarity about the possible results of the subsequent analysis.

Wind Direction Description: To develop the description of the wind direction it was not possible to use the WRPLOT program because this program only elaborates wind roses from hourly frequency data series, therefore, being the data of this study daily frequency, we chose the special tool for wind roses of the Windographer program. [39,p.40] Therefore, as the data for this study is of daily frequency, we opted for the special tool for wind roses of the Windographer program, [31] with which the wind roses of the three stations within the study period were elaborated, which allowed determining the predominant direction of the wind. [19] These roses plot the direction of the wind flow showing where the wind comes from, which is useful for the development of the spatial analysis of the wind roses.

Spatial and vector analysis of the wind: Once the wind roses were obtained, we proceeded to make a map that would allow us to observe the wind behavior in the study area, allowing us to establish the predominant wind direction for each station. [16][20] The wind roses were then mapped to establish the predominant direction of the wind for each station. Likewise, using the statistical data obtained through the Weibull distribution and the wind direction data obtained with the wind roses, these data were georeferenced in the MAGNA Colombia Bogotá projected flat coordinate system in ArcGIS™ software. Then the geostatistical interpolation of the data was performed using the inverse distance weighted method (IDW) of the predominant wind direction and speed data to generate a vector representation of both speed and direction, [40] which allows the identification of wind flow parameters in the area as well as their relationship with the local geography thus establishing the wind regime of the municipality.

Wind energy analysis: To carry out the energy analysis of the municipality, the Windographer program was used once again, this time a special tool was used that allows the analysis of the power density of the data series in W/m2 as well as the classification of the wind according to the energy it can produce. [31] Once these data were obtained, we proceeded to georeference them in the coordinate system mentioned above in the ArcGIS™ software, then the geostatistical interpolation of the energy data was performed in the same way that was done with the wind data, to obtain fields of equal energy magnitude within the municipality which allows identifying areas of high energy density that can be used to generate energy.

Determination and selection of wind turbines: Consequently, with the energy data of the municipality, a review of the possible wind turbines capable of generating energy with the conditions present in the municipality was carried out, taking into account the factory specifications of the turbines consulted, such as turbine start-up speed, orientation, number of blades, nominal power, etc. (Tables 3a and 3b), [10][41], etc. (Tables IIIa and IIIb). For practical purposes, the wind turbine catalog of Windographer [31] because in this catalog can also be found wind turbines that can be useful for this research.

Table IIIa. Part of the catalogue resulting from the wind turbine review, basic specifications section.

Model Name	Producer	Number of blades	Rotor Diameter (m)	Sweeping Area (m^2)
Aircon 10kW	Aircon	3	7.1	39.6
Ampair Pacific Hawk	Ampair	3	1.2	1.13
Jonica Impianti	Jonica Impianti	3	8	50.3
Proven WT 6000	Proven Energy Products Ltd.	3	5.5	23.76
Proven WT 15000	Proven Energy Products Ltd.	3	9	63.62

Table IIIb. Part of the catalogue resulting from the wind turbine review, section turbine operating speed.

Model Name	Wind Speed (m/s)			
	Minimum Cutting Speed	Rated Speed	Maximum Cutting Speed	Maximum Speed
Aircon 10kW	2.5	11	32	52.7
Ampair Pacific Hawk	3	12.6	N/A	50
Jonica Impianti	3.5	12.5	37.5	42.5
Proven WT 6000	2.5	12	N/A	65
Proven WT 15000	2.5	12	N/A	65

Determination of estimated performance and restrictions of wind turbines: Once the review of wind turbines and energy data from the study area was done, we proceeded to evaluate the energy that can generate these wind turbines using the Windographer program which has an application capable of performing analysis of turbine output power and net energy generated. [38][31] Afterward, possible environmental restrictions - humidity and temperature - that could affect the generation of energy in the municipality were evaluated.

Analysis of Results

In this section, you will find the results obtained from this research in statistical, spatial and vector matters, as well as the discussion and comparison with previous studies.

Statistical analysis of the data: To determine the degree of relationship existing between the distribution of the data and the Weibull probability function, a histogram was used to compare the velocity frequencies of the data with the Weibull probability, as well as the statistical coefficient of determination that can take a value between zero and one, where one represents a perfect fit between the distribution of the data and the probability function used, as can be seen in the following figure, the station Paramo Chingaza a statistical coefficient R2of 0.8052.

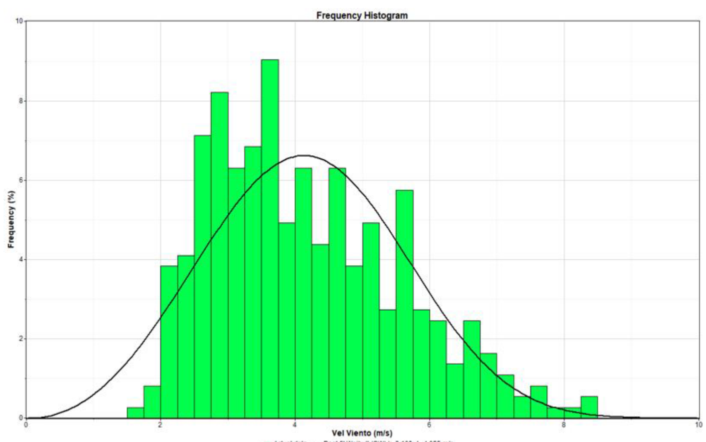


Figure 3. Histogram station Páramo Chingaza, R 2=0.8052.

According to the histogram, it can be seen that the winds with the highest frequency are winds with speeds less than 4 m/s, however at a general level the distribution of the data tends to look quite similar to the Gaussian or normal distribution, this corresponds to the information of the wind atlas of Colombia where the distribution of the wind speed data also tends to the Gaussian or normal distribution. [42] Regarding the statistical analysis, the Weibull k shape factor for the analyzed stations was grouped and observed, identifying that the station with the highest value of this shape factor is the distribution corresponding to the PTAR Tocancipá station with a k= 5.137, followed by the stations Páramo Chingaza and PNN Chingaza with values of k= 3.169 and k= 2.883 respectively, while about the Weibull scale factor c the highest value corresponds to the station Páramo Chingaza with a value c= 4.655 followed by the stations PNN Chingaza and PTAR Tocancipá with values c= 1.955 and c= 1.893 respectively (Table IV), the latter indicates the potential of the study area according to Azal et al. [43] the higher the value of the factor c is, the higher the wind potential of the site.[43]

In the study area, a relationship between the standard deviations and the maximum values registered in this set of stations can be observed, since it is observed that the highest values of standard deviation as well as maximum speed corresponding to the Páramo Chingaza station with values of 1.406 m/s and 8.388 m/s respectively, in the same way, the lowest values of standard deviation (0.38 m/s) and maximum speed (3.071 m/s) correspond to the PTAR Tocancipá station. Regarding the frequency tables, these allow observing together with the standard deviation data that the PNN Chingaza and PTAR Tocancipá stations present the highest stability in wind magnitude since they have a high percentage of data within the range corresponding to the mean (79.72% and 82.47% respectively) while the Páramo Chingaza station is the most variable station since 63.01% of the data is outside the interval corresponding to the mean (Table V).

Table IV. Statistical parameters of the stations in the study area.

Station	Average (m/s)	Standard Deviation (m/s)	Weibull K	Weibull C (m/s)	Max. speed (m/s) (m/s)
Chingaza Paramo	4.167	1.406	3.169	4.655	8.388
Chingaza National Park	1.743	0.598	2.883	1.955	5.868
Tocancipá WWTP	1.741	0.38	5.137	1.893	3.071

Table V. Wind speed frequencies for the study area.

Station	Class Intervals (Wind m/s)				
	0.0 - 2.0	2.0 - 4.0	4.0 - 6.0	6.0 - 8.0	>=8
Chingaza Paramo	3.29%	53.7%	36.98%	6.02%	0%
Chingaza National Park	79.72%	19.72%	0.55%	0%	0%
Tocancipá WWTP	82.47%	17.53%	0%	0%	0%

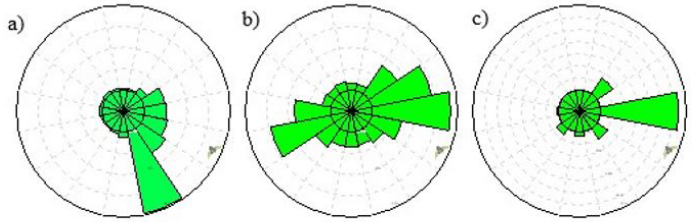
Regarding the averages of the study area (Table IV) it is observed that the station Páramo Chingaza has the highest value of all averages, with a value of 4.167 m/s compared to the values of the other two stations PNN Chingaza and PTAR Tocancipá (1.743 m/s and 1.741 m/s respectively), the value shown by the Páramo Chingaza station is similar to that shown in the Kousseri region in the extreme north of Cameroon where the wind speed values oscillate between 3.29 m/s and 4.38 m/s. [17] .

Wind Direction Description: The following is a description of the information obtained from the wind roses for each of the stations used in the study period:

Páramo Chingaza: The wind roses of this station show that the wind comes from the south-southeast direction mainly, followed by a smaller but appreciable tendency of coming from the east directly, indicating that the wind flow comes from the southeast with direction towards the northeast of the station.

Chingaza NP: The wind roses for this station show a visibly more varied behavior than the other two stations as the wind seems to come from all directions, highlighting two main trends that show origin from both east and northwest, this may be due to the location of the station as well as nearby elements that may alter the wind flow near it.

PTAR Tocancipá: The wind roses of this station show a constant behaviour of the wind flow which comes almost entirely from the east, which shows that the wind flow moves from the east towards the west of the station, a behaviour that could also occur to the north of the study area.



Wind roses for the municipality of Guasca, Stations a) "Páramo Chingaza", b) "PNN Chingaza" and c) "PTAR Tocancipá" respectively.

The information obtained from the wind roses shows a quite unequal behaviour of the wind regime from one station to another, however all the stations show a common characteristic and that is that the wind flow comes mainly from the east and crosses the municipality towards the west, as shown in the following figure.

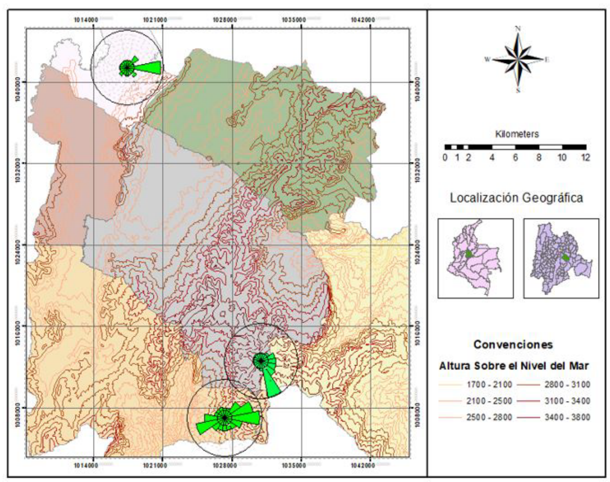


Figure 5. Spatially georeferenced wind roses for the municipality of Guasca.

This behaviour is similar to the observation in the wind potential study by Zamora, Lambert and Montero in Baja California, where there are also wind trends from the east to the west in the Mexicali region. [19]This behaviour can be explained at a more general level, because being located between the tropics of Cancer and Capricorn, Colombia is subject to receive the trade winds coming from the northeast in the northern hemisphere and from the southeast in the southern hemisphere.[22][42]

Spatial and vector analysis of the wind: When performing the spatial and vector analysis of the data it is observed that the wind flow in the municipality behaves in a very similar way to that shown by the wind roses, according to the geostatistical analysis two wind currents are observed, the first coming from the northeast through the municipality of Guatavita, and the second coming from the southeast from the Chingaza páramo, both converge in the municipality of Guasca with direction towards the west of the municipality. In the same way it can be observed that the highest wind speeds are found towards the southern region of the municipality, which shows speeds that reach 4 m/s, similar to what Avellaneda Cusaria's study shows in the Chontales páramo, where it is shown that the average wind speed is in the interval of 4 and 5 m/s, which is also similar to the results obtained in the study of the Chontales páramo. [26] It is also similar to the results obtained in the Hatyai campus of the Prince of Songkla University where an average wind speed of 3.86 m/s is shown. [2]

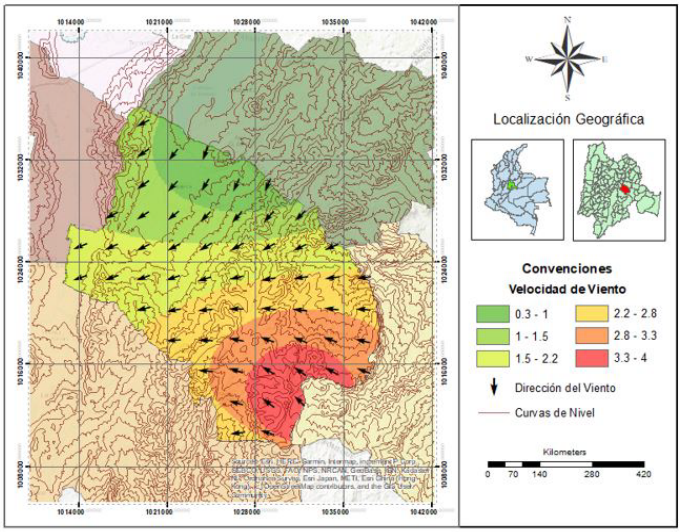


Figure 6. Geostatistical and vector analysis of wind speed and direction in the municipality of Guasca.

According to the Beaufort scale, the wind speeds present at the Páramo Chingaza station (4 m/s) correspond to category 3 winds, i.e. weak breezes. [42] According to the wind atlas of Colombia, winds higher than 3 m/s generally occur over the mountainous area of the central and eastern cordilleras, which corresponds to the area of the Páramo Chingaza station. [42] This corresponds to the study area because it is located in the eastern mountain range of the country.

Wind energy analysis: The energy analysis of the municipality consisted of determining the energy density per unit area of the data obtained from the meteorological stations consulted, obtaining power density values in W/m^2. These values were then analyzed geostatistically, as shown in the following figure.

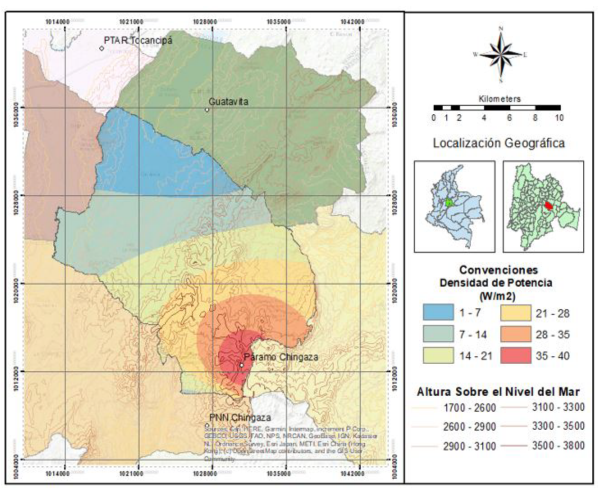


Figure 7. Geostatistical analysis of the energy potential for the municipality of Guasca.

According to the previous figure, it can be observed that the Páramo Chingaza station shows the highest energetic values of all the three stations, which is positive data for the study area since it is the only station that is inside the study area. It is observed that the highest energy supply is found towards the south of the municipality, since this region shows power density values that reach 40 W/m 2.

The above described corresponds with what is shown by the Nanjing station in Jiangsu province, China shows similar power density values [15]as well as the wind atlas of Colombia where it is explained -in a very general way- that the power density values in the Andean region of the country oscillate between 8 W/m2and 125 W/m 2. [42] However, according to Amaya, Saavedra and Arango, the values shown by the analyzed stations (Table 6) correspond to wind power class 1 (Poor) because the power density value is below 100 W/m2 . 2[25] Likewise, according to Zhou, Wu and Liu in their corresponding study, this value corresponds to a poor wind resource zone. [15]

Table VI. Power density and wind power class for the study area.

Station	Average (m/s)	Max. speed (m/s) (m/s)	Power Density (W/m^2)	Wind Energy Class
Chingaza Paramo	4.167	8.388	40	1 (Poor)
Chingaza National Park	1.743	5.868	3	1 (Poor)
Tocancipá WWTP	1.741	3.071	3	1 (Poor)

Determination and selection of wind turbines: To determine if the wind conditions of the municipality are suitable to generate energy, a search for wind turbine models capable of generating energy from the capacities of the municipality was carried out, as mentioned above in section 2.2.9. Using the Windographer program, the following graph was obtained showing the power curves that can generate some of the turbines consulted with the energy conditions shown by the Páramo Chingaza station.

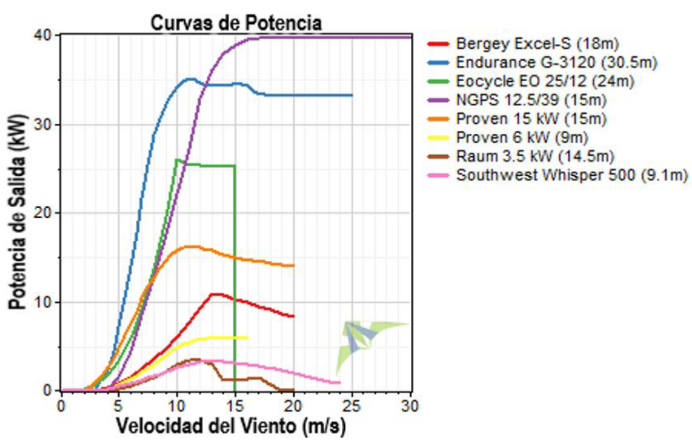


Figure 8. Wind turbine power curves with the conditions of the study area. **Source:** Author 2020. [31] .

As shown in the figure above, several turbines can take advantage of the wind potential of the municipality of Guasca because they can generate energy with wind speeds of less than 4 m/s, which can be translated as good performance characteristics at low wind speeds, which can be useful for energy self-sufficiency at the residential level. [44] .

Determination of estimated performance and wind turbine constraints: The following is a description and analysis of the information obtained from the net power generation analysis, as well as the evaluation of the environmental constraints for the study area.

The estimated performance of wind turbines: When performing turbine performance analysis, it can be observed that multiple turbines can take advantage of municipal wind conditions, as shown in section 3.5. Among the analyzed turbines, the models with the highest net average output power and net energy (Table 8) are the Endurance G-3120, Eocycle EO 25/12 and Proven 15 models, and their net power output is 4.9 kW, 2.2 kW and 2.3 kW, as shown in Table VII,

TableVII. Net mean power output values obtained were with the values of the study area.

Average Net Power Output (kW)							
Bergey Excel-S (18m)	Endurance G-3120 (30.5m)	Eocycle EO 25/12 (24m)	NGPS 12.5/39 (15m)	Proven 15 kW (15m)	Proven 6 kW (9m)	Raum 3.5 kW (14.5m)	Southwest Whisper 500 (9.1m)
0.5	4.9	2.2	0.9	2.3	0.3	0.2	0.2

Table VIII. Net energy is produced under the conditions of the study area.

Net Energy (kWh)							
Bergey Excel-S (18m)	Endurance G-3120 (30.5m)	Eocycle EO 25/12 (24m)	NGPS 12.5/39 (15m)	Proven 15 kW (15m)	Proven 6 kW (9m)	Raum 3.5 kW (14.5m)	Southwest Whisper 500 (9.1m)
4,415.66	42,711.59	19,669.02	7,913.95	20,038.63	2,481.27	1,510.51	1,720.04

Restrictions to the performance of wind turbines: When analyzing the geographical conditions of the municipality, it was observed that the south of the study area is almost entirely within the Chingaza National Natural Park, that is, the area with the greatest energy supply of the study area is almost entirely within a protected area, which may result in an obstacle to the possible implementation of turbines in the municipality.

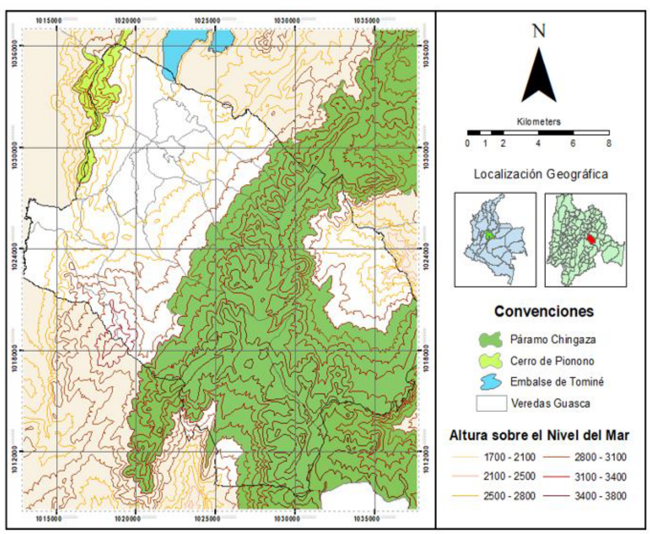


Figure 9. Geographic constraints of the study area.

Likewise, when analyzing the humidity and temperature conditions of the study area, it is observed that the municipality presents temperatures mainly between 6o C and 12o C as well as a relative humidity index that ranges between 80% and 85% in almost all the territory, which can be a possible obstacle for energy production.

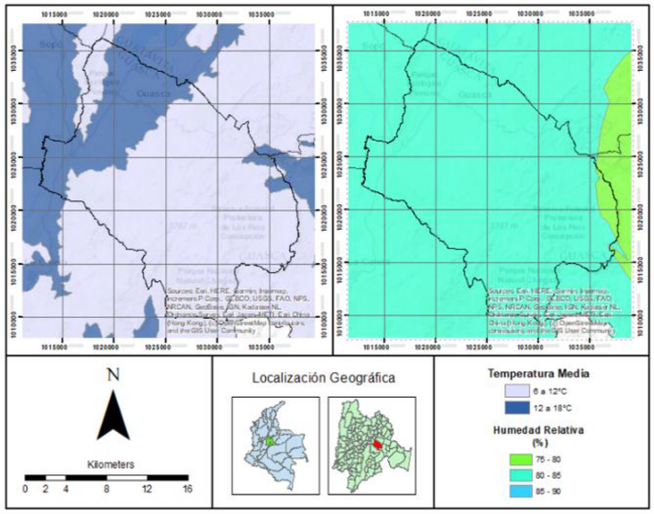


Figure 10. Temperature and humidity conditions in the municipality of Guasca.

Conclusions

Based on the observations in the two statistical analyses, it can be established that the highest wind speed data are found towards the south of the municipality of Guasca, Cundinamarca. According to what was observed in the wind roses and the spatial analysis of the data, it is established that the wind flow in the municipality of Guasca comes mainly from the east (both from the southeast as shown in the data of the stations Páramo Chingaza and PNN Chingaza and from the northeast as shown in the data of the station PTAR Tocancipá) and crosses the municipality towards the west. The greatest energy supply of the municipality of Guasca is located towards the southern region of the municipality, which makes it suitable for small-scale energy generation, in aspects such as energy self-sufficiency at the residential level. However, the analysis of environmental restrictions shows that the southern area of the municipality of Guasca is almost completely within the territory of the Chingaza National Natural Park, which is an important obstacle for the possible future implementation of wind energy systems.

In any case, it should be noted that the existence of other stations in the municipality of Guasca that had to be discarded either because of lack of data or because they did not measure wind speed and direction data indicates that a more detailed study in this municipality or neighboring municipalities could obtain more promising data than the present study for the implementation of wind energy systems in the region.

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