Wind and Solar Energy Potential Assessment for Development of Renewables Energies Applications in Bucaramanga, Colombia.

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Abstract. Currently, the trend of micro-grids and small-scale renewable generation systems implementation in urban environments requires to have historical and detailed information about the energy potential resource in site. In Colombia, this information is limited and do not favor the design of these applications; for this reason, must be made detailed studies of the energy potential in their cities. In this paper is presented the wind and solar energy resource assessment for the city of Bucaramanga, based on the monitoring on four strategic points during the years 2010, 2011 and 2012. According to the analysis, is evidenced a significant solar resource throughout the year ascending on average to 1 734 kWh/m², equivalent to 4.8 kWh/m²/day. Also, from a wind statistical study based on the Weibull probability distribution and Wind Power Density (WPD) was established the wind potential as Class 1 according to the scale of the Department of Energy of the United States (DOE), since the average speed is near 1.4 m/s. Due this, it is technically unfeasible the using of micro-turbines in the city, even so their potential for natural ventilation of building was analyzed. Finally, is presented a methodology to analyze solar harvesting by sectors in the city, according to the solar motion and shadowing caused by existing structures.

1. Introduction

The design of renewable energy systems requires energy potential assessment to properly size its elements, model the behavior of power flows and design the energy management systems. While in countries like Colombia have been identified significant energy potentials, there are significant barriers to entry for this type of systems as a weak legal framework, the lack of financial incentives and limited information about the resource available [1].

Due this, it is important that the designs of these systems have as priority the search of the best financial options, for what is necessary to have information sources that describe and characterize renewable energy resources in the country. These information sources allow establishing the feasibility of implementing certain types generation in some areas of the country, thus encouraging the development of projects that implement systems based in renewable energy.

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2. Wind and Solar potential assessment in Colombia

The behavior of solar radiation in the country can be described according to the study region: in the Caribbean area, where it is estimated the most potential, it’s perceived a daily average close to 5.5 kWh/m², with an annual estimate of 2 190 kWh/m²; in the Pacific area is estimated the lower potential with 3.0 kWh/m² daily average estimated, and an annual estimate of 1 278 kWh/m². Colombia is the country in the region with the best solar potential, with a daily average of 4.5 kWh/m² in almost all the territory [2].

Regarding the wind resource is identified that the best potential is in the Caribbean area, specifically in La Guajira, with a power density of 700 W/m² at 10 m and 1700 W/m² at 50 m, being the more attractive region from a technical standpoint [3]. Due to the wide availability of resource in this area, is identified wind power as a renewable energy source with better features to achieve a higher percentage of participation in the national electricity system.

3. Climate and geography of Bucaramanga

Bucaramanga is located at 7° 08’ N latitude and 73° 08’ W longitude. The climate is classified by IDEAM as follows: at low altitude areas of the city as warm dry, and at high altitude areas as dry temperate. The winds mostly come from the north and northeast, with relatively low average speeds and a maximum value of 2 m/s, especially during the months of January and March; the strongest winds occur between the months of August to October with speeds between 3 m/s and 5 m/s [4].

4. Data source

The solar and wind resource of the city will be evaluated by studying meteorological variables such as wind speed and direction, temperature and solar radiation. For this, will be analyzed hourly frequency data of the years 2010, 2011 and 2012 in four strategic points of the city. This information was provided by the Corporación de la Defensa para la Meseta de Bucaramanga (CDMB) and the Universidad Industrial de Santander.

The first station is called E1 (Centro), and is located at downtown, the second station is called E2 (Real de Minas), and is located at west, the third station E3 (Norte) is located at north, close to the station E4 (UIS), located at the UIS central campus.

5. Wind assessment

The wind resource assessment refers to the way in which the characteristics most predominant of wind is studied for wind power generation [5]. The wind is a random variable, difficult to model and predict, but can be described by a probability distribution function (PDF) based on in-situ measurements [6]. FDP allows to characterize, depending on the reliability of the measurements and the model fit, the wind behavior and the probability of occurrence for each speed at the area where is planned to install a wind turbine.

The wind data analysis is performed by Weibull FDP determine by Equation (1), which depends of two parameters; \( k \) knows as shape parameter and \( C \) as scale parameter. \( f(v,k,C)=\frac{k}{C}\left(\frac{v}{C}\right)^{k-1}e^{-\left(\frac{v}{C}\right)^k} \)

Theoretically, the power increases with wind speed cube [7]. To study the power available at the site is used the Wind Power Density (WPD). As part of the DOE’s Federal Wind Energy Program, the Battelle-Pacific Northwest Laboratory has developed a classification zone with respect to its WPD in W/m². This classification includes a numerical ranking from the lowest level (Class 1) to the higher value (Class 7) [8]. Areas classified as Class 4 or higher are considered to be suitable for generating at large-and small-scale. While Class 2 areas are considered marginal for the development of these projects and Class 1 are not appropriate areas for investment.

In general, the wind resource is scarce in Bucaramanga. The average wind speeds recorded at all stations do not exceed 1.5 m/s. According to the analysis of the data, a quarter of the year winds have speeds approaching 0.5 m/s. Although wind speeds with great potential are presented, greater than 3 m/s, these are recorded in less than 15% of the total hours per year, so that the installation of large
wind turbines would not be viable, since the resource estimate is not significant. The greatest resource is estimated at station E1, with an average speed greater than 1.4 m/s, and the average annual energy greater than 40.8 kWh/m². Furthermore, the station E2, has the lowest wind resource, with an average speed of 1 m/s, where over 30% of hours per year, the wind has a velocity below 0.1 m/s and is estimated an energy annual of 25 kWh/m², as is shown in Table 1.

Table 1. Summary of the analysis of the main parameters for the study of wind potential in Bucaramanga, at a height of 10 m.

| Station | Year | v (m/s) | k | C (m/s) | WPD (W/m²) | $E_{an}$ (kWh/m²) | Class |
|---------|------|---------|---|---------|-------------|------------------|-------|
| E1      | 2010 | 1.42    | 1.42 | 1.57    | 4.89        | 41.66            | Class 1 |
|         | 2011 | 1.39    | 1.42 | 1.53    | 4.56        | 39.96            | Class 1 |
|         | 2012 | 1.40    | 1.43 | 1.54    | 4.65        | 40.88            | Class 1 |
| E2      | 2011 | 1.02    | 1.00 | 1.02    | 2.91        | 22.69            | Class 1 |
|         | 2012 | 1.05    | 1.05 | 1.07    | 2.85        | 25.03            | Class 1 |
| E3      | 2010 | 1.34    | 1.21 | 1.43    | 5.26        | 42.81            | Class 1 |
|         | 2011 | 1.27    | 1.23 | 1.36    | 4.29        | 37.32            | Class 1 |
|         | 2012 | 1.37    | 1.30 | 1.49    | 5.00        | 43.46            | Class 1 |
| E4      | 2010 | 1.48    | 0.99 | 1.48    | 5.82        | 45.96            | Class 1 |

Weibull’s FDP for E1 has a shape parameter equal to 1.42 and a scale parameter equal to 1.57 (for 2010), which represents a narrow curve, with a little occurrence probability of higher velocities than most probable velocity (0.67 m/s). This station presents the better estimation of WPD, with values near to 5 W/m².

For E2, the WPD allowed to observe a not considerable wind resource at west of the city, with values not higher than 3 W/m² at 10 m and 18 W/m² at 50 m, classified as Class 1 according to the DOE scale. The winds in this area of the city come mostly in SE and SSE. For E3, the most probability velocity remains 0.5 m/s, with speeds up to 7 m/s only in 2% of annual hours.

Finally, the station located on UIS campus presents Weibull’s FDP parameters less than unity, so that frequency curve decays exponentially. Therefore it is possible to conclude that the probability of speeds higher than average speed is reduced significantly. In this area the wind resource does not exceed 11.64 W/m² at 50 m, and the estimated annual energy reaches to be higher to 45.96 kWh/m².

6. Solar assessment

The solar resource assessment requires the statistical characterization of the incident radiation at specific locations on the Earth’s surface. This analysis is the key to the development of projects related to solar energy generation, because it allows sizing the solar potential and model the energy performance of these systems [9].

The solar potential assessment requires historical measurements covering several years, because this allows estimate properly the systems’ capacity which impact on the design stage, the initial investment and the final generation cost [10].

There are several ways to assess the energy potential, as satellite images characterization of Earth’s surface [9], and direct measurement of variables in the study site [10]. For this case, direct measurement data was analyzed in order to calculate, the average annual energy ($E_y$), given by Equation (2), where $R_i$, corresponds to radiation for hour $i$ in W/m².

$$E_y = \frac{1}{1000} \sum_{i=1}^{8760} R_i \left( \text{kWh} / \text{m}^2 \right)$$

(2)

The Peak Sun Hours are a factor that allows measure total daily energy received at a study point with respect to a value of 1000 W/m², commonly used to describe nominal characteristics of solar energy equipments. Otherwise described, corresponds to the number of hours of exposure per day, with this level of radiation, required to obtain a total energy equivalent to the certain value [11]. According with the criteria presented in [12], values greater than 3 PSH mean that the site is
considered a suitable location for installation of solar systems. Calculating PSH is determined by Equation (3), where $R_i$ corresponds to radiation for the hour $i$ in W/m².

$$ PSH = \frac{1}{1000} \sum_{i}^{24} R_i \ (h) \quad (3) $$

In general, it is observed that the solar resource available in the city shows outstanding levels and therefore suitable characteristics for the implementation of photovoltaic solar panels and other applications related to solar energy. In the two stations with higher average annual energy values (E1 and E2) these exceed in most cases 1700 kWh/m², while in the other stations (E3 and E4) values are near to 1600 kWh/m². In total there is an average daily value of 4.8 kWh/m², which is equivalent to 4.8 PSH. Taking into account the criteria described above is determined that the city is a suitable location for the installation of solar systems. Values with greater relevance related to solar potential assessment are presented in Table 2. Temperature measurements show an average total daily temperature of 22.55 °C and for sunshine hours of 26 °C, and a maximum average value of 29.08 °C and a minimum of 19.05 °C.

### Table 2. Summary of the analysis of the main parameters for the study of solar potential in Bucaramanga.

| Station | Year | Average Annual Energy [kWh/m²] | Average Radiation [kWh/m²] | Maximum Radiation [kWh/m²] | Minimum Radiation [kWh/m²] | Average PSH [h] | Average Temperature [°C] |
|---------|------|--------------------------------|----------------------------|-----------------------------|-----------------------------|----------------|-------------------------|
| E1      | 2009 | 1722.201                       | 4.991                      | 7.636                       | 1.638                       | 4.991          | 21.08                   |
|         | 2010 | 1734.032                       | 5.160                      | 9.438                       | 1.197                       | 5.160          | 20.82                   |
|         | 2011 | 2016.71                        | 6.074                      | 11.378                      | 1.631                       | 6.074          | 20.47                   |
| E2      | 2011 | 1646.23                        | 4.510                      | 6.741                       | 1.335                       | 4.510          | 23.34                   |
|         | 2012 | 1715.142                       | 4.686                      | 6.855                       | 1.719                       | 4.686          | 23.88                   |
| E3      | 2010 | 1553.477                       | 4.315                      | 7.184                       | 0.91                        | 4.315          | 24.84                   |
|         | 2011 | 1673.670                       | 4.624                      | 7.239                       | 1.283                       | 4.624          | 24.30                   |
|         | 2012 | 1698.468                       | 4.691                      | 7.157                       | 1.770                       | 4.691          | 24.79                   |
| E4      | 2010 | 1186.616                       | 4.599                      | 6.939                       | 1.631                       | 4.599          | 22.92                   |

### 7. Methodology for the analysis of photovoltaic solar use

Taking into account the available solar potential in Bucaramanga, and that the city is a mostly residential area, it is considered relevant to analyze the PV generation in situ, specifically for the satisfaction of the household energy consumption. Initially, data are established about the description of urban (step 1), such as: climate, energy demand and urban distribution; subsequently, the basic estimation of the PV system for satisfying the household energy demand is done (step 2); and finally, the shadowing effect is considered on the generation in situ (step 3).

#### 7.1. Generic data - citywide

Bucaramanga has an area of 165 km², an average temperature of 26°C and a solar radiation of 4.8 kWh/m²/day. The sun movement affects the north facade during 5 months per year (from April to August – period A) and the other 7 months (from September to March) it affects the south facade; but, it is characterized for a significant solar height for hours with highest sun radiation. Its population is consisted by 147 200 household, in 1 341 blocks, for that the dwelling average area would be 73 m².

#### 7.2. Estimation of installed capacity required by dwelling

The monthly generation (MG) depends of the area ($A$), the number of PSH, the PV panels efficiency ($\eta_p$), and the efficiency of the management and energy conversion step ($\eta_{MEC}$) and the and it can be expressed according to the Equation (4) [13].

$$ MG = A \cdot PSH \cdot \eta_p \cdot \eta_{MEC} \cdot 30 \quad (4) $$

With the purpose of determine the size of the PV system for compensating the energy consumption per dwelling, it is required to estimate the area by Equation (5). For that, MG is equaled to monthly
electrical energy consumption (MEEC); that is 200 kWh. The value of PSH is 4.8 by data shown in the numeral 6. The values of \( \eta_P \), \( \eta_{MEC} \) are taken from [13] and represent the technological characteristics of panels, inverters and charger available in the Colombian market. The needed area per dwelling is 12.4 m\(^2\). For an installed capacity density of 150W/m\(^2\), the PV system should be of 2 kW; this is equivalent to the fifth part of the area dwelling.

\[
A = \frac{\text{MEEC}}{\eta_P \cdot \text{PSH} \cdot \eta_{MEC} \cdot 30} = \frac{200 \text{ kWh}}{\text{month}} = 12.4 \text{ m}^2
\]

7.3. Shadowing effect

Bucaramanga is characterized by a high growing in horizontal property (apartments); thus, to determine the PV potential is needed a shadowing analysis caused by the buildings. In the Figure 1(a) is shown the shadows zones that a building generates for the periods A (from September to March) and B (from April to August). The zone of the period A is to the south and corresponds to the shadows caused by the building when the sun radiation affects the north facade; manner similar but contrary happens with the period B.

![Sunchart of Bucaramanga with Solea-2](a). Sunchart of Bucaramanga with Solea-2

![Shadowing curves.](b). Shadowing curves.

**Figure 1.** Characterization of shadowing curve caused by a building in Bucaramanga.

In the Figure 1(b) these projections on the ground are given in function of the height building with respect to its location. It is established that dwellings on the west and east side of the building only could generate energy of significantly way during half time of solar availability each day, and the zones locates in the north and south side could only generate in normal conditions during half year.

For the case of apartments, the use of PV system can be implemented on roof, but overall in the façades. It is important to clarify that according the sun movement, the level generation in façades would be least to the half in comparison to a system on roof without shadows, so the required area would be larger and surely it is not possible to achieve the self-supply.

8. Conclusions

The wind resource in Bucaramanga has a low energy potential, so it is not recommended the implementation of wind turbines in this area. Although some wind speed may exceed 3 m/s, its frequency is less than 15% of annual hours. Also, it’s identified that in over 25% of hours per year the wind speeds does not exceed 0.5 m/s, the measurements carried out on all stations are classified as Class 1 according to the values of WPD.

The solar resource in Bucaramanga has a high potential, so the implementation of photovoltaic panels or systems that take advantage of solar power is convenient. The measurements carried out at all stations exceed the criterion of 3 PSH and is estimated an annual energy close to 1 600 kWh/m\(^2\).
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