



Contribution of Cartography to the Optimization of the Evaluation of Wind Energy Potential in the Republic of Cameroon: Case of Bitchoua Highlands

**VadelTsoigni Eneckdem¹, Rodrigue Aimé Feumba², Odovie Tsomo³
and Jean Roger Bogning^{4*}**

¹*Department of Geography, Faculty of Arts, Letters and Social Sciences, University of Yaoundé I,
P.O.Box -755, Yaoundé, Cameroon.*

²*Department of Geography, Higher Teacher Training College, University Of Yaoundé 1, P.O.Box 47,
Yaoundé, Cameroon.*

³*Department of Geography, Faculty of Letters and Social Sciences, University Of Douala, P.O.Box-
3132, Douala, Cameroon.*

⁴*Department of Physics, Higher Teacher Training College, University of Bamenda, P.O.Box-39,
Bamenda, Cameroon.*

Authors' contributions

This work was carried out in collaboration among all authors. Author ETV carried out the field trips to carry out the measurements, initiated the writing and analysis of the results obtained. Author FRA defined the work, supervised the achievement of results in the field and critical analyses. Author TO participated in the proofreading of the draft and the critical analyzes as well as the literature review. Author BJR coordinated and supervised the writing of the article and verified the physical and mathematical dimension of the results obtained. All authors read and approved the final manuscript.

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ABSTRACT

This study deals with a model combining cartography with mathematical simulation for the optimal evaluation of wind potential in the context of the absence of networks of in-situ observation stations. It is based on both geographic Information Systems (GIS), climate data from NASA Surface Meteorology and Solar Energy (SSE) from 1985 to 2018, and field survey data from 2018. The NASA-SSE data, made it possible to obtain information on the direction of the winds, to determine

*Corresponding author: E-mail: rbogning@yahoo.com;

parameters of distribution of wind speed frequencies (by the Weibull method). Then, we proceeded to the processing and numerical simulation of the data to provide predictions of the electrical energy that could be generated. By mobilizing GIS, the study proposes a decisional mapping allowing the planning and realization of wind energy projects in the studied area. It appears from the work carried out in the field that with an average wind speed of 2.56 m / s (at 50 m from the ground) the winds of Bitchoua have an average power density estimated at 1612.64 W. Under current operating conditions defined by the Betz limit, it would be possible to recover from the local wind, thanks to a 50 m diameter wind turbine, an electrical power of approximately 956.87 W / s, for a maximum average of 974.17 W / s. The spatial representation of this potential presents the Center and North-East of Bitchoua as the most suitable sectors for the installation of wind turbines in the locality. Indeed, with an average wind speed of 2.8 m / s, the area has an average wind power density evaluated at 13.45 W, for an available power of 4221.53 W. Under current conditions of exploitability, the recoverable potential in this part would be about 1251.79 W / s, for 1275.07 W / s on average maximum (well above the local average).

Keywords: Wind energy; GIS; modeling; wei bull distribution; bitchoua.

1. INTRODUCTION

In the opinion of several experts, the increase in the world population and climate change could increase energy needs. However, energy consumption is one of the main causes of global warming and environmental degradation [1,2]. To reconcile developmental and ecological challenges, the need to consider an energy transition to renewable energies is imperative in several respects for human societies. Indeed, because of their availability and sustainability, renewable energies such as wind power would make it possible to reverse the trend of energy choices in countries for a convincing and sustainable development. Although recognized since 2009 as the second source of renewable energy in the world, wind energy remains very little explored and unexploited in Cameroon, despite its a priori considerable potential in the African highlands [3,4,5]. In this way, the use of wind energy would be an interesting avenue, able to reduce the electricity deficit in African countries such as Cameroon, which has significant uplands that can be used. However, the planning of initiatives in this direction is still fraught with inadequacy or even the absence of analysis or assessment of the potential that can be mobilized in the localities. Most of the work identified on the issue is fundamentally centered on mathematical and statistical analyzes with a view to the modeling and numerical simulation of wind data, through models of modeling of the wind distribution [6,7,8,9,1,4]. However, a geographical object in essence, the wind is above all a climatic parameter which varies with time and space. Also, a poor appreciation of its spatial dynamics (very often recurrent in many projects in sub-Saharan Africa) has in many

cases led to the disappointment and the decrease in the community acceptability of renewable energy projects [10]. Globally, there is the problem of poor appreciation, or even low demand for the territory in energy projects for the benefit of over-mobilization of technocratic dimensions. Indeed, the territory in which the mobilizable resource is located is very often not sufficiently questioned, even though it carries more advantages than those seen by technocrats. In this way, spatial analysis would make it possible to make a contribution, however modest, to an optimal assessment of the wind energy potential. Hence the present study aims to shed light on the contribution of cartography and spatial analysis in the assessment of wind energy potential in an upland ecosystem in Cameroon. Based on the postulates of the geography of energies, this modest reflection questions among other things, the analysis of the geographical determinants of energy production: wind energy if applicable. This study is carried out with a view, to reconnecting energy sciences with the territory, from which they derive their operational anchoring. So the work is organized as follows: section 2, briefly presents the location of the study, section 3, presents the materials and methods used, section 4, presents the results and section 5 concludes the work.

1.1 Location and Geographical Context of the Study Area

Bitchoua is a rural locality in the Department of Ndé in the West Region of Cameroon. Thus, the study covers the contiguous localities of Bitchoua-Nord (district of Tonga) and Bitchoua 1 and 2 (district of Bangangté), all located in the western highlands. These localities form the

Bitchoua ensemble which extends from 4° 59' to 5° 44' North latitude and from 10° 36' to 10° 40' East longitude. The area is located on the south-eastern edge of the Bamiléké plateau, a geographical entity ensuring the transition with the South Cameroon plateau. With an average altitude of around 914 m, the area appears as a southern protuberance of the Bamileke plateau. The relief is characterized by hills crossed by more or less deep valleys (Fig. 1).

Bitchoua is a morphological complex with variable altimetry, composed globally of influences, bordered by rather deep valleys allowing to delimit different watersheds. We are gradually moving from the base altitude areas in the South East (with an average altitude of 791 m) to the high altitude areas in the North-West (with an average altitude of 1117 m), strongly

windy. Bathed in a sheltered mountain-type monsoon climate, the area is watered by windy currents. Thus, covering an area of 40.58 km², it is an area with a linear morphology where populations are concentrated along departmental roads and trails to the peaks of interflows.

2. MATERIALS AND METHODS

The adopted methodology combines the modeling and numerical simulation of wind data, with spatial and cartographic analysis through Geographic Information Systems (GIS). It is also a question of returning to the considerations and mathematical or physical concepts which make it possible to make the descriptive junction of the observations on the ground and the energy aspect.

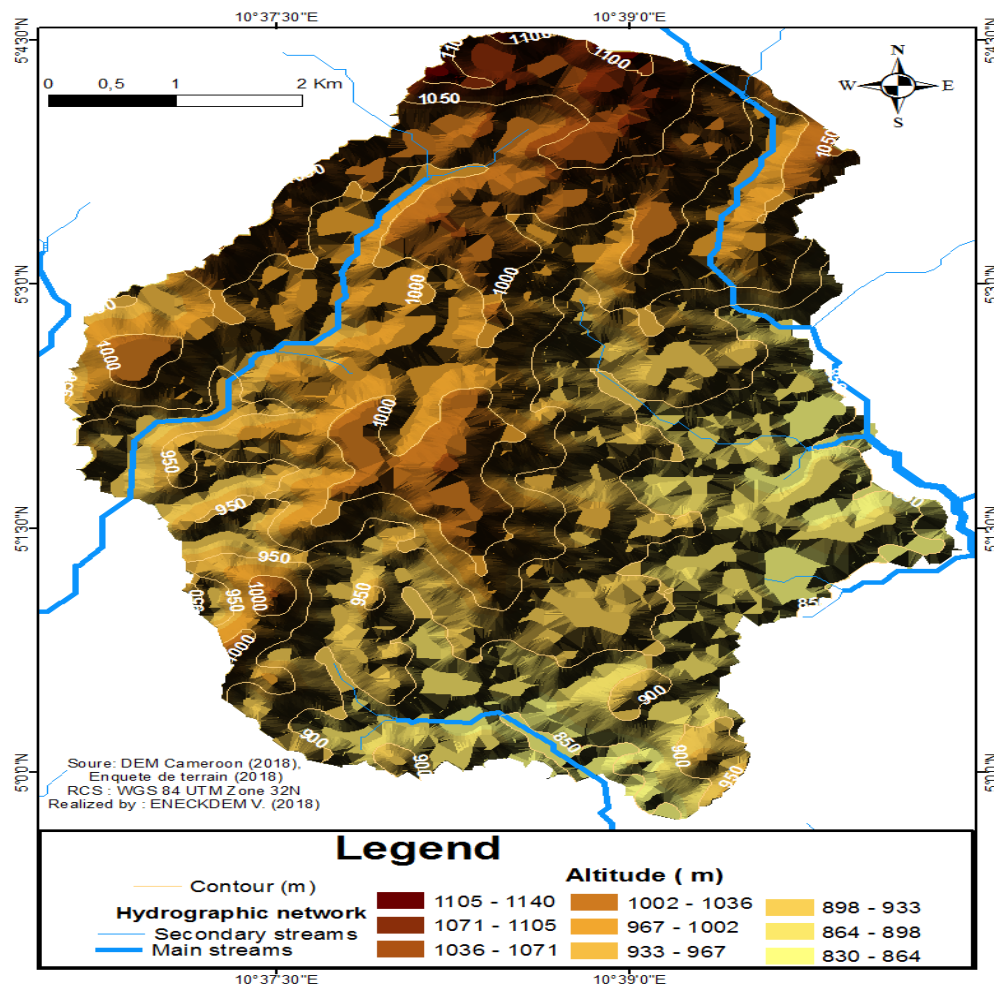


Fig. 1.The topography of Bitchoua locality

2.1 Modeling and Mathematical Simulation of Wind and its Energy

2.1.1 Analysis of the vertical variation of the horizontal wind speed

Weather data has shown that when you rise in altitude, the wind speed increases. The vertical variation of the horizontal wind speed can be translated by an extrapolation law permitting to determine the average wind speed at the height of the hub of installed wind turbine [8]. This law is given

$$\frac{V}{V_0} = \left(\frac{h}{h_0} \right)^\alpha, \quad (1)$$

where $V_0 (m/s)$ and $V (m/s)$ are respectively the average wind speeds determined at heights $h_0 (m)$ and $h (m)$; α is the shear coefficient depending on the roughness of the ground. The shear coefficient (depending on the roughness of the ground) α is given by equation (2) of Justus [11] allowing to estimate the shear coefficient by knowing the wind speed V_0 at a height h_0 [1],

$$\alpha = \frac{0.37 - 0.088 \ln(V_0)}{1 - 0.088 \ln\left(\frac{h_0}{10}\right)}. \quad (2)$$

2.1.2 Modeling of wind speed variations

Like Tar [12] the study uses the Weibull model for modeling wind speed. This is because of its proven effectiveness and the ease of determining its two parameters [1]. It is the most widely used statistical distribution model for wind speed modeling. It depends on two parameters namely: the shape parameter k (which provides information on the shape of the distribution) and the scale parameter C . This model is based on the probability density function $f(V)$ and the distribution function $F(V)$ which are given by the following equations

$$f(V) = \frac{k}{C} \left(\frac{V}{C} \right)^{k-1} \exp \left[- \left(\frac{V}{C} \right)^k \right], \quad (3)$$

$$F(V) = 1 - \exp \left[- \left(\frac{V}{C} \right)^k \right], \quad (4)$$

where, $V (m/s)$ is the wind speed, k is the shape parameter and $C (m/s)$ is the scale parameter.

The probability density function $f(V)$ indicates the probability (or fraction of time) for which the wind has a speed v . The Weibull distribution function or cumulative distribution function of the speed V , $F(V)$ indicates the fraction of time (or the probability) for which the wind speed is less than or equal to V .

To determine the Weibull parameters (equation below), the empirical method is used here, which is based on the use of the standard deviation to estimate the Weibull parameters according to the following equations [13]

$$k = \left(\frac{\sigma}{V_m} \right)^{-1.086}, \quad (5)$$

$$C = \frac{V_m}{\Gamma \left(1 + \frac{1}{k} \right)}, \quad (6)$$

where, Γ is the gamma function, given by the following equation:

$$\Gamma(x) = \int_0^\infty t^{x-1} e^{-t} dt. \quad (7)$$

The standard deviation of the wind speed is given by the following equation

$$\sigma = \left[\frac{1}{n-1} \sum_{i=1}^n (V_i - V_m)^2 \right]^{1/2}. \quad (8)$$

2.1.3 Power density analysis and available power in the wind

Power density dP is the power available in the wind per unit area [14]. The following equation gives its average expression using the average value of the speed [15] and the density of the air. It should be noted that the density of the air varies slightly depending on the temperature and the height above the ground relative to the sea level. However, in several works it is stopped at $1.225 kg/m^3$ as a constant, so difficult to assess [1].

$$dP = \frac{1}{2} \rho V_m^3, \quad (9)$$

where V_m (m/s) is the average wind speed and ρ (kg / m^3) is the density of the air. As for the average wind speed, it is given by the following equation where V_i is the wind speed of each statistical observation:

$$V_m = \frac{1}{n} \sum_{i=1}^n V_i. \quad (10)$$

From there, we can deduce the Power available in the wind (P) for an area (S) of a wind turbine. It is equal to the Power density dP multiplied by the area (S) swept by the blades of the wind generator. The length of the blades is an important parameter, because it defines the recoverable power. Thus, we deduce the power available in the wind by the equation

$$P = \frac{1}{2} \rho V_m^3 S, \quad (11)$$

where P is the power of the wind (W), S is the area covered by the blades of the wind generator and ρ is the density of the air ($1.225 \text{ kg} / \text{m}^3$ under standard conditions at $20^\circ / \text{c}$).

The length of the blades is an important parameter because it defines the recoverable power. Thus, the longer the blades, the larger the scanning surface, the lower their frequency of rotation. To optimize the wind potential, it is advisable to consider medium wind turbines [8]. The study chooses a "Fuhrlander - FL30" turbine wind generator (with a starting wind speed of 2 m/s) of 50 m in diameter, which makes 40 revolutions per minute, suitable for rural areas [16]. However, according to the physical law of the Betz limit (developed by German physicist Albert Betz in 1919 regarding wind turbines), it is impossible to harness 100% of the energy of the wind. This is because not all of the kinetic energy of the wind can be captured by the wind turbine, because the speed downstream of the rotor is never zero. Also, if the rotor captured all the energy from the wind, there would no longer be any displacement of the mass of air behind the rotor. Thus, it was shown by Betz that the maximum energy recoverable in the wind by the rotor is equal to 16/27, or about 59.3% of the total wind energy [10]. On this basis, we can

deduce the recoverable power in the wind (P_r), taking into account the maximum production coefficient (C_{pmax}) expressed by the Betz limit ($16/27 = 0.59$). Thus, the recoverable power of the wind is given as follows:

$$P_r = C_{pmax} \cdot \frac{1}{2} \cdot \rho \cdot v_m^3 \cdot S = 0,59 \cdot \frac{1}{2} \cdot \rho \cdot v_m^3 \cdot S, \quad (12)$$

Taking into account all the other efficiencies of a wind turbine such as that of the generator or the gearbox, the overall efficiency of a machine is around 50% of the Betz limit. Also to conclude, we estimate the average maximum recoverable power or usable power (P_e) per unit area by the equation [17]:

$$P_e = 0.37 S V_{vent}^3. \quad (13)$$

2.2 Spatial and Cartographic Analysis

A GPS (GARMIN etrex 10) was used to survey some strategic points and make a "tracking" between these points. The boundaries of the area have been specified on the basis of participatory mapping and georeferenced to establish the study area. Once all this data was recorded in the GPS, the Mapsource software was used as a tool for extracting and exporting to the Excel spreadsheet, then to GIS software for further processing.

The cartographic processing and spatial analysis of the data mobilized the climatological wind data on the locality (for the period from 01/01/1983 to 08/08/2018) and the local Digital Elevation Model (DEM). This made it possible to build models that cross these variables in order to model the windy deposit. The analysis of the Digital Terrain Model (DEM) served as a basis for the construction of an altimetric model to identify the areas that would be the windiest in Bitchoua and its surroundings. The cartographic processing was organized around the superposition of wind data (Direction and speed) on the altimetric model to identify and zoning areas with strong wind. The tools used for cartographic processing are listed in Table 1.

3. RESULTS

3.1 Wind data in the Locality of Bitchoua

This contribution retains as an important parameter for the evaluation of the wind potential

the wind speeds (V_0) at 50m from the ground (h_0). At this height, there are periods of strong winds (maximum speed) and periods of moderate winds (average speed) and periods of weak winds (minimum speeds). Analysis of the data series presents two main windy periods: December-March and July-August (Fig. 2).

The analysis of the average wind speed curve with respect to the line of the minimum threshold value for the start of the Fuhrlander rotor - FL30 (2m/s), shows that the winds at Bitchoua are satisfactory enough to consider a wind power valuation. Also, other parameters such as the frequency distribution of the wind speed, the wind rose, as well as the estimate of the energy produced by a wind generator to be installed on the site should be studied. All this contributes to a better dimensioning of a wind system intended for the production of electricity in the locality.

3.1.1 Analysis of vertical and spatial variation of horizontal wind speed

Meteorology has shown that as you rise in altitude, the wind speed increases. Regarding

the vertical variation of the horizontal wind speed at a specific point, this variation whose equation was given above relies a lot on " α " which is the shear coefficient depending on the roughness of the ground. A high " α " reveals a strong ground roughness, because the coefficient varies widely depending on the topography of the site. Based on the locality shear coefficient, which amounts to 0.33, the vertical variation of the horizontal wind speed gives the following values (Fig.3).

We therefore retain that the vertical variation of the horizontal wind speed is strongly correlated with the height. Thus, with an average wind speed of 2.56 m/s at 50m from the ground, we go quickly from 3.22 m/s at 100m, up to 4.35 m/s at 250m from the ground. Hence the interest of large wind power plants.

In addition, different morphological units are equivalent to different classes of wind speeds. Thus, by coupling altimetry to wind data, we realize that the relief does indeed influence the spatial distribution of horizontal wind speeds (Fig. 4).

Table1.Cartographic processing and analysis tools

Software	Version	Utilities
Mapsource	6163	Retrieving tracks and Waypoints
ArcGis®	10.2.2	-Data processing and analysis -Treatment of the different thematic classes - Cartographic dressing
Adobe Illustrator®	CS5	Cartographicfinalization

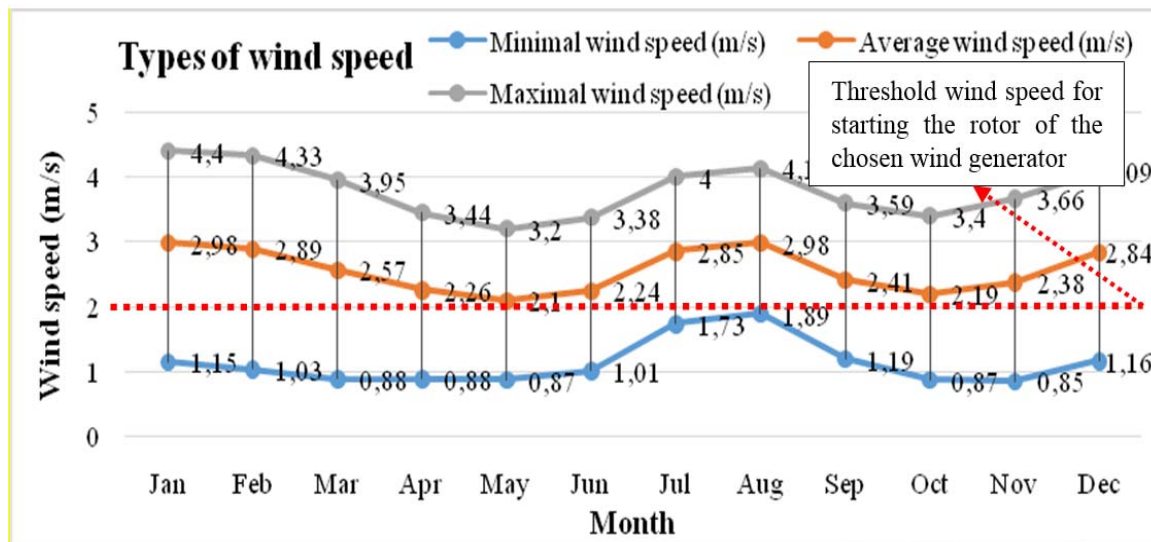


Fig. 2.Minimum, average and maximum wind speeds at 50 m at Bitchoua

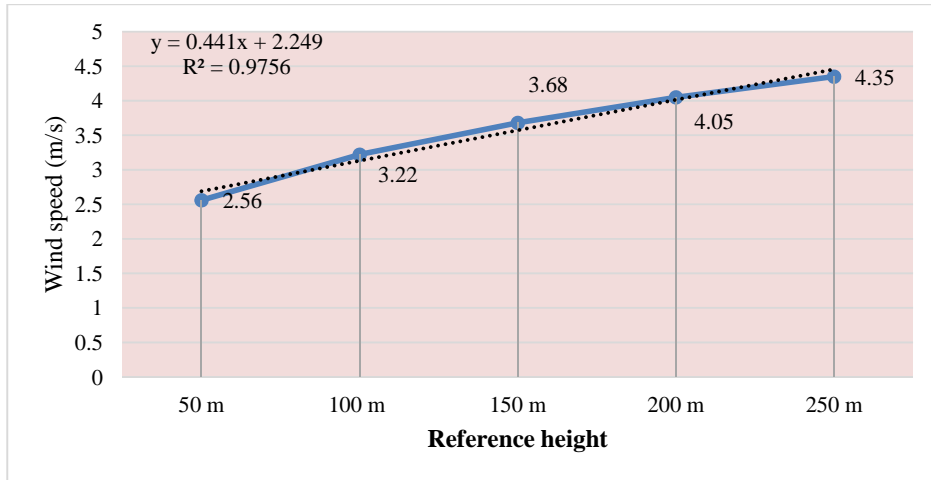


Fig. 3. Vertical variation of horizontal wind speed

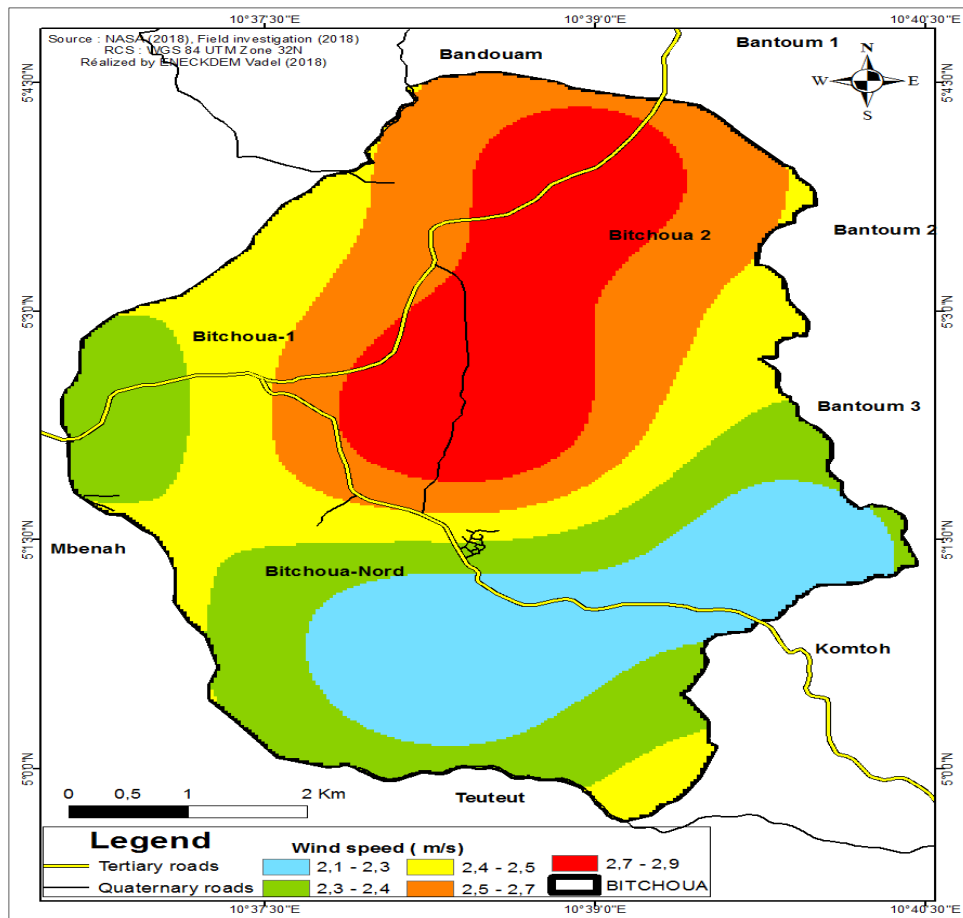


Fig. 4. Spatialization of wind speeds in Bitchoua

It emerges from spatial analyzes that the distribution of wind speeds obeys more or less that of the general morphology of the topography of the locality. In this regard, at Bitchoua 2, the winds are generally stronger than anywhere else in the area under consideration. On the other hand, in Bitchoua-Nord, the winds are generally the weakest in the locality. Thus, we can a priori conclude that Bitchoua 2 (area with the highest topography of the locality), would be the most suitable area for the production of wind energy.

3.2 Modeling of Variations in wind Speed and Direction

3.2.1 Modeling of variations in wind speed

In the assessment of wind potential, knowledge of the distribution of wind speeds (Fig. 5) is an important parameter, allowing a good estimate of the energy that can be produced by a wind generator in the locality of Bitchoua.

For the period studied, we note that the wind speed varies from 1 to 6m/s. Over this range, the curve of the probability density and that of the

distribution function practically "match". The occurrence is concentrated in the speed range 2 to 4m/s, with a frequency peak for the speed value of 3m/s. That said, we can conclude that a wind speed recurrence is around 3 m/s.

3.2.2 Wind direction modeling

The modeling of the wind directions is based on the prevailing winds, with a view to distinguishing the main windy corridors of the locality of Bitchoua (Fig. 6).

Bathed in the Cameroonian high altitude climate, with its predominance of winds coming from the North-East and East towards the West, the locality is influenced to a lesser extent by this global regime. In the opinion of the populations, in fact, Bitchoua is a fairly windy locality throughout the year. Generally, the area is drained by easterly winds from Bantoum (1, 2 and 3). Regarding its spatial distribution, it emerges from the interviews and focus groups that the North-East is the windiest area of the site.

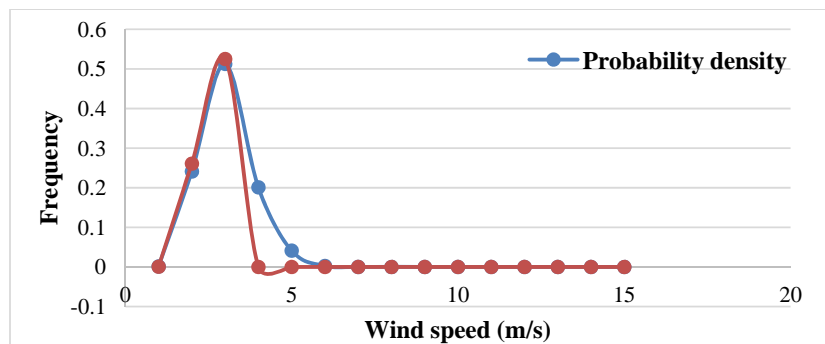


Fig. 5. Modeling of the variation of wind speed by the Weibull distribution

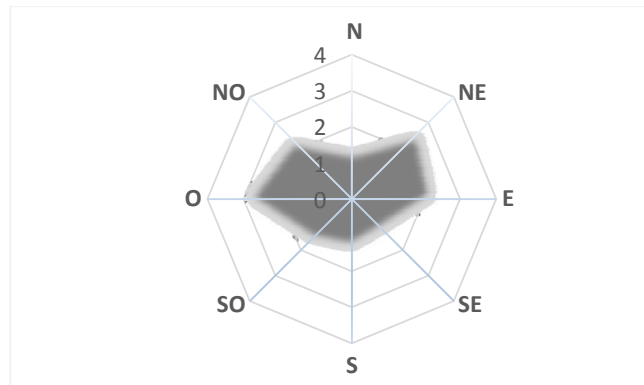


Fig. 6. Compass rose prevailing in Bitchoua

3.2.3 Cartographic modeling coupled with wind speed and direction

Based on data from prevailing winds, coupled modeling of wind speed and direction allows zoning of high potential windy corridors in the locality of Bitchoua (Fig. 7).

According to the discretized classes, we can easily appreciate the trajectories of the prevailing winds. In general, the locality is swept by an easterly wind; from the Bantoum (1, 2, 3), heading west (Bassamba) and south-west towards Teuteut and Mbeunah. As for the prevailing winds (average speed 2.8 m / s), they mainly sweep the area of Bitchoua 2, coming from Bantoum 2 and 3, in a westerly direction towards Bassamba. However, there are also low intensity winds (2.3 m / s) which are generally trapped in the valleys, and therefore their directions are conditioned by the peaks that border them.

3.3 Power Density and Power Available in the Wind

3.3.1 Wind power density

Power density (dP) is widely used in the evaluation of wind potential and the energy produced by a wind generator. Based on the Manwell equation [15] presented above, the average wind dP in the locality of Bitchoua is estimated at around 10.28 W/m². On an annual scale, this Power density can also be calculated by multiplying the average dP by the number of hours in the year, estimated at 8760h. Thus for the locality of Bitchoua, it is estimated at 90,052.8 Wh/m². It should be noted that this value is quite large and allows wind power generation initiatives to be possible.

3.3.2 Power available in the wind

With an estimated average wind speed of around 2.56 m / s, at 50m diameter wind turbine would be suitable to generate electricity at Bitchoua. Thus, the kinetic power of the wind P (in Watt), which crosses a surface ($S = 157m^2$) perpendicular to its direction is evaluated for the locality at approximately 1612.64W. Taking into account the losses attributable to the machinery and the instruments, one can estimate thanks to the theorem of the "Betz limit" the average quantity of energy recoverable in the wind which blows at Bitchoua at approximately 956.87 W / s,

that is to say 974 , 17 at most. The spatial analysis of the results, delivers a discretization of the values in the locality. Thus, a distinction is made between areas with high potential and those with low wind potential (Fig. 8).

The mobilization of GIS and mapping tools makes it possible to realize that the average value of the wind energy production potential tends to smooth the natural variability of the physical components that determine it. Thus, realize that there are areas with much lower potential than average (the South-East of Bitchoua) and areas with relatively higher potential (the North-East). Indeed, the Center and the North-East of Bitchoua appear to be the most suitable areas for wind turbines, with average wind speeds of 2.8 m/s. Here, the average power density of the wind can be evaluated at 13.45 W/m², for an available power of approximately 4221.53 W. Under current operating conditions, the recoverable potential in this part would be approximately 1251.79 W/s, for 1275.07 W/s on average maximum (well above the local average). The mapping of this power shows a gradual decrease in this power as we go south-east, in areas of low wind potential.

4. DISCUSSIONS

Firstly, for such an exercise, it is generally considered that the data from ground stations are more reliable than the satellite data used here. However, the decree creating the meteorological structures of the National Meteorological Directorate (DMN) of Cameroon specifies that they must be located in the capitals of departments, hence their non-existence in rural localities like Bitchoua [5]. However, it is in these remote areas that many Renewable Energy Technologies could be effectively exploited [18]. This is why the present study is based on models with reassessed reliability which rely on satellite data. In its conduct, the study and modeling of wind potential relied primarily on the Weibull method, although it is not always suitable for all wind speed distributions. Which distributions may vary in turn depending on the nature of the area. This is why we have often seen authors have also resorted in recent years to new models of the wind distribution, like the models: Gamma, Normal, Lognormal and Rayleigh. Nevertheless, following the work of Tar [12] having studied the choice of an optimal model of wind speed distribution by comparison of the different distributions to that of Weibull, it appears that the

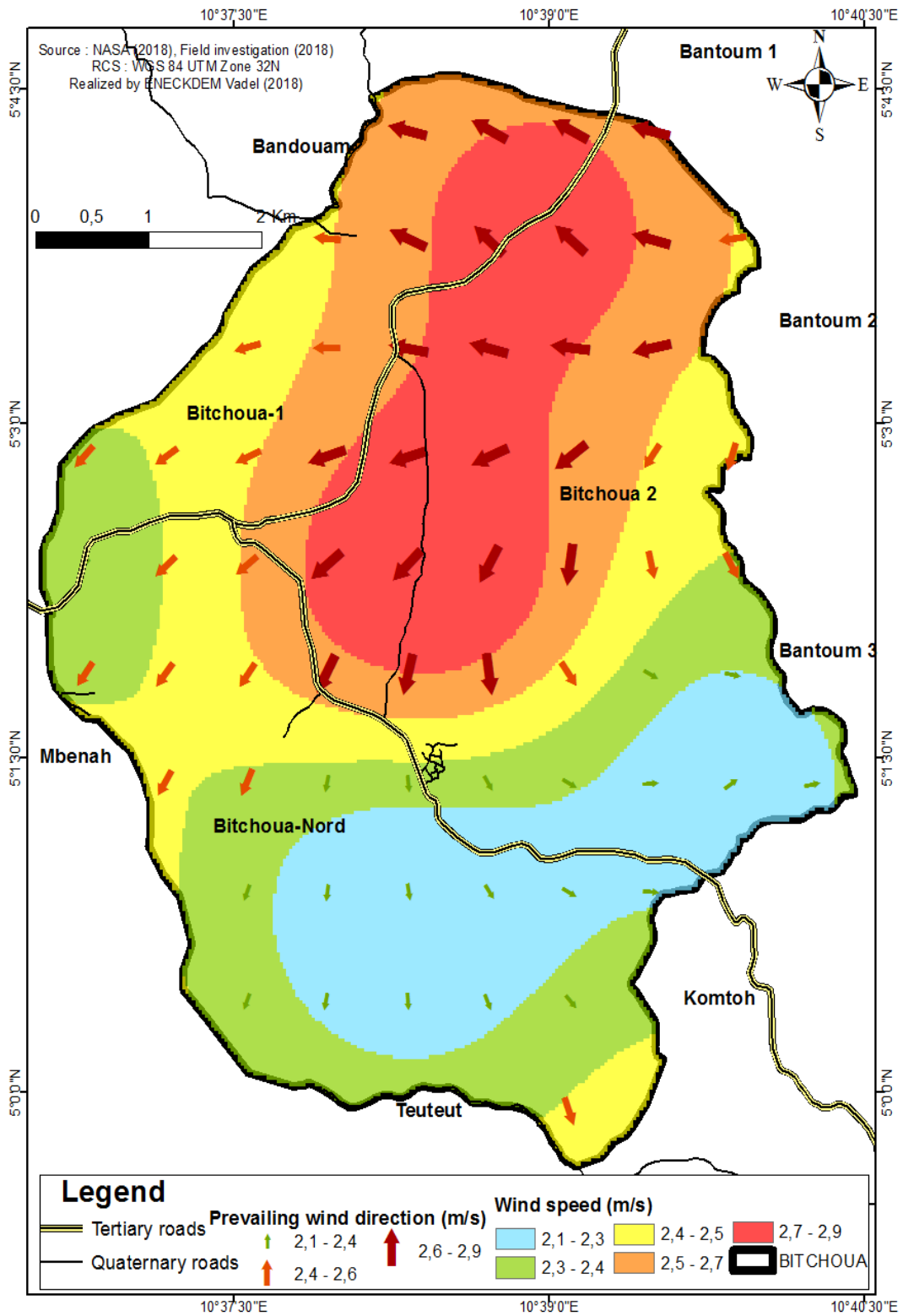


Fig. 7. Modeling of wind directions and speed in Bitchoua

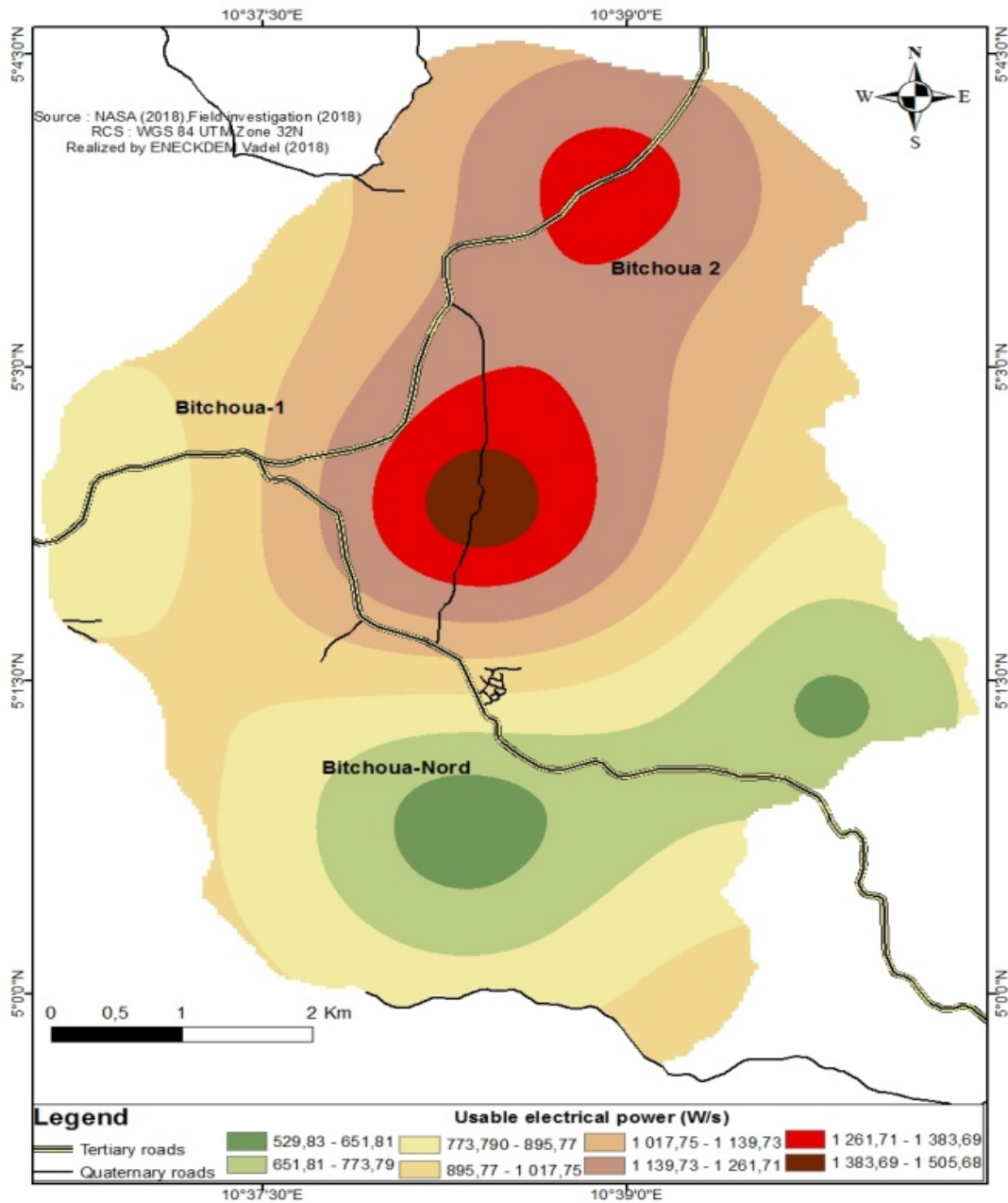


Fig. 8. Spatialization of the prediction of exploitable electrical energy in Bitchoua

model give rather good approximations of around 51.03% [1]. However, the Weibull model is the most recommended because of the ease of determining its two parameters and the fallibility of its estimates [12]. Reasons why it is increasingly used in numerous studies [19, 20, 21, 12, 22].

The results of this reflection, in terms of strategies for evaluating wind energy potential,

closely resemble the work of several authors identified in the literature [19, 20, 23, 21, 12, 24, 25, 26, 27, 28, 22, 1, and 4]. Indeed, as in the precursors, the study was the subject of statistical analysis and simulation of the wind by determining the average characteristics (average speed, wind rose, etc.) and used the Weibull distribution for the modeling wind speed [29]. However, following the work of previous authors, the study gives a point of honor to spatialization,

through a discretization mapping of areas with high, medium and low potential in wind energy. Indeed, unlike other specialists, this study makes a contribution, however modest it may be, to an assessment of the potential for wind energy which combines Geographic Information Systems (GIS). This would provide decision-makers with a valuable tool capable of guiding their choices and informing these decisions effectively and efficiently.

5. CONCLUSION

This work examines the contribution of mapping and spatial analysis in the assessment of wind energy potential in an upland ecosystem in Cameroon. To carry out this reflection, the study used wind data (speed and direction), altimetry and geographic data. These data were processed through probabilistic and spatial analyzes to extract useful information. It emerges from the analyzes that Bitchoua is a locality conducive to the development of renewable energies from wind sources. The evaluation of the wind potential reveals in the locality, an average power density of the wind estimated at about 10.28 W / m^2 , which would allow to develop an optimal power of 1612.64 W, thanks to a wind generator 50 m in diameter. However, taking into account the losses attributable to machinery and instruments, it would be more accurate to estimate the average electrical power likely to be generated by such a wind generator (surface area $S = 157 \text{ m}^2$) at 956.87 W / s , for about 974.17 W / s on average maximum. It emerges from the spatial analysis, that there would be areas (the North-North-East of the locality) which would offer a potential much higher than that of the average calculated in the present study. In carrying out this contribution, some intrinsic limitations should be noted. Enter games for such an exercise, it is recommended in climate sciences to use in situ climate data, which are more reliable than the satellite data used here [9]. So the study recommends to improve the reliability of the results of the work to install quality weather stations and to work with their data sets. Moreover, this reflection opens a gap in research on the sizing of a wind farm adapted to the variability of geographic contrasts.

So beyond what has just been said, what should be intensified in our future work will be to take into account numerical simulations, interactions between wind turbines and the environment and wind-wind turbines also called wake effect, in

order to provide a closer estimate of the energy production of a possible wind farm.

Far from the academic work that is done in this manuscript, the main motivation was to contribute to the energy problem facing our country. We have chosen for this purpose the wind energy track which is under exploited. So, we made the decision to have an eye on the potential wind turbines of Bitchoua. This work is therefore for us a pioneering work in a series of future works in the field of wind energy.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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