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Research Paper

Techno-economic assessment of wind energy conversion systems for power generation for the city of N'Djamena in Chad

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A B S T R A C T

Around the world, with a significant increase in installed capacity each year, wind power is one of the most profitable forms of renewable energy. In this study, three commercial wind turbines, namely Bonus 300kW/33, Bonus 1MW/54 and Vestas 2MW/80, were selected as large-scale wind power conversion systems (WECS) for the technical evaluation of production electricity for the N'Djamena site in Chad. The economic evaluations of these three WECS for power generation are calculated using the Cost Calculation Technique (PVC). Thus, the results obtained show that the highest capacity factor is 15.29% with Bonus 1MW/54 while the lowest at 11.39% with Bonus 300kW/33. The minimum average cost per kWh is 23 US$ / kWh with the 1 MW/54 Bonus, while the highest cost is 33.8 US$ / kWh with a Bonus of 300 kW / 33.

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1. Introduction

Excessive use of fossil fuels can lead to energy and environmental problems. Hence, several countries are obliged to explore the clean sources of energy [1]. In recent decades, wind energy has been used much more in many countries [2]. By making a comparative study of economic resources in view of climatic constraints, reference should be made to the choice of macro-sites to enable the determination of the most favorable sites for wind farms [3]. The choice of macro-sites from the results of the research can provide a crucial basis for wind projects [4-6]. Among the factors to be taken into account for the choice of macro-sites, one can retain the wind energy [7-9]. Wind energy resources can be clearly and efficiently estimated [10, 11]. Wind speed is a disturbing hallmark in the estimation of wind energy [12, 13]. Generally, depending on the observed wind speed data and probabilistic distribution functions, the frequency distribution function can be obtained [14]. In developing countries, it is important to carefully study and understand the energy model to ensure a good standard of living [15]. Wind characteristics such as speed and direction can be developed to determine the wind potential of a site [16]. In many countries around the world, studies and assessments of wind characteristics and the potential of wind energy are being conducted. These countries are the Hong Kong islands whose wind analysis was discussed by Lu et al. [17]. Youm et al. conducted research on the potential of wind power in Senegal using the Weibull probability distribution [18]. For the production of electricity, the wind is an inexhaustible energy resource and appreciable for its non-pollution [19]. Among the renewable energy sources available, wind energy has increased rapidly over the past two decades [20]. Among renewable energy sources such as environmental protection, the security of supply, biodiversity and other socio-economic factors, wind energy is also to be promoted whose growth is the fastest in the world [21]. Due to population growth and industrialization in recent days, in Ethiopia energy production is increasing rapidly. To transform, develop energy resources such as wind, solar, biomass, hydroelectricity, natural gas and geothermal energy can be used within the framework of an optimal economy [22, 23]. Around the world, there are many investigations focused on the assessment of distinctive characteristics of the wind and a study to discern the feasibility of wind projects [24, 25]. In fact, in all regions of Ethiopia, the very limited potential of different sources of renewable energy has been studied [26]. However, the techno-economic evaluation of wind energy conversion systems for power generation for the city of N'Djamena in Chad has never been the subject of a study. It is therefore important to make an economic estimate with a close interest in wind power production in Chad, which will allow investors to secure long-term compensation to improve the profitability of wind power. In addition, wind power generation has been progressing with sustained momentum for some 40 years. In 2018, the commissioning of new wind power plants (onshore and offshore) represented 51.3 GW worldwide. The main objective of this article is to assess the wind resources of the N'Djamena site in the Sahelian zone of Chad. This study focuses on the presentation of the compass rose, the factor of capacity, power and energy as well as the various costs associated with the use of wind energy.

2. Methodology

2.1. Presentation of the data used

Table1. Presentation of the geographical coordinates of the site

Variable	Value
Longitude	15°2 E
Latitude	12 °8 N
Elevation	294 m
Anemometer Height	10 m
Period(year)	20

2.2. Wind potential

The two parameters Weibull probability density function is used to estimate wind speed variations using the following equation:

$$f(v) = \left(\frac{k}{c}\right).\left(\frac{v}{c}\right)^{k-1}.exp\left(-\left(\frac{v}{c}\right)^{k}\right),(k > 0, v > 0, c > 1) \quad (1)$$

To estimate the Weibull parameters, several methods are proposed among which, one can quote: method of the standard deviation, method of the energy form factor, graphical method, method of the maximum of likelihood, method of the density of power and method of the moment. In this study, we used the energy form factor method. It is defined by the following equations [27, 28]. The shape parameter can be estimated as follows [29]. Instead, the scale factor can also be obtained mathematically [30].

2.3. Validation of the wind speed at different heights

The wind speed considered in this study is measured at 10 m altitude at ground level.
For the application of wind energy, it is important to extrapolate the wind speed to the height of the hub .The most commonly used method for this purpose is power law. It is expressed by the following relation [31].

$$v(z_2) = v(z_{10})\left(\frac{z_2}{z_{10}}\right)^{\alpha_1} \tag{2}$$

The exponent α_1 is assumed to be 0.143 (or 1/7). It can be determined as [32]:

$$\alpha_1 = \frac{[0.37-0.088ln(v_{10})]}{\left[1-0.088ln\left(\frac{z_{10}}{10}\right)\right]} \tag{3}$$

The extrapolated Weibull parameters are linked by the expressions below

$$\mathrm{c}(h) = c_0\left(\frac{h}{h_0}\right)^n \tag{4}$$

$$k(h) = k_0\left[1-0.088ln\left(\frac{h_0}{10}\right)\right] / \left[1-0.088ln\left(\frac{h}{10}\right)\right] \tag{5}$$

2.4. Estimated output power for WECS

By considering such a system, for this site, power curves associated with wind turbines, the annual energy output of a selected site can be calculated .WECS cannot exploit its maximum efficiency in general, because of the power rating, and wind shutdown and depending on the wind characteristics of the site, cut-off speeds must be defined. One of the important performance parameters of wind turbines is the capacity factor (C_f) which is a proportion of the average power (Pe, ave) up to the rated electrical power (Per) and is estimated at using the following mathematical equations[33]:

$$P_{e,ave} = P_{eR}\left\{\frac{e^{-\left(\frac{v_c}{c}\right)^k}-e^{-\left(\frac{v_r}{c}\right)^k}}{\left(\frac{v_r}{c}\right)^k-\left(\frac{v_c}{c}\right)^k} - e^{-\left(\frac{v_f}{c}\right)^k}\right\} \tag{6}$$

and the capacity factor C_f of a wind turbine is given by [34]:

$$C_f = \frac{P_{e,ave}}{P_{eR}} \tag{7}$$

$$E_{out} = 8760 * t * P_R * A * C_f \tag{8}$$

2.5. Analysis of the cost of wind energy

The ability to produce energy at a minimum operating cost depends on the feasibility of a wind power plant. The key parameters governing wind energy economics include capital cost, power generation, power generation, operating and maintenance costs, turbine life and fuel efficiency discount.

From one region or country to another, these factors vary. Thus, among all the parameters listed, the generation of electricity using WECS and their investment costs are the most important factors. Moreover, in addition to the cost of the wind turbine set by the manufacturers, the specific cost of a wind turbine changes from one manufacturer to another. Therefore, the specific cost of a wind turbine can be taken (minimum and maximum values) given the band interval [35].

The present value of costs (PVC) is determined using relationship [36]:

$$PVC = I + C_{omr} \times \left[\frac{1+i}{r-i}\right] \times \left[1 - \left(\frac{1+i}{1+r}\right)^t\right] - S \times \left(\frac{1+i}{1+r}\right)^t \tag{9}$$

where, r represents the interest rate, i the inflation rate, t the useful lifetime of turbine, *S* is the scrap value.

To estimate PVC, the following quantities and assumptions are retained:

- *r* and *i* are respectively 11.97% and 3.60%.
- The service life (t) of the machine is 20 years.
- O & M costs: A significant portion of the total annual operating costs of a wind turbine, but their value is not fixed. Operating costs vary each year with changes in inflation and interest rates.

In this study, we admit that the annual Com costs are of the order of 7.5% of the investment cost of the studied wind system (system price /lifetime).

– The factor (S) is an additional cost for most wind farms, located near rural areas of the country. Therefore, installation costs (including the cost of civil works, turbine transportation, and road construction) are still high, compared to the costs that would be incurred if the wind turbines were installed in an urban area. It is admitted here that (S) is equal to 10% of the price of the wind turbine.
– As most projects are carried out in rural areas, the cost of land and civil works are not high. They can therefore be estimated at 20% of the price of the wind turbine.
– The Cost of Electricity (COE) per unit kWh using the PVC method is then expressed by the following expression:
–

$$COE\ (\$/kWh) = PVC / E_{out} \qquad (10)$$

3. Results and discussion

3.1. Wind rose

The wind rose plays a very important role in locating sites suitable for the installation of a wind turbine. Figure 1 shows the wind rose for the N'Djamena site. The predominant sectors are South (S), North-West (NW), South-West (SW), South-South-West (SSW) and the dominant sectors are North (N), North-North-East (NNE) and North-North-West (NNW).

We also note, the more the color tends to dark green, the more direction is important for the wind turbine installation. The more the color tends towards the light green, the more the direction is less important.

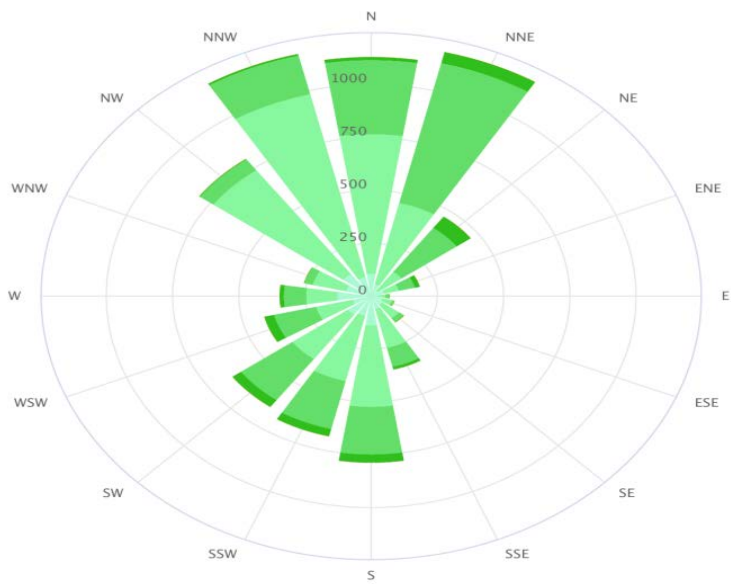

Fig 1. The wind rose

3.2. Extrapolation of wind speed to 30.50 and 67 m altitude

Figure 2 presents the monthly variations of extrapolation of wind speed at 30 m, 50 m and 67 m for the N'Djamena site. This table shows the variation from 3.311 m / s to 5.49 m/s to 30 m; from 3.846 to 6.217 m/s at 50 m and 4.19 at 6.677m/s at 67m. In addition, it is observed that at 30 m altitude, the average annual speed is 4.35 m/s; at 50 m it increases to 4.98 m/s and at 67 m it is 5.38 m/s. This allows us to conclude that the wind speed increases with altitude.

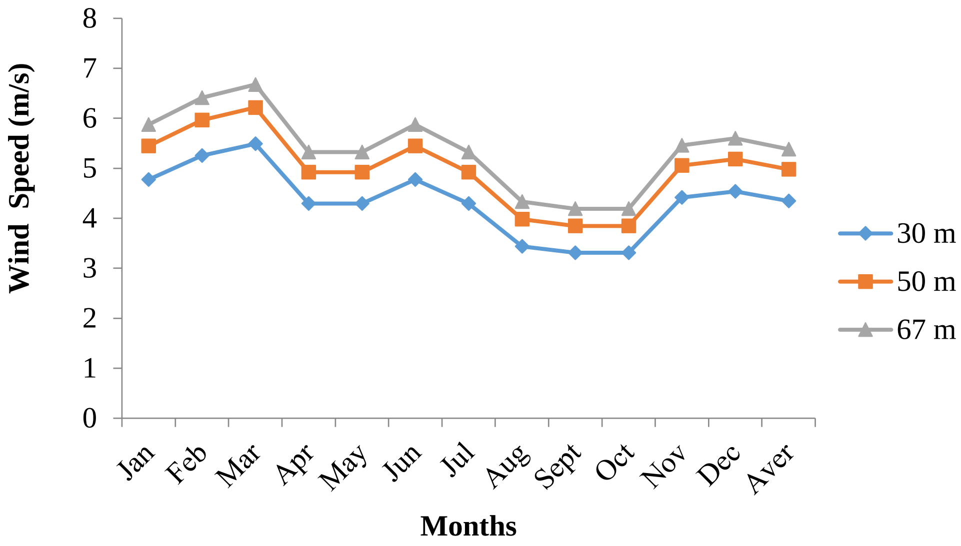

Fig.2 Extrapolation of wind speed to 30.50 and 67 m altitude

3.3. Extrapolation of the Weibull k parameter

Figure 3 presents the monthly variations of the extrapolation of the shape parameter at 30 m, 50 m and 67 m for the N'Djamena site. This table shows the variation from 3.563 to 4.729 at 30 m; from 3.579 to 4.75 to 50m and 3.588 to 4.763 to 67m. On the other hand, at 30 m altitude, the annual value of the Weibull form parameter is 4.27; at 50 m it is 4.293 and at 67 m it goes to 4.30. This allows us to conclude that the shape parameter increases with altitude.

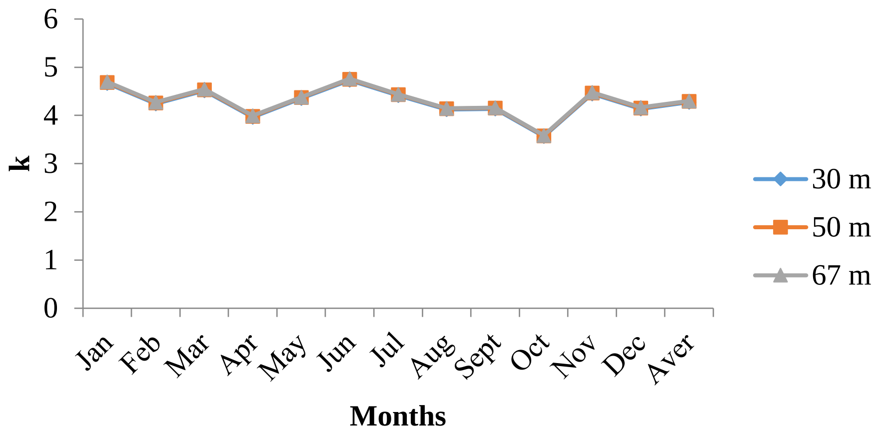

Fig 3. Extrapolation of the shape parameter (k)

3.4. Estimation of the electric power supplied by wind turbines

Three wind turbines are chosen to evaluate wind energy. It's about: Bonus 1 MW/54, Bonus 300 kW/33 and Vestas 2 MW/V80. Their rated power (P_R) is 1000, 300 and 2000 kW, respectively.

Table 2. Choice of selected wind turbines and their characteristics

Characteristics	Bonus 300 kW/33	AN Bonus 1MW/54	Vestas 2MW/80
Rated power P_R *(kW)*	300	1000	2000
Hub height *h (m)*	30	50	67
Rotor diameter *(m)*	33.4	54.2	80
Rated wind speed *Vr (m/s)*	14	15	16
Cut-in wind speed *Vc (m/s)*	3	3	4
Cut-off wind speed V_f *(m/s)*	25	25	25

Table 3. Different values of the cost of wind turbines [38]

Size of wind turbines (kW)	Specific cost ($/kW)	Average cost ($/kW)
<20	2200-3000	2600
20-200	1250-2300	1775
>200	700-1600	1150

3.5. Present value of Cost of wind electricity

Figures 4 and 5 present the monthly values of the cost of wind energy in US$ per kWh and XAF per kWh respectively.

Thus, figure 4 shows that the costs vary from 0.67 to 4.66 $/kWh (Bonus 1MW/54); 0.70 to 6.11 $/kWh (Vestas 2MW/V80) and 0.85 to 7.69 $/kWh (Bonus 300kW/33).

As for figure 5, the costs vary from 364.83 to 2530.63 XAF/kWh (Bonus 1MW/54);

380.08 to 3318.28 XAF/kWh (Vestas 2MW/V80) and 462.22 to 4178.73 XAF/kWh (Bonus 300kW/33). We see that the amount is higher in XAF.

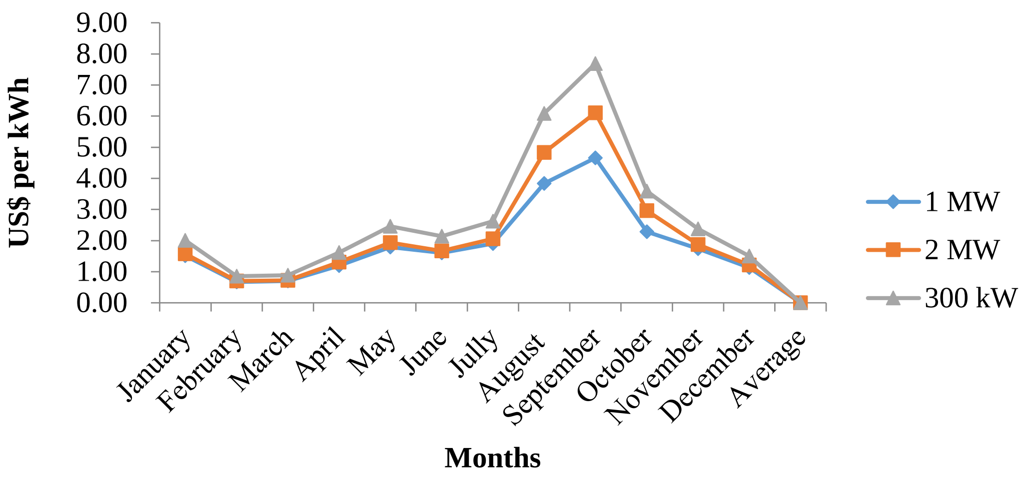

Fig 4.Cost of Energy (US$ per kWh)

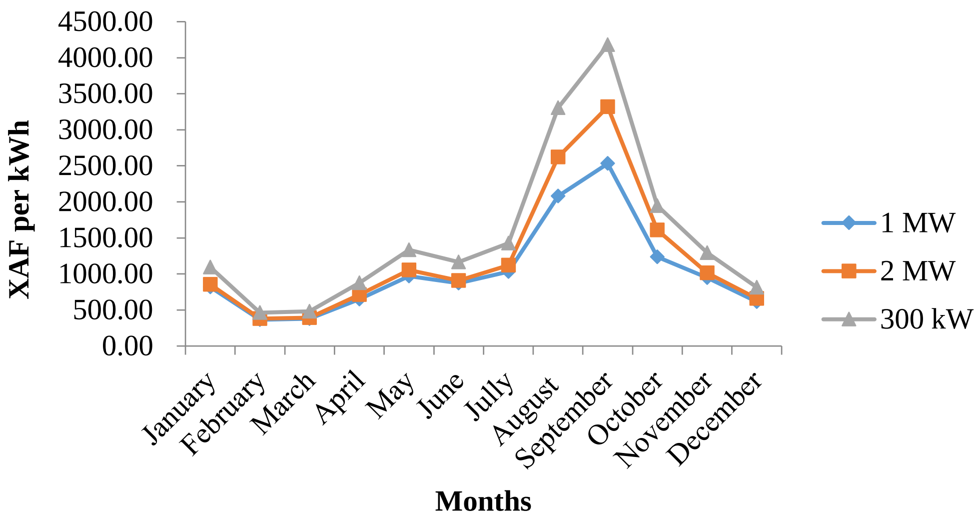

Fig 5. Cost of Energy (XAF per kWh)

Table 4 presents the different annual values of the characteristics for the three wind turbines. Thus, the value of the average annual power varies from 34.18 to 283.31 kW/year. The capacity factor varies from 11.39% to 14.17%. Finally, the annual production varies from 24609 to 203984 MWh / year.

Table 4. Calculated annual energy estimate for selected wind turbines for selected sites

	Bonus 300 kW/33	Bonus 1MW/54	Vestas 2MW/V80
Pe,m (kW/Year)	34.18	152.89	283.31
Cf (%)	11.39%	15.29%	14.17%
Eout (MWh/Year)	24 609	110 080	203 984

Where Cf (%) is the capacity factor of the wind turbine, E_{out} (MWh / year) is the annual production of accumulated energy, $P_{e,\,m}$ (kW / year) is the annual power produced by the wind turbine.

Table 5 also presents the different annual values of the characteristics for the wind turbines in question. Thus, the nominal electric power varies from 300 to 2000kW. The cost in $ is $ 23 to $ 33.8. In the CFA franc, this cost varies from 12495.5 to 18377.7 XAF.

Table 5. Presentation of the annual values of the capacity factor, power averages, energy produced and the cost of energy produced at different hub heights.

	Bonus 300kW/33	Bonus 1MW/54	Vestas 2MW/V80
P_{out}	34.18	152.89	283.31
P_{er}	300	1000	2000
Cf (%)	11.39%	15.29%	14.17%
E_{out}	374250.2	1674101.7	3 102 266
$C_{US\$}$	33.8	23.0	27.0
C_{XAF}	18377.7	12495.5	14647.0

4. Conclusions

This work makes a techno-economic assessment of wind power conversion systems for power generation for the city of N'Djamena in Chad. Thus, it is presented the rose of the wind for the city of N'Djamena. The capacity factor, power and energy are respectively 15.29%, 152.89 kW/year and 110.080 MWh/year using the Bonus 1MW/54 wind turbine. The various costs related to the use of wind energy have been evaluated, with the average minimum cost per kWh of $ 23.0/kWh. It also emerges in this study that in view of the prices of the wind turbines considered, the price is high. It is therefore desirable in the future to use other characteristics of wind turbines whose prices could be affordable to the population.

5. Acknowledgment

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Nomenclature

$\boldsymbol{k_0}$ and $\boldsymbol{c_0}$ are the shape and scale parameters at the measured height h_0 and the height of the hub h.

k and c are the Weibull form factor and the scale factor

PVC, Present Value of Cost

COE, Cost of Energy

WECS, Wind Energy Conversion System

C_f, Capacity factors (%)

V_f, cut-off wind speed (m/s)

V_r, rated wind speed (m/s)

V_c, cut-in wind speed (m/s)

A, availability of the wind power resource for generating electricity

t, use full life time of turbine in years (20 years)

P_R, Rated power (kW)

C_{om}, is the operation and maintenance cost(7,5% of the investment cost)

6. References

[1] B V. Ermolenko, G V. Ermolenko, YA Fetisova, LN Proskuryakova ,Wind and solar PV technical potentials: Measurement methodology and assessments for Russia, Energy 137 (2017)1001–12.

[2] J.Yang, C. Zhang, Q. Sun & G. Wang, A survey on wind farm sitting. Acta Energiae Solaris Sinica (2012).

[3] J. Schallenberg-Rodríguez, N. García Montesdeoca, Spatial planning to estimate the offshore wind energy potential in coastal regions and islands. Practical case: The Canary Islands, Energy 143(2018) 91–103.

[4] YC Deng, Z. Yu, Methodology of wind resource assessment in wind farm Macrositing based on reference wind turbine, Energiae Solaris Sinica 11(2010)1516–20.

[5] M. H. Soulouknga, S. O. Oyedepo, S. Y. Doka, T.C. Kofane, Assessment of Wind Energy Potential in the Sudanese Zone in Chad, Energy and Power Engineering 9(2017)386-402

[6] J. Dong, T T. Feng, Y S Yang, Macro-site selection of wind/solar hybrid power station based on ELECTRE – II, Renewable & Sustainable Energy Reviews,35(2014)194-204.

[7] Li QW. Micro-setting and wind power research of Da Tang Ji Lin xiang yang. Jilin University (2011).

[8] Shaahid SM, Al-Hadhrami LM, Rahman MK., Economic feasibility of development of wind power plants in coastal locations in Saudi Arabia, Renew Sustain Energy Rev19(2013)589–97.

[9] Na Wang, Research of Wind Energy Resource Assessment in Wind Farm Macro—siting, Hunan University (2015)

[10] C.Mattar, MC. Guzmán-Ibarra, A techno-economic assessment of offshore wind energy in Chile, Energy 133(2017)191–205.

[11] B N. Miranda-Blanco, E. Díaz-Dorado, C. Carrillo, State estimation for wind farms including the wind turbine generator models, Renewable Energy71(2014)453-465.

[12] C. Herrero-Novoa, IA. Pérez, ML. Sánchez, MÁ. García, N. Pardo, B. Fernández-Duque ,Wind speed description and power density in northern Spain, Energy 138(2017)967–76.

[13] S. Muhammad Lawan, WA. Wan Zainal Abidin,Wind energy assessment and mapping using terrain nonlinear autoregressive neural network (TNARX) and wind station data,Cogent Eng (2018).

[14] M. Gökçek, A. Bayülken, Ş. Bekdemir, Investigation of wind characteristics and wind energy potential in Kirklareli, Turkey, Renew Energy 32(2007)1739–52.

[15] A. Ucar, F. Balo, A seasonal analysis of wind turbine characteristics and wind power potential in Manisa, Turkey, Int J Green Energy 5(6) (2008) 466–79.

[16] B. Yaniktepe, T. Koroglu, MM. Savrun, Investigation of wind characteristics and wind energy potential in Osmaniye, Turkey, Renew Sustain Energy Rev 21(2013)703–11.

[17] L. Lu, H. Yang, J. Burnett, Investigation on wind power potential on Hong Kongislands: an analysis of wind power and wind turbine characteristics, Renew Energy 27(2002)12.

[18] I. Youm, J. Sarr, M. Sall, A. Ndiaye, MM. Kane, Analysis of wind data and wind energy potential along the northern coast of Senegal, Renew Sustain Energy Rev 8(2005)95–108.

[19] A. Ucar, F.Balo, Evaluation of wind energy potential and electricity generation at six locations in Turkey, Applied Energy 86(2009) 1864–1872.

[20] G. Murat, G. Mustafa Seedar, Evaluation of electricity generation and energy cost of wind energy conversion systems (WECSs) in Central Turkey, Applied Energy 86(2009)2731–2739.

[21] S.A. Akdag, O. Guler, Evaluation of wind energy investment interest and electricity generation cost analysis for Turkey, Applied Energy 87(2010)2574–2580.

[22] S. A. Akdag, & A. Dinler, A new method to estimate Weibull parameters for wind energy applications, Energy Conversion and Management 50(2009) 1761–1766.

[23] Ch. Breyer, A. Gerlach, M. Hlusiak, C. Peters, P. Adelmann, J. Winiecki, Electrifying the poor: Highly economic of-grid PV systems in Ethiopia a basis for sustainable development (2009).

[24] T. L. Acker, S. K. Williams, E. P. N. Duque, G. Brummels, J. Buechler, Wind resource assessment in the state of Arizona: Inventory, capacity factor, and cost, Renewable Energy 32(2007) 1453–1466.

[25] H. S. Bagiorgas, M. N. Assimakopoulos, D. Theoharopoulos, D. Matthopoulos, G. K. Mihalakakou, Electricity generation using wind energy conversion systems in the area of Western Greece, Energy Conversion and Management 48(2007) 1640–1655.

[26] K. Shiva Prashanth, G. Satyanarayana, Statistical scrutiny of Weibull parameters for wind energy potential appraisal in the area of northern Ethiopia, Renewables:Wind, Water and Solar 14(2) (2015) 1–15.

[27] M.H. Soulouknga, D.K. Kaoga, N. Djongyang, S.D. Yamigno, Comparaison du potentiel énergétique éolien des trois zones climatiques du Tchad, Revue des Energies Renouvelables 19 (2016) 49 – 58.

[28] A. K. Azad, M.G. Rasul, R. Islam, I.R. Shishir, Analysis of wind energy prospect for power generation by three Weibull distribution methods, Energy Procedia 75 (2015)722 – 727.

[29] P. A. C. Rocha, R. C. de Sousa, C. F. de Andrade, da Silva, M. E. V. , Comparison of seven numerical methods for determining Weibull parameters for wind energy generation in the northeast region of Brazil, Applied Energy 89(2012)395–400.

[30] A. Balouktsis, D. Chassapis, T. D. Karapantsios, A nomogram method for estimating the energy produced by wind turbine generators, Solar Energy 72 (2002) 251–259.

[31] E. K. Akpinar, S. Akpinar, An assessment on seasonal analysis of wind energy characteristics and wind turbine characteristics, Energy Conversion and Management 46(2005) 1848–1867.

[32] C.G. Justus, A.Mikhail, Height variation of wind speed and wind distributions statistics, Geophys.Res.Lett 3(1976) 261-264.

[33] M.H. Soulouknga, S. O. Oyedepo, S.Y. Doka, T. C. Kofane, Evaluation of the cost of producing wind‐generated electricity in Chad, International Journal of Energy and Environmental Engineering (2020).

[34] D. K. Kidmo, K. Deli, D. Raidandi, S. D.Yamigno, Wind energy for electricity generation in the far north region of Cameroon, Africa-EU Renewable Energy Research and Innovation Symposium, RERIS 2016, 8-10 March 2016.

[35] M. S. Adaramola, S. S. Paul, S. O. Oyedepo, Assessment of electricity generation and energy cost of wind energy conversion systems in north-central Nigeria, Energy Conversion and Management 52(2011) 3363–3368.

[36] A.S. Ahmed Shata, R. Hanitsch, Evaluation of Wind Energy Potential and Electricity Generation on the Coast of Mediterranean Sea in Egypt, Renewable Energy 31(2006)1183 – 1202.