WIND SPEED POTENTIAL ASSESSMENT OF SELECTED CLIMATIC ZONES OF ETHIOPIA

Endalew Ayenew[1], Santoshkumar Hampannavar2

•

[1]College of Electrical & Mechanical Engineering, Addis Ababa Science and Technology University, Ethiopia
Professor, School of Electrical and Electronics Engineering, REVA University, Bengaluru, India
end_enday@yahoo.com

Abstract

In this paper the wind speed potential assessment of different climatic zones of Ethiopia are proposed. Statistical analysis of wind speed were carried out using Rayleigh and Weibull probability density functions (PDF) for a specific location. Real time Typical Meteorological Year (TMY) data was used for the wind speed potential assessment of three different climatic zones and to plot wind rose diagram.

Keywords: Wind speed assessment, Statistical analysis, Wind Energy

I. Introduction

Wind is one of the globally recognized potential renewable energy source and it is important to have an inclusive knowledge about the wind characteristics for efficient planning and implementation of wind power generation plants. The wind energy assessment is very crucial and draws attention of researchers. Wind resources assessment is a basic requirement for the following reasons: i) wind power is proportional to the cube of the wind speed (10% difference in wind speed leads to 33% changes in wind power), ii) fluctuating wind speed and wind shears. According to the statistics the country has existing wind energy capacity of about 18.7GW with wind speed of 7.5 to 8.8 m/s at 50m height above the ground level. Wind energy is recognized throughout the world as a cost-effective energy plant. It is environmentally friendly solution for energy shortages, i.e. reduce climate change effect, greenhouse gas emission and protection of biodiversity. Wind power plant helps to reduce over three billion tons of CO_2 emissions annually [1- 6]. As per the advanced scenario as shown in Table 1 the wind power could reach nearly 2,000 GW by 2030 [6].

Wind power could reach 2,000 GW by 2030 and supply up to 17-19% of global electricity [7]. Even though wind potential resource is very high in Ethiopia but still it contributes only 0.06% of wind power generation globally. Global Wind Energy Outlook (GWEO) explores the future of the wind energy industry up to 2050 and according to the International Energy Agency's policies scenario considering World Energy Outlook as a baseline, two scenarios were specifically developed.

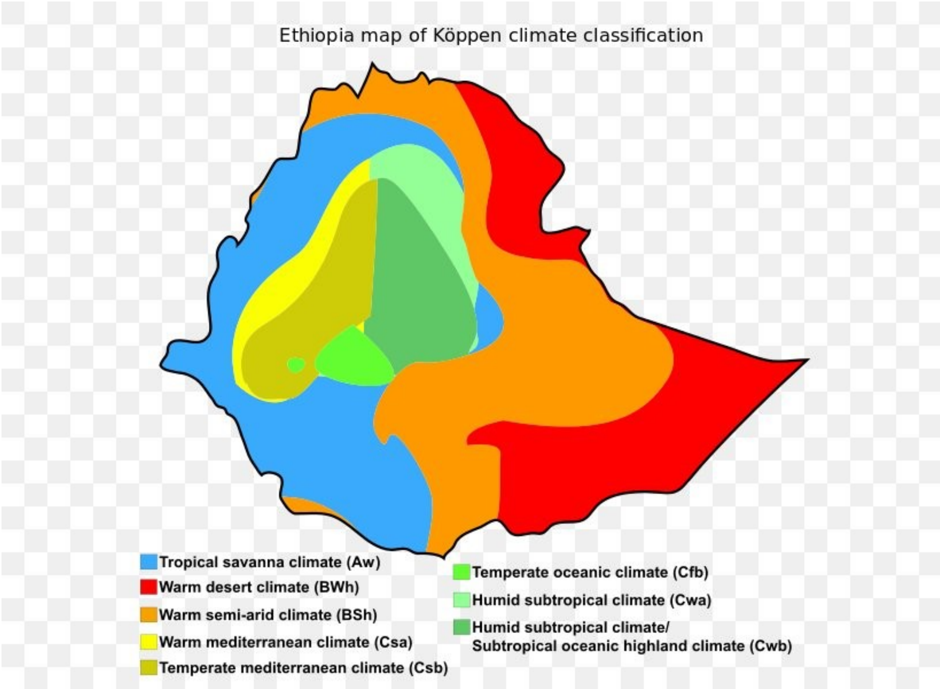

Figure 1: *Köppen Climate Classification Geography of Ethiopia (Source: FAVPNG.com)*

Figure 1. shows the Koppen climatic classification of Ethiopia and it is observed that there are eight climatic zones. Firstly, statistical analysis of one station is comprehensively carried out using Weibull and Rayleigh probability density functions. Secondly, the wind rose diagram is plotted considering Typical Meteorological Year (TMY) data for three different stations located at three different climatic zones.

II. Statistical Models for Wind Speed Assessment

To describe the wind speed distributions, many probability density functions (PDF) have been used such as beta, gamma, lognormal, Rayleigh and Weibull functions. Rayleigh and Weibull models are widely accepted according to the literature studies. Weibull function is preferred due to its flexibility in terms of shape factor and scale factor but suffers from the problem that cannot be used for calm wind speeds [8-14].

Two parameter Weibull probability density function (PDF) is given by

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^{k}} \tag{1}$$

Weibull cumulative distribution function (CDF) is given by

$$F(v) = \int_{0}^{v} f(v)\,dv = 1 - e^{-\left(\frac{v}{c}\right)^{k}} \tag{2}$$

where v is the wind speed, k is shape parameter and c is scale parameter [15-18]. The value of the shape factor relates it to other PDF i.e. if k =2 it becomes Rayleigh distribution.

Table 1: *Global wind power scenario*

Total Capacity in MW	2013	2014	2015	2020	2030
New Policies Scenario	318,128	356,322	396,311	610,979	964,465
Moderate Scenario	318,128	363,908	413,039	712,081	1,479,767
Advanced Scenario	318,128	365,962	420,363	800,615	1,933,989

Rayleigh PDF is given by

$$f(v)=\frac{\pi}{2}\left(\frac{v}{v_m^2}\right)e^{-\left(\frac{\pi}{4}\left(\frac{v}{v_m}\right)^2\right)} \tag{3}$$

where v_m is mean wind speed.

Rayleigh CDF is given by

$$F(v)=1-e^{\left(-\frac{\pi}{4}\left(\frac{v}{v_m}\right)^2\right)} \tag{4}$$

Energy pattern factor method (EPF) is used to determine the Weibull distribution parameters. Monthly mean power density (MMD) is given by

$$P=0.5A\rho\sum_{i=0}^{n}\frac{v_i^3}{n} \tag{5}$$

$$MMD=\frac{P}{A}=0.5\rho\sum_{i=0}^{n}\frac{v_i^3}{n} \tag{6}$$

where A is swept area, v_i is wind speed in the sample measured at instant *i*, n represents total days in a month and ρ is air density
Energy pattern factor is given by

$$EPF=\frac{\sum_{1}^{n}\frac{v_i^3}{n}}{\left(\sum_{1}^{n}\frac{v_i}{n}\right)^3}=\frac{\left(\frac{MMD}{0.5\rho}\right)}{v_m^3} \tag{7}$$

According to the shape factor, Weibull distribution is described as

$$k = 1 + \frac{3.69}{EPF^2} \tag{8}$$

The scaling factor is given as

$$c = \frac{v_m}{\Gamma\left(1 + \frac{1}{a}\right)} \tag{9}$$

For gamma function

$$\Gamma(k) = \int_0^\infty x^{k-1} e^{-x} dx \; and \; \Gamma(1+k) = k\,\Gamma(k) \tag{10}$$

Weibull power density is given by

$$\begin{aligned} \frac{P_{Weibull}}{A} &= 0.5\rho v_m^3 = 0.5\rho\left(c\Gamma(1+\frac{1}{k})\right)^3 \\ &= 0.5\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \end{aligned} \tag{11}$$

Rayleigh power density is given by

$$\frac{P_R}{A} = \frac{3}{\pi}\rho v_m^3 = \frac{3}{\pi}\rho c^3 \tag{12}$$

III. Results and Discussion

I. Statistical Assessment of Wind Speed

Real time wind samples were collected for one TMY for Adama, Ethiopia wind site. The data was collected at a height of 10 meter and 40 meter above the ground for which wind speed varies between 6 m/s and 14 m/s; and 12 ms/and 17 m/s respectively. Figure 2 and Figure 3 shows the Weibull and Rayleigh PDFs respectively. Annual average estimated power densities calculated using Rayleigh and Weibull models are 532 W/m^2 and 370 W/m^2 respectively. Rayleigh model provides better power extraction than the Weibull model for Adama wind site.

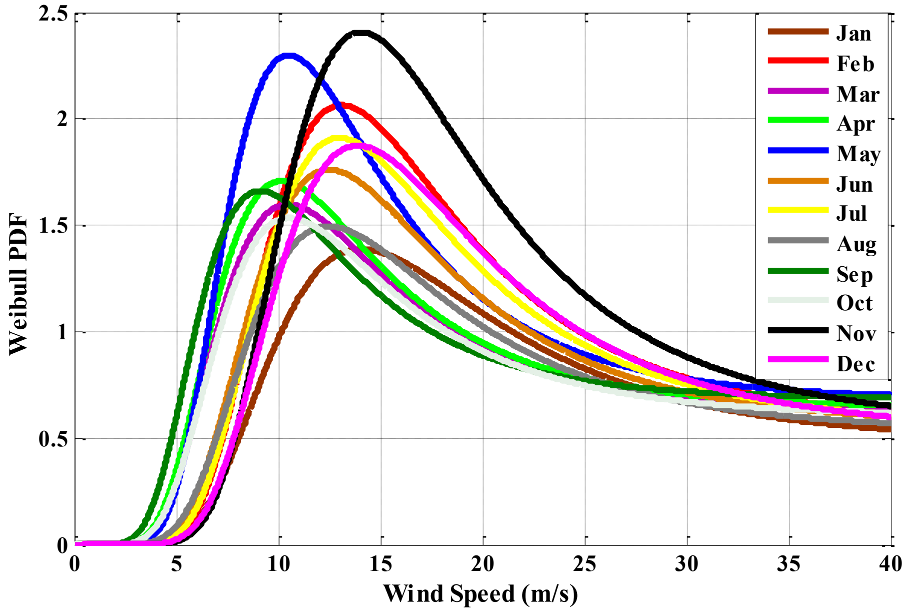

Figure 2: *Weibull Probability Density function*

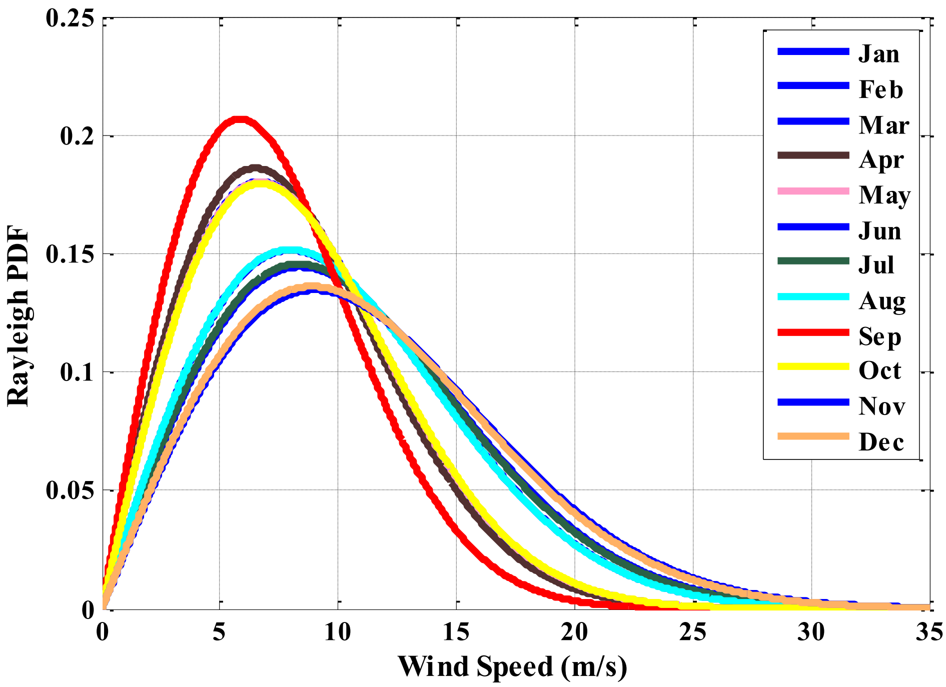

Figure 3: *Rayleigh Probability Density function*

II. Wind Speed Assessment

Wind speed for three different regions (Tropical Savanna Climate, Warm Semiarid Climate and humid subtropical Climate) were assessed by plotting wind rose diagrams. Three cities considered for the assessment are: i) Gondar, ii) Dire Dawa, iii) Addis Ababa (capital city of Ethiopia).

For the tropical savanna climate, Gondar was considered and the wind rose diagram (wind velocity and direction) was plotted using the TMY [19-22] data as shown in Figure 4. The wind blows greater than 8 m/s towards East direction which is around 70%. In the south east direction wind blows at a speed of 4 m/s which turns to be 10% of wind in that city.

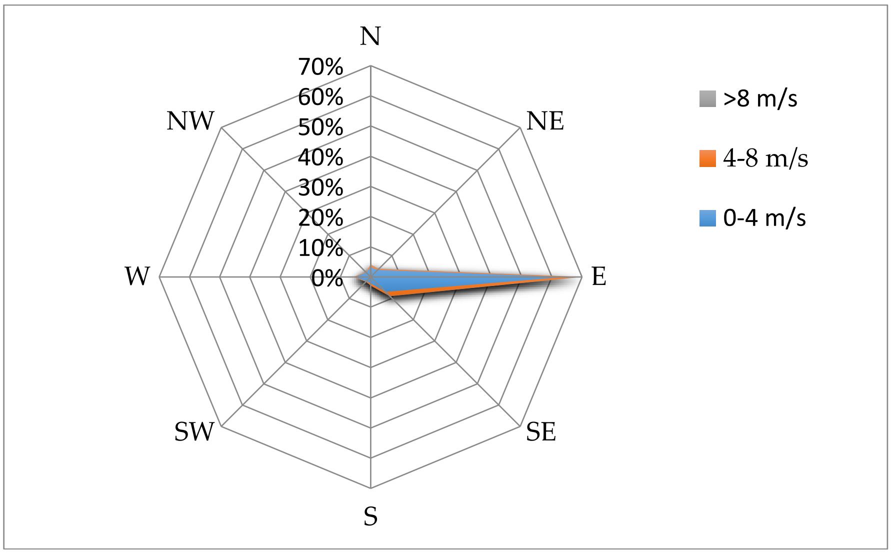

Figure 4: *Tropical Savanna Climate (Gondar)*

For the warm semiarid climate, Dire Dawa was considered and the wind rose diagram was plotted using the TMY data as shown in Figure 5. The wind blows greater than 7 m/s towards West direction which is around 30% and it is interesting to note that the wind blows in East direction at a rate of 4-5 m/s which amounts to 22.5%. Towards North West it is observed that the wind blows at a rate of 4 m/s which turns out to be around 15%.

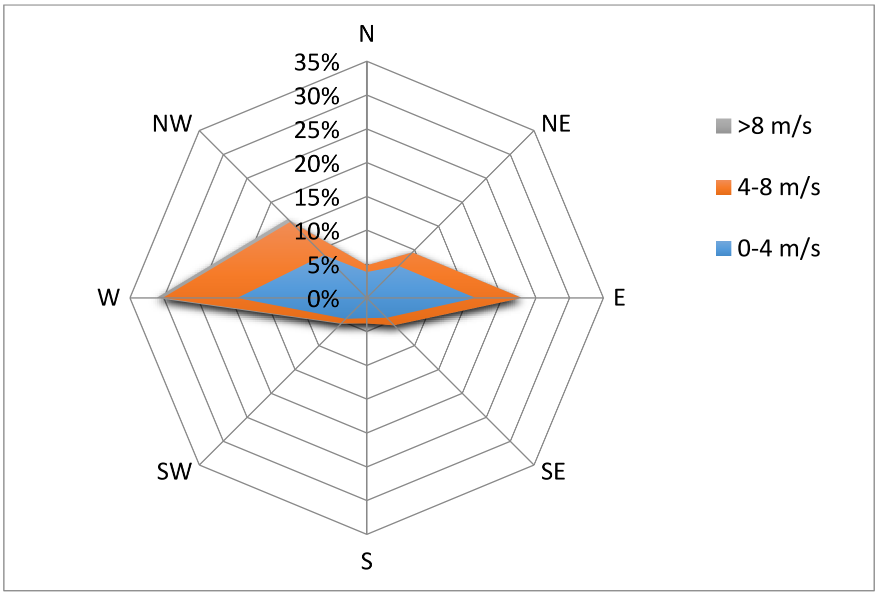

Figure 5: *Wind Rose Diagram (Dire Dawa)*

For the humid subtropical climate, Addis Ababa (capital City of Ethiopia) was considered and the wind rose diagram was plotted using the TMY data as shown in Figure 6. It is depicted from Figure 6 that the wind blows in the North direction at a speed of 8-12 m/s which turns out to be 25% of the total wind in that city. Wind blows greater than 6 m/s in the North West direction and amounts to around 10%. In East wind blows at 4 m/s which is about 6%.

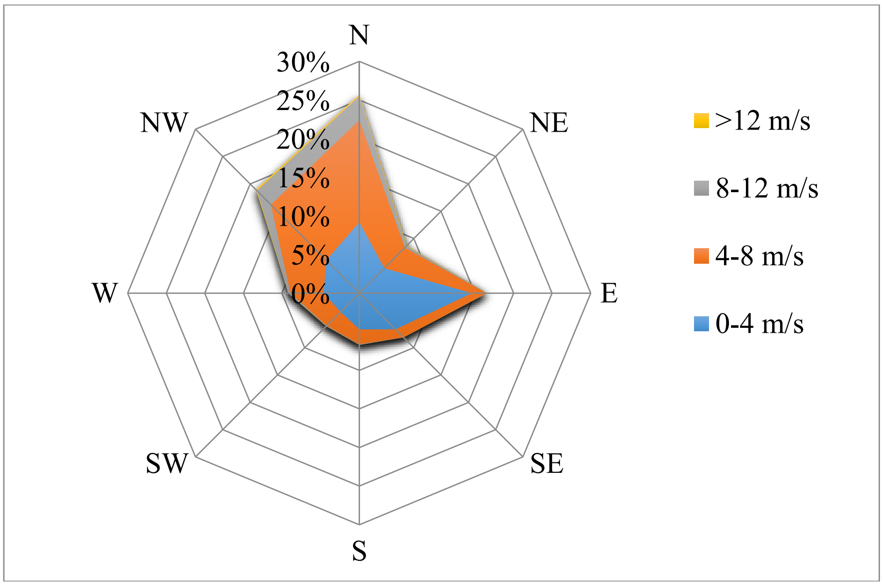

Figure 6: *Wind Rose Diagram (Addis Ababa)*

IV. Conclusion

The wind speed potential assessment of three different climatic zones of Ethiopia were presented. The statistical analysis of wind speed potential of ADAMA was carried out and it is found that Rayleigh PDF is better than the Weibull PDF. The wind rose diagrams were plotted for three different climatic zones (Tropical Savanna Climate, Warm Semiarid Climate and humid subtropical Climate) of Ethiopia. This study will help the electrical utility companies for possible future expansion plans or to start new projects.

References

[1] S. Mathew. Wind Energy Fundamentals Resource Analysis and Economics, Springer-Verlag, Berlin Heidelberg, 2006.

[2] J. F. Manwell, J. G Mcgowan. A. L Rogers. Wind Energy Explained: Theory, Design and Application, John Wiley & Sons, 2009.

[3] V. Nelson. WIND ENERGY Renewable Energy and the Environment, Taylor & Francis Group, 2014.

[4] J. W Twidell, A. D Weir. Renewable Energy Resources, Taylor & Francis, 2006.

[5] Li X. Green Energy: Basic Concepts and Fundamentals, Springer-Verlag London, 2011.

[6] Chang T P. (2011). Estimation of wind energy potential using different probability density functions. Appl Energy; 88: 1848–56.

[7] Centre for Wind Energy Technology, Course material, Seventh international training course on wind turbine technology and applications, Chennai, 2011.

[8] J A. Carta, P. Ramirez. (2007).Use of finite mixture distribution models in the analysis of wind energy in the Canarian Archipelago. Energy Convers Manage; 48: 281–91.

[9] B. S. Premono, P. Tjahjana. (2016). Wind energy potential assessment to estimate

performance of selected wind turbine in northern coastal region of Semarang-Indonesia. International Conference on Engineering, Science and Nanotechnology, AIP Conf. Proc. 1788.

[10] A. Altunkaynak, T. Erdik, I. Dabanlı, Z. Sen. (2012). Theoretical derivation of wind power probability distribution function and applications. Applied Energy, 92: 809–814.

[11] D.H. Rajapaksha, K. Perera. (2016). Wind Speed Analysis and Energy Calculation based on Mixture Distribution in Narakkalliya Sir Lanka. J. Natn Sci Foundation, 44 : 409-416.

[12] J. A. Carta, P. Ramirez. (2007). Use of Finite Mixture Distribution Models in the Analysis of Wind Power in the Canarian Archipelago. Energy Conversion and Management , 48: 281-291.

[13] R. Kollu, S. R. Rayapudi, S.Narasimham, K. Pakkurthi. (2012).Mixture probability distribution functions to model wind speed distributions. International Journal of Energy and Environmental Engineering, 3:27.

[14] TP. Chang. (2011).Estimation of wind energy potential using different probability density functions. Appl Energy, 88:848–56.

[15] TP. Chang. (2011). Performance comparison of six numerical methods in estimating Weibull parameters for wind energy application. Appl Energy, 88: 272–82.

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

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

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

[19] K.N. Patil, S.C. Kaushik .(2015). Study of Climatic Potential for Natural Ventilation in Buildings for Typical Indian Cities. International Journal of Ventilation, 13: 369-380.

[20] K.N. Patil, S. C. Kaushik, S. N. Garg.(2018). Performance Prediction and Assessment of Energy Conservation Potential for a Light Pipe System in Indian Composite Climate of New Delhi. ASME. J. Sol. Energy Engineering, 140: 0510121-0510129.

[21] K.N. Patil, S. C. Kaushik, A. Aggarwal. (2020). Evaluation of Natural Ventilation Potential for Indoor Thermal Comfort in a Low-Rise Building in Arid and Semi-arid Climates of India. Advances in Energy and Built Environment. Lecture Notes in Civil Engineering, Springer, Singapore 36.

[22] S.Hampannavar, K.N.Patil, S.Manasani, R.Y.Udaykumar, R.P.Mandi, C.Nandakumar. (2021).Wind Potential Assessment for Micropower Generation in Tropical Wet Climate of India. Recent Advances in Power Systems, Lecture Notes in Electrical Engineering, 699 : 337-348.