ANALYSIS OF WIND ENERGY POTENTIAL IN SELECTED REGIONS IN NIGERIA AS A POWER GENERATION SOURCE

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
GODSTIME ERHABOR

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering

NICOSIA, 2019

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Approval of Director of Graduate School of Applied Sciences

Prof. Dr. Nadire ÇAVUŞ

We certify this thesis is satisfactory for the award of the degree of Master of Science in Mechanical Engineering

Examining Committee in Charge:

Assist. Prof. Dr. Youssef KASSEM	Supervisor, Department of Mechanical Engineering, NEU
Prof. Dr. Adil AMIRJANOV	Department of Mechanical Engineering, NEU
Assoc. Prof. Dr. Hüseyin ÇAMUR	Department of Mechanical Engineering, NEU

I hereby declare that, all the information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name:

Signature:

Date:

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To my parents, with love…

ABSTRACT

This study shows the wind speed characteristics and wind power potential of four locations in Nigeria: Edo, Delta, Abia and Bauchi from 2008- 2017 duration. The data was obtained from the Nigerian Meteorological Center Furthermore, to examine the capabilities of a vertical axis wind turbine to generate power at the locations.

The annual mean wind speed for the four locations in this study is ranges from 2.3 knots to 4.7 knots which is 1.2 m/s to 2.4 m/s respectively at a 10m; this indicates the locations have low wind energy potential. The GEV proved to be the best fit to the wind speed data for the locations of Delta, Abia, and Bauchi, while Weibull analysis for Edo. It was observed that Edo has the highest winds and its wind power analysis is the best location for collecting wind energy.

The annual wind power values ranged from 2.30W/m^2 to 9.34W/m^2 at 10m height. These values shows that the wind power potential of these locations could be possible to exploited using small-scale wind turbines at the locations. It was concluded that VAWT with a comparable rated output would produce more power in the locations than a HAWT due to less noise and more efficient. Subsequently, with a power rating of 4kW the Wind-dam had the lowest energy production cost among the considered vertical axis wind turbine.

Keywords: Economic analysis; Nigeria; Distribution functions; Statistical analysis; Vertical axis wind turbine; Wind speed characteristics

ÖZET

Bu çalışma, 2008 - 2017 süresinden itibaren Edo, Delta, abia ve Bauchi olmak üzere nijerya'daki dört yerin rüzgar hızı özelliklerini ve rüzgar enerjisi potansiyelini göstermektedir. Veriler Nijeryalı Meteoroloji Merkezi'nden elde edildi ayrıca, yerlerde güç üretmek için dikey eksenli rüzgar türbininin yeteneklerini incelemek. Bu çalışmada dört lokasyon için yıllık ortalama rüzgar hızı, 2.3 knot ile 4.7 knot arasında değişmektedir; bu, 10m'de sırasıyla 1.2 m/s ila 2.4 m / s arasındadır; bu, konumların düşük rüzgar enerjisi potansiyeline sahip olduğunu gösterir. Gev, Edo için Weibull analizi yaparken, Delta, Abia ve Bauchi'nin yerleri için rüzgar hızı verilerine en uygun olduğunu kanıtladı .Edo'nun en yüksek rüzgara sahip olduğu ve rüzgar enerjisi analizinin rüzgar enerjisini toplamak için en iyi yer olduğu gözlenmiştir. Yıllık rüzgar enerjisi değerleri 2.30 W/m2 ila 9.34 W/m2 arasında 10m yükseklikte değişiyordu. Bu değerler, bu konumların rüzgar enerjisi potansiyelinin, konumlarda küçük ölçekli rüzgar türbinleri kullanılarak sömürülebileceğini göstermektedir. Karşılaştırılabilir bir nominal çıkışa sahip VAWT'NİN, daha az gürültü ve daha verimli olması nedeniyle bir HAWT'TAN daha fazla güç üreteceği sonucuna varılmıştır. Daha sonra, 4kw güç derecesi ile Winddam, dikey eksenli rüzgar türbini arasında en düşük enerji üretim maliyetine sahipti.

Anahtar kelime: Ekonomik analiz; Nijerya; dağıtım fonksiyonları; istatistiksel analiz; dikey eksenli rüzgar türbini; rüzgar hızı özellikleri

CHAPTER 1

INTRODUCTION

1.1 Overview

The demand for energy increases as the world population growth rises. To improve the standard of living in developing countries and maintain the growth in industrialized countries, energy use cannot be avoided. Renewable energy in a higher share can be used more efficiently as an energy source. Today, the rise of wind energy use is a developing technology. Wind energy is a local resource and it has been the most promising clean source of energy all over the world, to combat and overcome the existing power issues it is vital to conduct a research on the technical and economical possibilities. (Köse 2004)

The main source of energy demand is fossil fuels and it plays a key role to the world supply. However, fossil fuels have a negative environmental impact and it is in limited resource. Therefore, energy sources rational utilization and management, and renewable energy source usage are vital. (Aynur.U 2010)

Environmental protection, energy security and sustainable development are achieved by an increasing role of Renewable energy. Nowadays, other forms of renewable energy technologies are becoming more expensive but wind energy as one of the cleanest form is highly recommended because of its falling cost. (Ahmed O Hanane 2010)

Wind energy can be captured by blowing wind into turbines that convert kinetic energy from wind into mechanical energy and subsequently into electrical energy. (Alam HM 2010)

Countries in Europe and Northern America use wind energy to produce electricity on a large scale. (Ahmed SA 2010)

Wind power generation potential and its characteristics can be observed by carrying out a necessary a long term meteorological observation. Wind speed data is needed to acquire such potential. (Aynur U 2010)

1.2 Electricity Problems in Nigeria

The hindered industrialization and economic growth in Nigeria is as a result of poor generation means. The power crisis has been reformed by various means but no visible changes seem to be happening. The industries which were once there moved to a more secure and environmental friendly nation with a stable power supply. Furthermore, basic amenities such as healthcare system, water supply and petroleum distribution are in jeopardy due to terrible state of the nation's economy and inability to meet its electricity demand. The major challenges researchers find in Nigeria's power generation are factors such as obsolete equipments, poor power plant maintenance, and vandalism of energy producing equipments but through a well planned maintenance, producing methodology and funding it can be revived.

1.3 Renewable Energy

Natural resources which energy can be generated from is Renewable energy. This implies energy resources can be replenished in a short amount of time, which in turns makes it an unlimited source of energy. Electric power is generated by using various forms of conversion methods to convert renewable energy sources such as wind, solar and geothermal.

1.3.1 Wind power

Wind power is clean source of energy and has zero emissions. It also has a low fossil fuel dependence.

- **Pros**
  1. It is a cheap form of energy
  2. It requires minimum space
  3. It functions at any time of day as long as wind blows

- **Cons**
  1. Centrifugal forces damages blades
  2. Wind is need to generate electricity i.e. no wind no power

1.3.2 Solar energy

Solar energy converts sunlight into electricity by means of photovoltaic or concentrated sunlight.

It has different types of collectors namely Compound Parabolic Concentrator, Flat- plate Collector, Parabolic through Collector and Evacuated- tube Collector.

1.4 Aim of Study

In Nigeria little is known about wind potential and limited studies have been done on it. This thesis aims to study, analyze, evaluate and justify the following research objectives for the following states in Nigeria (Edo, Delta, Abia, Bauchi).

1. Wind speed, direction and potential at selected locations.
2. Wind speed characteristics according to time (months, seasons and years).
3. Does wind speed change with respect to height at different location?
4. Which distribution function is best to evaluate wind potential data?
5. Which Locations gives the highest capacity factors and least cost?

6. The most fitting wind turbine class for each location.
7. Is wind energy a good option for a given location?

1.5 Overview of Thesis

Chapter 1 gives an overview of renewable energy and its demand, also a short description on the electricity problems in Nigeria and the aim of the study.

In chapter 2, recent studies on wind potential is discussed as well as the economic analysis of the wind turbine and wind power density.

Chapter 3 shows the different methods used to analyze the meteorological data and the use of simulation tools used for this study. It shows the description of the location chosen for this study and ten models used to evaluate wind potential.

In chapter 4, the results obtained from the study as well as analysis done with the mentioned parameters.

Chapter 5 gives the detailed report on the findings and conclusion of the study.

CHAPTER 2

LITERATURE REVIEW AND ECONOMIC ANALYSIS

2.1 Recent Studies on Wind Potential

In past and recent years, wind energy studies have been carried out across the world. (M.S. Adaramola et al., 2011) investigated and analyzed the wind energy potential and economic analysis using wind speed data with a time frame of 19 to 37 year period at a 10 meter height, in six selected locations in North- central Nigeria. Levied cost method was used to evaluate small and medium size turbines for the selected locations.It was concluded that energy cost decreases, discount rate decreases by increasing the escalation rate of inflation.WECS was used by (O.S. Ohunakin et al., 2011) to evaluate production of electricity for a 36 year period data in 7 locations in Nigeria. A Technical assessment was conducted and the data was subjected to a 2- parameter Weibull analysis for four commercial wind turbines. Nordex N80 - 2.5MW wind turbine was most suitable for Kano which had the highest annual wind power and Suzlon S52 for Yelwa which had the lowest annual wind power.At 15 different locations (T.R. Ayodele et al., 2016) evaluated the possibility of producing electricity by utilizing wind energy. For a period of 4-16 years they used a daily average of wind speeds at 10 meter height. The capacity factor estimation for the appropriate wind turbine was used for each location. The unit cost of energy for the turbines was calculated by using the present value cost method. The results showed high rates of wind speeds at Jos and Kano, also they are economically viable for grid integration application.(Olayinka S. Ohunakin et al., 2011) investigated the wind energy potential in Jos using a 37 year wind speed data at a height of 10m subjected to a 0- parameter Weibull Analysis. The location Jos is suitable for wind turbine application as the analysis shows it falls under class 7 of the international system of wind classification. Two commercial turbines AN Bonus 300kW/33 and AN Bonus 1 MW/54 were evaluated by using the capacity factor estimates. The maintenance cost and relative estimated costs of € 0.025, €

0.015, € 0.016 per kWh of energy were produced under two different values of yearly operations.

Investigating detailed knowledge of the wind characteristics, such as speed, direction, continuity, and availability determines the wind energy potential for the selected site. Thus, the wind power plants are obtained by selecting a proper wind turbine and micro sitting process.In the most recent years, various countries worldwide have studied numerous research on wind characteristics and wind power potential. In the Mamara region of Turkey, Go¨kc¸ek et al. (2007) researched the wind characteristics and wind potential of Kırklareli province. The data observed yielded the annual mean power density and weibull function to be 13.85W/m2 and 142.75. In the eastern Mediterranean region, hourly wind data was used to find the wind energy potential from seven stations, from 1992-2001 by Sahin et al. (2005). The mean power density of 500 W/m2 was found in many areas of this region at 25m from the ground.

Along the Mediterranean Sea in Egypt, Ahmed Shata and Hanitsch (2006) evaluated the wind energy potential by using wind data from ten coastal meteorological locations. The locations monthly and annual mean wind power densities were derived. Sidi Barrani, Mersa Matruh, and El Dabaa proved to be the best out of all ten studied locations. At El Dabaa station a wind turbine of capacity 1MW was found to generate an energy output per year of 2718 MWh, and the production costs were 2V cent/kWh. In Lithuania, Marciukaitis et al. (2008) researched the power situation and future potential of wind energy usage. It was evualted that the average annual wind speed in Lithuania is 6.4m/s at 50m above ground. Kaldellis (2008) examined the wind potential of the Aegean Archipelago. He showed that the Aegean Archipelago has an excellent wind potential and wind energy applications can substantially contribute to fulfilling the energy needs of the island.

2.2 Wind power density (WPD)

The representative value of the wind energy potential of an area is the Wind power density (WPD). It details the distribution of wind energy via a model of wind power density at several wind velocity values. The wind speed relies on the air density as well as the WPD as illustrated by:

$$\frac{P}{A} = \frac{1}{2}\rho v^3 \tag{3.1}$$

$$\frac{P}{A} = \frac{1}{2}\rho v^3 f(v) \tag{3.2}$$

Moreover, the mean wind power density can be estimated using Eq. (3.3)

$$\frac{\bar{P}}{A} = \frac{1}{2}\rho \bar{v}^3 \tag{3.3}$$

Where A is a swept area in m^2, P is the wind power in W, ρ is the air density (ρ= 1.225kg/m^3) and v is wind speed in (m/s).

2.3. Wind Speed Variation

The simple power law model is usually used to convert the wind speeds at different heights, for wind energy assessments. It is depicted as

$$\frac{v}{v_{10}} = \left(\frac{z}{z_{10}}\right)^{\alpha} \tag{3.4}$$

Where v_{10} is the wind speed at the original height z_{10}, v is the wind speed at the wind turbine hub height z, and α is the surface roughness coefficient, it is dependent on the locations characteristics. The wind speed data was measured at the height of 10 m above the ground; therefore, the value of α can be obtained from the following expression

$$\alpha = \frac{0.37 - 0.088 ln(v_{10})}{1 - 0.088 ln(z_{10}/10)} \qquad (3.5)$$

2.4 Analysis of Wind Performance

2.4.1 The energy output of wind turbines

Total power output (E_{wt}) of wind turbines can be expressed by Equation (3.7) Futhermore, the power curve of the wind turbines can be estimated with a parabolic law, as given by (Equation (3.6)).

$$P_{wt(i)} = \begin{cases} \mathrm{P_r} \dfrac{v_i^2 - v_{ci}^2}{v_r^2 - v_{ci}^2} & v_{ci} \le v_i \le v_r \\ \dfrac{1}{2} \rho A C_p v_r^2 & v_r \le v_i \le v_{co} \\ 0 & v_i \le v_{ci} and v_i \ge v_{co} \end{cases} \qquad (3.6)$$

$$E_{wt} = \sum_{i=1}^{n} P_{wt(i)} \times t \qquad (3.7)$$

where v_i is the vector of the possible wind speed at a given location, $P_{wt(i)}$ is the vector of the equivalent wind turbine output power in W, v_{ci} is the cut-in wind speed (m/s), P_r is the rated power of the turbine in W, v_{co} is the cut-out wind speed (m/s) of the wind turbine and v_r is the rated wind speed (m/s). C_p is the coefficient of performance of the turbine, and it is a function of the tip speed ratio and the pitch angle. The coefficient of performance is considered to be constant for the whole range of wind speed and can be calculated as

$$C_p = 2\frac{P_r}{\rho A v_r^3} \tag{3.8}$$

2.4.2 Capacity factor (CF)

The capacity factor (CF) of a wind turbine is the fraction of the total energy generated by the wind turbine over a period of time to its potential output if it had operated at a rated capacity throughout the whole time period. The capacity factor of a wind turbine based on the local wind program of a certain site could be calculated as

$$CF = \frac{E_{wt}}{P_r.t} \tag{3.9}$$

2.5. Economic Analysis Of Wind Turbines

Different methods have been used to calculate the wind energy cost such as PVC methods]. The Present Value of Costs (PVC) is expressed as:

$$PVC = \left[I + C_{omr}\left(\frac{1+i}{r-i}\right) \times \left[1 - \left(\frac{1+i}{1+r}\right)^n\right] - S\left(\frac{1+i}{1+r}\right)^n\right] \tag{3.10}$$

where r is the discount rate, C_{omr} is the cost of operation and maintenance, n is the machine life as designed by the manufacturer, i is the inflation rate,I is the investment summation of the turbine price and other initial costs, including provisions for civil work, land, infrastructure, installation, and grid integration and S is the scrap value of the turbine price and civil work.

The cost per kWh of electricity produced (UCE) can be expressed by the following:

$$EGC = \frac{PVC}{t \times P_r \times CF} \tag{3.11}$$

2.5.1 Wind turbines cost analysis

Cost for almost any wind turbine product could be expressed as cash per kilowatt (1dolar1 /kW).

This specific cost expression is able to differ among manufacturers. Consequently, in the simplification on the analysis, the range of the cost for every one of the classes is given in the table 4.3 under (Mathew, 2007).

Table 2.1: Cost ranges of a wind turbines (Mathew, 2007)

Power Rate (kW)	Specific cost ($/kW)	Average cost ($/kW)
10–20	2200–2900	2550
20–200	1500–2300	1900
>200	1000–1600	1300

The financial growth of every wind power generation plant is within direct proportionality to its ability to generate electricity at low cost of operation (Kristensen et al., 2000). To determine the cost of energy generation by wind turbine, the following parameters are to be considered (Gökçek as well as Genç, 2009):

1. Turbine electrical energy generation over average wind speed.
2. Maintenance and operational expenses (Co&m).
3. Discount rate
4. Investment cost, which includes the basis as well as the power grid connection costs.
5. Plant lifetime.

The parameters detailed above are mainly location dependent.Thus, the key variables are definitely the turbine efficiency as well as the expenditure costs.

The electrical energy production of wind turbines is subject to wind conditions; thusly, the best alternative on the plant site is an essential component in acquiring financial reasonability (Belabes et al., 2015).

For last literature, various techniques have been worn inside the calculation of blowing wind control cost that is discussed inside (Lackner et al., 2010).

The present value cost method (PVC), will be the adopted way for the assessment, and furthermore this is a result to consider related monetary components just as accounts for the different occurrences of costs and incomes. The PVC method can be expressed as

$$PVC = \left[I + C_{omr}\left(\frac{1+i}{r-i}\right) \times \left[1 - \left(\frac{1+i}{1+r}\right)^n\right] - S\left(\frac{1+i}{1+r}\right)^n\right] (3.12)$$

where r is the discount rate, C_{omr} is the cost of maintenance and operation, n is the machine life as designed by the manufacturer, i is the inflation rate,I is the investment summation on the turbine price along with other initial expenses, including provisions for municipal labor, installation, infrastructure, land, and then power system integration as well as S scrap valuation on the turbine price as well as civil labor.

Table 2.2: PVC method variables values (Diaf and Notton, 2013)

Parameter	**Value**	**Parameter**	**Value**
r[%]	8	*I* [%]	68
i[%]	6	*S* [%]	10
n [year]	20	& [%]	7

The cost per kWh of electricity generated (UCE)as expressed by Gass et al. (2013) can be determined by the following expression

$$UCE = \frac{PVC}{t \times P_r \times CF} \tag{3.13}$$

CHAPTER 3

METHODOLOGY

3.1 Materials and Methods

In this section, at a height of 10m at four locations in Nigeria, the statistical analysis of wind speed is discussed. The wind power densities at the studied locations were obtained by using ten distribution functions. The wind speed at different hub heights was estimated by using the power law method. The yearly energy outputs, capacity factor and electricity generated cost were analyzed for small scale wind turbines of different types and sizes. Figure 3.1 shows the procedure analysis of this study.

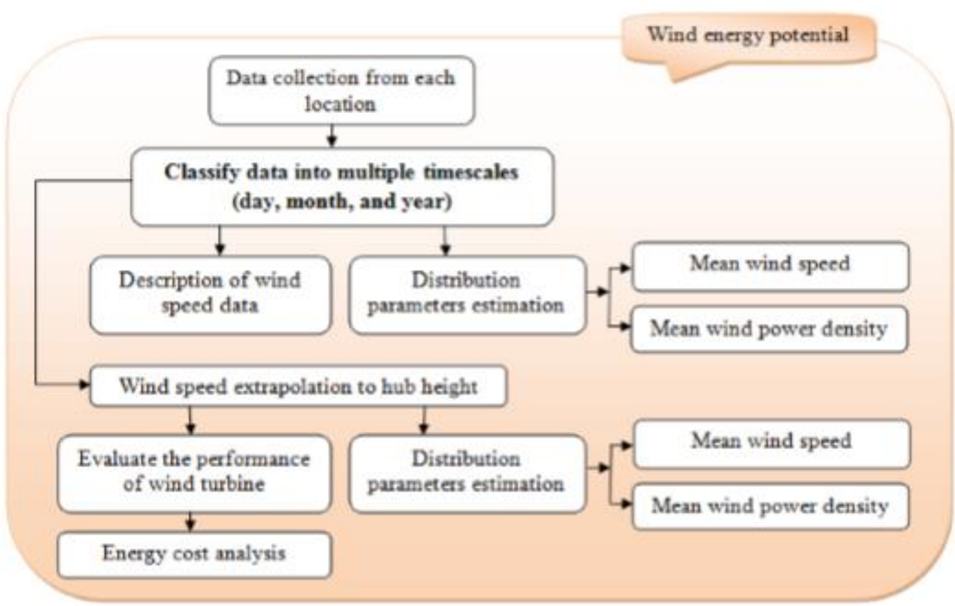

Figure 3.1: The flowchart for analysis steps of the study

3.2 Description of Selected Locations

Table 3.1: Description of locations

	Location			
	Bauchi	Edo	Delta	Abia
Latitude	10.6371° N	6.5438° N	5.5325° N	5.4309° N
Longitude	10.0807° E	5.8987° E	5.8987° E	7.5247° E
Population	2.17million	3.2million	4.1million	2.3million
Period of records	2008-2017	2008-2017	2008-2017	2008-2017

Figure 3.2: The map of studied locations (Nations online project)

3.3 Wind Data Source

A monthly wind data for ten years (2008-2017) for the selected locations Edo, Delta, Abia and Bauchi, where available for this study and collected collect from the Nigerian Meteorological Agency (NiMet). The data was collected at a height of 10m on an hourly basis by using a cup anemometer and later the monthly average was calculated. The large quantity of data collected aims to increase accuracy of the results evaluated. This is illustrated in Table 3.1

3.4 Distribution Function and Estimated Model

It is essential that wind speed data is acquired for the assessment of renewable resources. Various types of distribution functions provide wind speed data for selected locations (Ouarda et al., 2015; Aries et al., 2018; Allouhi et al., 2017). In this study, ten various probability distribution functions will be utilized for the study of wind speed distribution at the selected locations. The ten distribution functions used in this study will show the probability distribution function (PDF) and cumulative distribution function (CDF) of selected locations. The parameter values of every distribution function used will make use of the Maximum likelihood method in this study. Lastly, Matlab R2015a and Easy fit software with a CPU-Intel Xeon E5-16XX, 64GB ram, 8 core and 64-bit Operating System were used to determine the parameters of the distribution functions.

Weibull distribution (W)

To estimate the wind power density and wind speed, Weibull distribution is usually used in studies (Bilal et al., 2013).The measured data is usually a good match (Akdağ et al., 2010). The probability density function (PDF) of the wind speed is given by:

$$\boldsymbol{PDF = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} exp\left(-\left(\frac{v}{c}\right)^{k}\right)} \qquad (3.1)$$

While the Cumulative Distribution Function (CDF) is given as:

$$\boldsymbol{CDF = 1 - exp\left(-\left(\frac{v}{c}\right)^{k}\right)} \tag{3.2}$$

Where; c is the scale parameter, it is the same unit of speed (m/s), and k is the shape parameter, which is dimensionless and v is the speed of the wind.

Gamma distribution (G)

It is a broadly used distribution function in wind evaluation studies, because it is usually associated with exponential and normal distributions (Belabes et al., 2015).

The probability density function (PDF) of the Gamma distribution function is given by:

$$PDF = \frac{v^{\beta-1}}{\alpha^{\beta}\Gamma(\beta)} \exp\left(-\frac{v}{\beta}\right) \tag{3.3}$$

While the Cumulative Distribution Function (CDF) is given as:

$$CDF = \frac{\gamma\left(\beta, \frac{v}{\alpha}\right)}{\Gamma(\beta)} \text{ (3.4)} \qquad (3.4)$$

Where, α is the scale parameter, and β is the shape parameter, which is dimensionless and v is the wind speed.

Lognormal distribution (LN)

The Galton distribution or Lognormal as it is commonly know, is a probability distribution of the normally distributed logarithmic variables of wind speed (Allouhi et al., 2017). The PDF of this function can be a obtained from this equation;

$$PDF = \frac{1}{v\sigma\sqrt{2\pi}} exp\left[-\frac{1}{2}\left(\frac{ln(v)-\mu}{\sigma}\right)^2\right] \qquad (3.5)$$

While the Cumulative Distribution Function (CDF) is given as:

$$CDF = \frac{1}{2} + erf\left[\frac{ln(v)-\mu}{\sigma\sqrt{2}}\right] \qquad (3.6)$$

Where, μis the scale parameter, and σis the shape parameter, which are dimensionless and v is the wind speed.

Logistic (L)

The probability distribution function is given by:

$$PDF = \frac{\exp\left(-\frac{v-\mu}{\sigma}\right)}{\sigma\left\{1+\exp\left(-\frac{v-\mu}{\sigma}\right)\right\}^2} \qquad (3.7)$$

While the Cumulative Distribution Function (CDF) is given as:

$$CDF = \frac{1}{1+\exp\left(-\frac{v-\mu}{\sigma}\right)} \tag{3.8}$$

Where, σ is the scale parameter, and μ is the area parameter, which are dimensionless and v is the wind speed.

Log-logistic distribution function (LL)

It is used to distribute the logistic form logarithmic variables of the wind speed (Alavi et al., 2016). The probability distribution function is given by:

$$PDF = \left(\left(\frac{\beta}{\alpha}\left(\frac{v}{\alpha}\right)^{\beta-1}\right) \bigg/ \left(1+\frac{v}{\alpha}\right)^{\beta} \right)^{2} \tag{3.9}$$

While the Cumulative Distribution Function (CDF) is given as:

$$CDF = \frac{1}{\left(1+\frac{v}{\alpha}\right)^{-\beta}} \tag{3.10}$$

Where, α is the scale parameter, and β is the shape parameter, which are dimensionless and v is the wind speed.

Inverse Gaussian distribution (IG)

For low speeds and low frequencies, this distribution function can be used as an alternative to the three-parameter Weibull distribution (Bardsley, 1980). The probability distribution function is given by:

$$\boldsymbol{PDF} = \left(\frac{\lambda}{2\pi v^2}\right)^{1/2} \boldsymbol{e}^{\left[\frac{-\lambda(v-\mu)^2}{2\mu^2 v}\right]} \tag{3.11}$$

While the Cumulative Distribution Function (CDF) is given as:

$$\boldsymbol{CDF} = \boldsymbol{\Phi}\left(\sqrt{\frac{\lambda}{v}}\left(\frac{v}{\mu} - \mathbf{1}\right)\right) + \boldsymbol{exp}\left(\frac{2\lambda}{\mu}\right)\boldsymbol{\Phi}\left(-\sqrt{\frac{\lambda}{v}}\left(\frac{v}{\mu} + \mathbf{1}\right)\right) \tag{3.12}$$

Where, μ is the mean parameter, and λ is the shape parameter, which are dimensionless and v is the wind speed.

Generalized Extreme Value (GEV)

It is the only conceivable limit distribution of proper normalized maxima in sequence of independent and identically distributed variables. The probability distribution function is given by:

$$PDF = \frac{1}{\alpha}\left[1 - \frac{\zeta(v) - \mu}{\alpha}\right]^{\frac{1}{\zeta} - 1} \exp\left[-\left(1 - 1 - \frac{\zeta(v) - \mu}{\alpha}\right)^{\frac{1}{\zeta}}\right] \tag{3.13}$$

While the Cumulative Distribution Function (CDF) is given as:

$$CDF = \exp\left[-\left(1 - 1 - \frac{\zeta(v)-\mu}{\alpha}\right)^{\frac{1}{\zeta}}\right] \tag{3.14}$$

It is a three-parameter function, where, μ is the area parameter, and ζ is the scale parameter, α is the shape parameters, which are dimensionless, and v is the wind speed.

Nakagami (Na)

The probability distribution function is given by:

$$PDF = \frac{2m^m}{\Gamma(m)\Omega^m} v^{2m-1} e^{\left(-\frac{m}{\Omega}G^2\right)} \tag{3.15}$$

While the Cumulative Distribution Function (CDF) is given as:

$$CDF = \frac{\gamma\left(m, \frac{m}{\Omega}v^2\right)}{\Gamma(m)} \tag{3.16}$$

Where, Ω is the scale parameter, and m is the shape parameter, which are dimensionless and v is the wind speed.

Normal (N)

The probability distribution function is given by:

$$PDF = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{v-\mu}{2\sigma^2}\right) \tag{3.17}$$

While the Cumulative Distribution Function (CDF) is given as

$$\boldsymbol{CDF = \frac{1}{2}\left[1 + erf\left(\frac{v-\mu}{\sigma\sqrt{2}}\right)\right]} \tag{3.18}$$

Where, σ is the standard deviation, and μ is the mean parameter, which are dimensionless and v is the wind speed.

Rayleigh distribution

This is a continuous probability distribution function.The Rayleigh distribution commonly occurs when wind velocity is analyzed in two dimensions. The probability distribution function is given by:

$$\boldsymbol{PDF = \frac{2v}{c^2} e^{-\left(\frac{v}{c}\right)^2}} \tag{3.19}$$

While the Cumulative Distribution Function (CDF) is given as:

$$\boldsymbol{CDF = 1 - exp\left[-\left(\frac{v}{c}\right)^2\right]} \tag{3.20}$$

It is a uni-parameter function where, c is the scale parameter, and v is the wind speed, which are both measured in m/s

Table 3.2: The Statistical Distributions Expressions

Distribution function	PDF	CDF
Weibull (W)	$PDF = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} exp\left(-\left(\frac{v}{c}\right)^{k}\right)$	$CDF = 1 - exp\left(-\left(\frac{v}{c}\right)^{k}\right)$
Gamma (G)	$PDF = \frac{v^{\beta-1}}{\alpha^{\beta}\Gamma(\beta)} exp\left(-\frac{v}{\beta}\right)$	$CDF = \frac{\gamma\left(\beta, \frac{v}{\alpha}\right)}{\Gamma(\beta)}$
Lognormal (LN)	$PDF = \frac{1}{v\sigma\sqrt{2\pi}} exp\left[-\frac{1}{2}\left(\frac{ln(v)-\mu}{\sigma}\right)^{2}\right]$	$CDF = \frac{1}{2} + erf\left[\frac{ln(v)-\mu}{\sigma\sqrt{2}}\right]$
Logistic (L)	$PDF = \frac{exp\left(-\frac{v-\mu}{\sigma}\right)}{\sigma\left\{1+exp\left(-\frac{v-\mu}{\sigma}\right)\right\}^{2}}$	$CDF = \frac{1}{1+exp\left(-\frac{v-\mu}{\sigma}\right)}$
Log-Logistic (LL)	$PDF = \left(\left(\frac{\beta}{\alpha}\left(\frac{v}{\alpha}\right)^{\beta-1}\right) \Big/ \left(1+\frac{v}{\alpha}\right)^{\beta}\right)^{2}$	$CDF = \frac{1}{\left(1+\frac{v}{\alpha}\right)^{-\beta}}$
Inverse Gaussian (IG)	$PDF = \left(\frac{\lambda}{2\pi v^{2}}\right)^{1/2} e^{\left[\frac{-\lambda(v-\mu)^{2}}{2\mu^{2}v}\right]}$	$CDF = \Phi\left(\sqrt{\frac{\lambda}{v}}\left(\frac{v}{\mu}-1\right)\right) + exp\left(\frac{2\lambda}{\mu}\right)\Phi\left(-\sqrt{\frac{\lambda}{v}}\left(\frac{v}{\mu}+1\right)\right)$
Generalized Extreme Value (GEV)	$PDF = \frac{1}{\alpha}\left[1-\frac{\zeta(v)-\mu}{\alpha}\right]^{\frac{1}{\zeta}-1} exp\left[-\left(1-1-\frac{\zeta(v)-\mu}{\alpha}\right)^{\frac{1}{\zeta}}\right]$	$CDF = exp\left[-\left(1-1-\frac{\zeta(v)-\mu}{\alpha}\right)^{\frac{1}{\zeta}}\right]$
Nakagami (Na)	$PDF = \frac{2m^{m}}{\Gamma(m)\Omega^{m}} v^{2m-1} e^{\left(-\frac{m}{\Omega}G^{2}\right)}$	$CDF = \frac{\gamma\left(m, \frac{m}{\Omega}v^{2}\right)}{\Gamma(m)}$
Normal (N)	$PDF = \frac{1}{\sqrt{2\pi\sigma^{2}}} exp\left(-\frac{v-\mu}{2\sigma^{2}}\right)$	$CDF = \frac{1}{2}\left[1 + erf\left(\frac{v-\mu}{\sigma\sqrt{2}}\right)\right]$

Rayleigh (R)		$PDF = \frac{2v}{c^2} e^{-\left(\frac{v}{c}\right)^2}$				$CDF = 1 - exp\left[-\left(\frac{v}{c}\right)^2\right]$		
W	**k**	Shape parameter	LL	$\boldsymbol{\beta}$	Shape parameter	Na	$\boldsymbol{m}$	Shape parameter
	c [m/s]	Scale parameter		$\boldsymbol{\alpha}$	Scale Parameter		$\boldsymbol{\Omega}$	Scale parameter
G	$\boldsymbol{\beta}$	Shape parameter	IG	$\boldsymbol{\lambda}$	Shape parameter	N	$\boldsymbol{\sigma}$	Standard deviation
	$\boldsymbol{\alpha}$	Scale Parameter		$\boldsymbol{\mu}$	Mean parameter		$\boldsymbol{\mu}$	Mean parameter
LN	$\boldsymbol{\sigma}$	Shape parameter	GEV	$\boldsymbol{\mu}$	AreaParameter	R	**c [m/s]**	Scale parameter
	$\boldsymbol{\mu}$	Scale Parameter		$\boldsymbol{\zeta}$	Scale Parameter			
L	$\boldsymbol{\mu}$	Area Parameter		$\boldsymbol{\alpha}$	Shape Parameter			
	$\boldsymbol{\sigma}$	Scale Parameter						

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Description of Wind Speed Data

The Tables 4.1 – 4.4 show the statistics for each location at a10m height. The tables represent the mean, median, standard deviation, coefficient of variance, Skewness, Kurtosis, minimum velocity and maximum velocity. The average wind speed varies from 2.33 knots to 4.684 knots which is about 1.2m/s to 2.4m/s respectively. The standard deviation is 0.59 in Delta and 0.82 in Edo. The Skewness values are positive in Delta and Bauchi, this shows that distribution is right- skewed. In Edo and Abia, the Skewness values are negative making it left – skewed. The coefficient of variance is highest in Bauchi at 34.33 and lowest in Abia at 17.41.

Table 4.1: Data collected for Edo

Location	Year	Mean	St Dev	CoefVar	Minimum	Median	Maximum	Skewness	Kurtosis
Edo	2008	4.844	1.028	21.230	3.700	4.700	7.100	1.370	2.310
	2009	5.578	0.976	17.490	4.100	5.300	7.200	0.320	-0.410
	2010	5.344	0.805	15.060	4.200	5.600	6.500	-0.220	-1.190
	2011	4.300	1.325	30.810	2.100	4.600	6.100	-0.300	-1.100
	2012	6.000	0.760	12.670	5.000	5.700	7.100	0.420	-1.340
	2013	6.067	0.912	15.040	4.400	6.300	7.300	-0.580	-0.020
	2014	3.633	0.689	18.970	2.800	3.600	5.100	1.190	1.840
	2015	3.656	0.464	12.690	3.000	3.700	4.500	0.460	-0.040
	2016	3.644	0.548	15.040	2.700	3.700	4.300	-0.360	-0.700
	2017	3.778	0.648	17.140	2.500	3.900	4.600	-0.980	0.660
	Average	4.6844	0.8155	17.614	3.45	4.71	5.98	0.132	0.001

Table 4.2: Data collected for Delta

Location	Year	Mean	St Dev	CoefVar	Minimum	Median	Maximum	Skewness	Kurtosis
Delta	2008	3.742	0.512	13.70	3.000	3.750	4.900	0.750	1.330
	2009	3.325	0.377	11.34	2.700	3.300	3.800	-0.230	-1.040
	2010	3.942	0.417	10.57	3.300	3.900	4.900	1.110	1.850
	2011	4.058	0.570	14.04	3.100	4.100	5.200	0.090	0.500
	2012	3.417	0.685	20.04	2.500	3.350	4.900	0.700	0.750
	2013	3.392	1.108	32.67	1.500	3.250	5.300	0.020	-0.270
	2014	1.883	0.395	20.98	1.200	1.900	2.400	-0.230	-1.340
	2015	2.367	0.446	18.84	1.700	2.350	3.400	0.910	1.720
	2016	2.050	0.723	35.27	0.900	2.150	3.300	-0.010	-0.350
	2017	2.208	0.696	31.52	1.100	2.150	3.400	0.170	-0.450
	Average	3.0384	0.5929	20.897	2.1	3.02	4.15	0.328	0.27

Table 4.3: Data collected for Abia

Location	Year	Mean	StDev	CoefVar	Minimum	Median	Maximum	Skewness	Kurtosis
Abia	2008	4.508	0.705	15.64	3.400	4.450	6.000	0.620	0.630
	2009	4.467	0.303	6.770	3.800	4.400	4.800	-0.700	0.550
	2010	4.033	0.591	14.66	2.800	4.200	4.800	-0.780	0.040
	2011	3.783	0.616	16.29	3.000	3.600	4.800	0.560	-1.060
	2012	3.608	0.815	22.59	2.100	3.500	5.000	-0.020	-0.290
	2013	3.800	0.663	17.44	2.550	3.775	5.050	-0.040	0.520
	2014	3.600	0.411	11.42	2.900	3.600	4.200	-0.100	-1.120
	2015	4.142	1.143	27.60	3.200	3.850	7.600	2.910	9.290
	2016	4.533	0.987	21.78	3.700	4.250	7.200	1.980	4.630
	2017	4.125	0.819	19.86	2.900	4.000	5.600	0.380	-0.460
	Average	4.0599	0.7053	17.405	3.035	3.9625	5.505	0.481	4.0599

Table 4.4: Data collected for Bauchi

Location	Year	Mean	StDev	CoefVar	Minimum	Median	Maximum	Skewness	Kurtosis
Bauchi	2008	1.367	0.589	43.13	0.700	1.400	2.600	1.080	1.360
	2008	1.367	0.589	43.13	0.700	1.400	2.600	1.080	1.360
	2008	1.367	0.589	43.13	0.700	1.400	2.600	1.080	1.360
	2009	1.256	0.725	57.72	0.200	1.700	2.000	-0.410	-1.890
	2010	1.167	0.374	32.07	0.500	1.100	1.700	-0.420	-0.260
	2011	2.411	0.625	25.94	1.700	2.300	3.700	1.130	1.160
	2012	2.656	0.823	31.00	1.700	2.700	3.900	0.290	-1.590
	2013	2.111	0.569	26.95	1.500	1.900	3.100	0.680	-0.990
	2014	2.044	0.517	25.31	1.100	2.000	2.900	-0.110	0.830
	2015	1.894	0.600	31.68	1.100	1.900	2.950	0.740	-0.140
	2016	4.644	1.493	32.15	0.800	5.100	5.700	-2.630	7.300
	2017	5.700	1.130	19.83	4.700	5.200	7.500	0.920	-0.980
	Average	2.332	0.718583	34.33667	1.283333	2.341667	3.4375	0.285833	0.626667

4.2 Characteristics of Wind Speed

4.2.1 Monthly wind speed

The initial step involves studying the wind speed behavior with respect to time to begin the wind speed data analysis. The figures 4.1 to 4.4 represent the mean wind speed on a monthly time frame and study for each location.

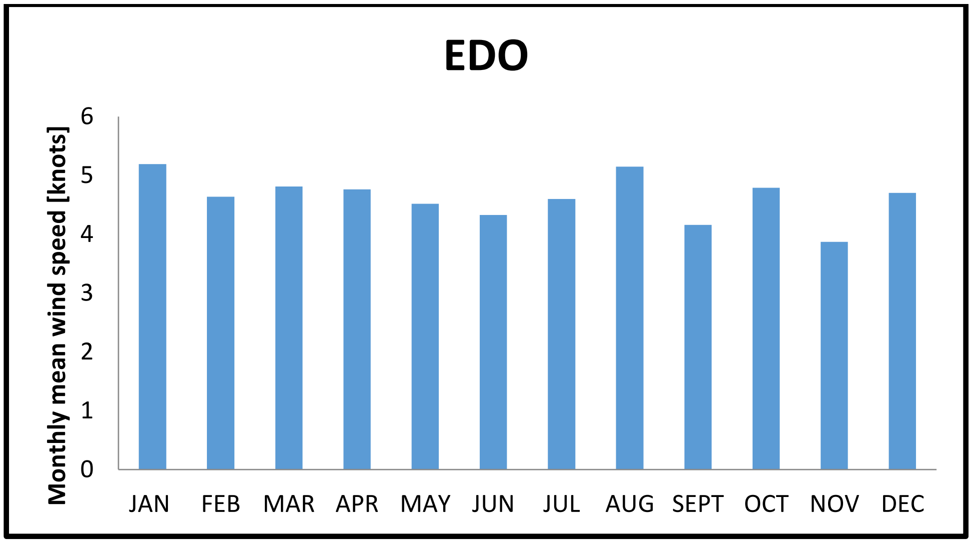

Figure 4.1: Average monthly mean wind speed in Edo

The highest mean wind speed value 5.18 knots in January and minimum of 3.87 knots in November for Edo while the level of change recorded in speed values varies from 2.2 knots in November 2017 and 7.3 knots March 2013.

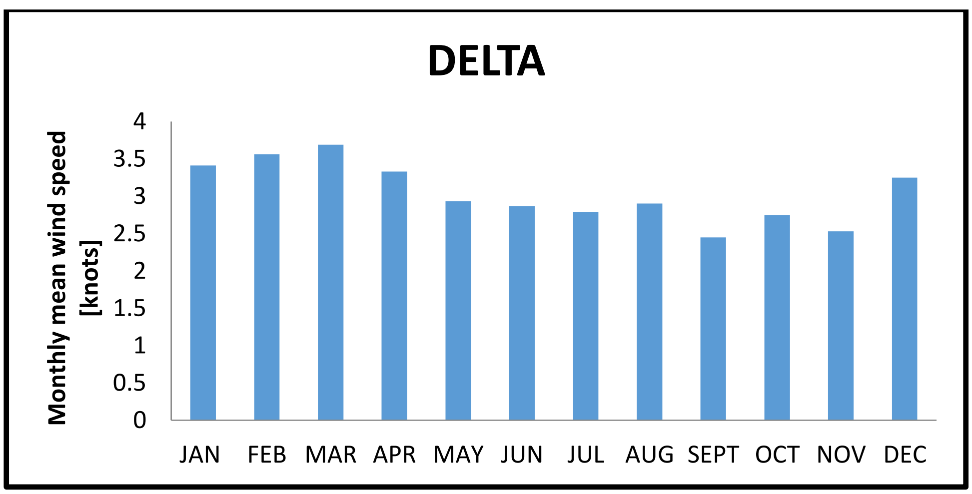

Figure 4.2: Average monthly mean wind speed in Delta

The highest mean wind speed value 3.69 knots in March and minimum of 2.45 knots in September for Delta while the level of change recorded in the speed values varies from 0.9 knots in July 2016 and 7.3 knots March 2008, February 2010 and December 2012.

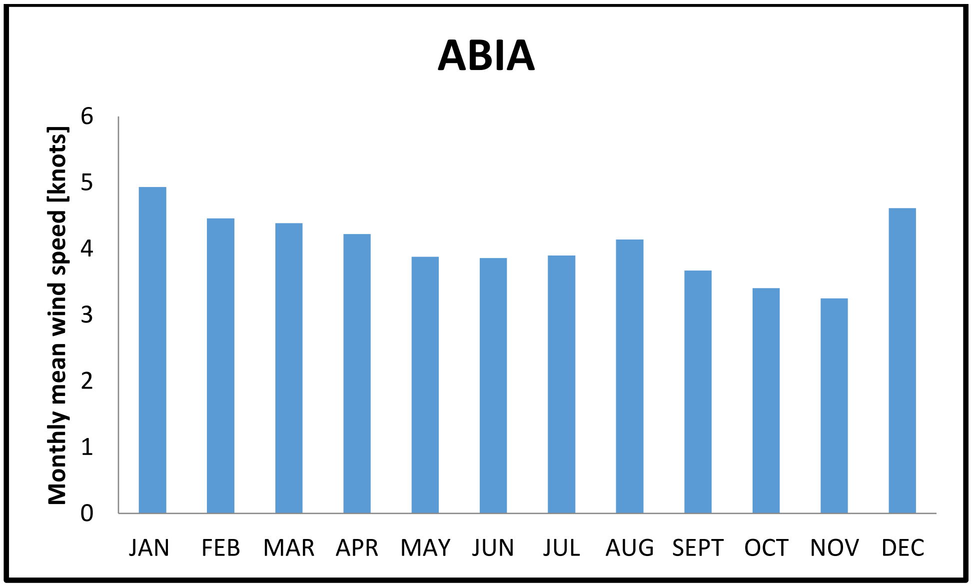

Figure 4.3: Average monthly mean wind speed in Abia

The highest mean wind speed value 4.935 knots in January and minimum of 3.25 knots in November for Abia while the level of change recorded in speed values varies from 2.1 knots in November 2017 and 7.2 knots January 2016.

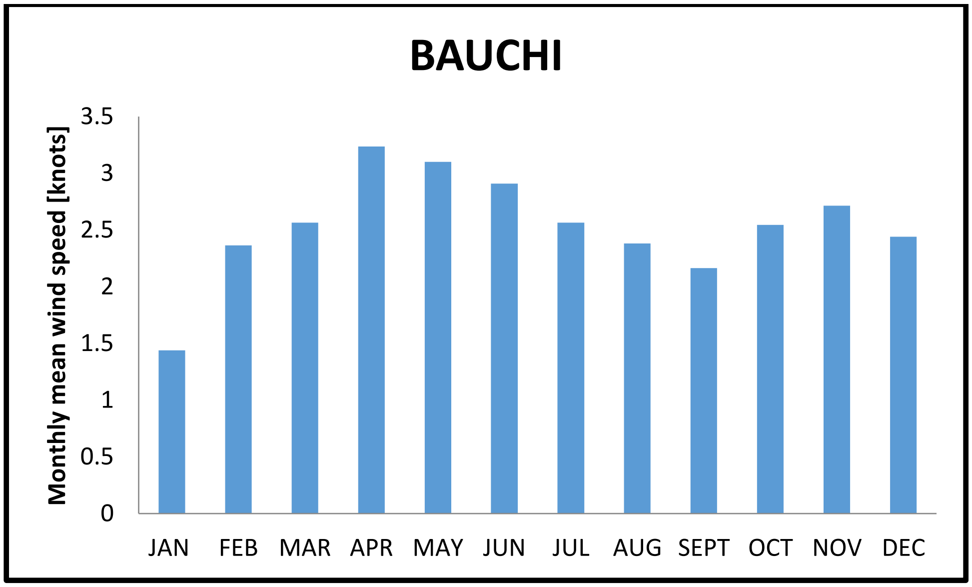

Figure 4.4: Average monthly mean wind speed in Bauchi

The highest mean wind speed value 3.235 knots in April and minimum of 1.44 knots in January for Bauchi while the level of change recorded in speed values varies from 0.2 knots in January 2009 and 7.5 knots February 2017.

4.2.2 Characteristics of wind speed at a 10m height

The mean wind speed data of the four locations is analyzed over time. Mean monthly wind speed shown in Fig 4.5

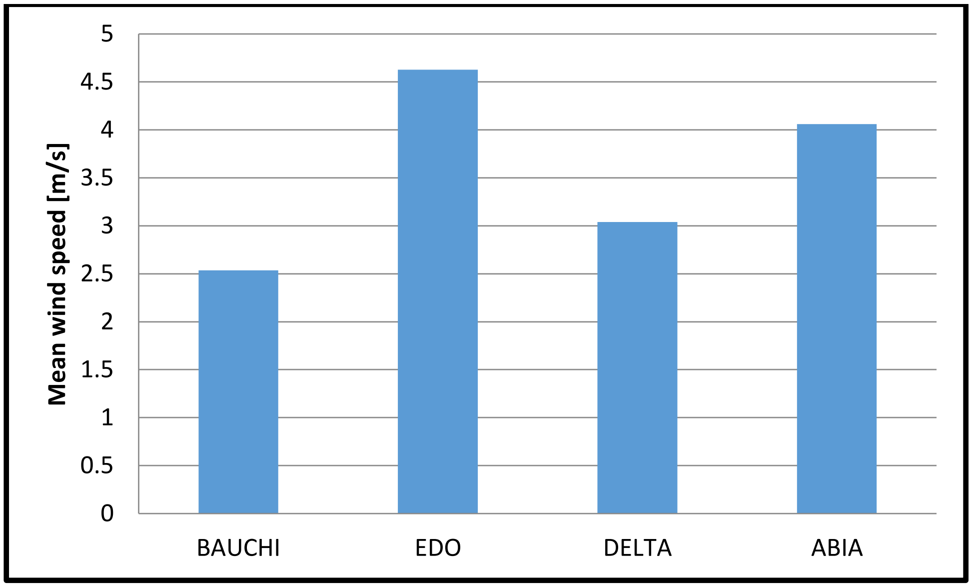

Figure 4.5: Annual mean wind speed at studied locations

During the ten year period in Edo, it is shown that the maximum annual mean wind speed of 5.19 knots was recorded in January, while the minimum recorded wind speed value is 3.87 knots in November. In Delta, the highest recorded value for the mean wind speed is 3.69 knots in March, while the minimum value recorded is 2.45 knots in September. In Abia, the highest recorded value for the mean wind speed is 4.935 knots in January, while the minimum speed value is 3.25 in November. In Bauchi, the highest recorded value for the mean wind speed is 3.235 knots in April, while the minimum speed value recorded is 1.44 knots in January. This is illustrated in Fig 4.6

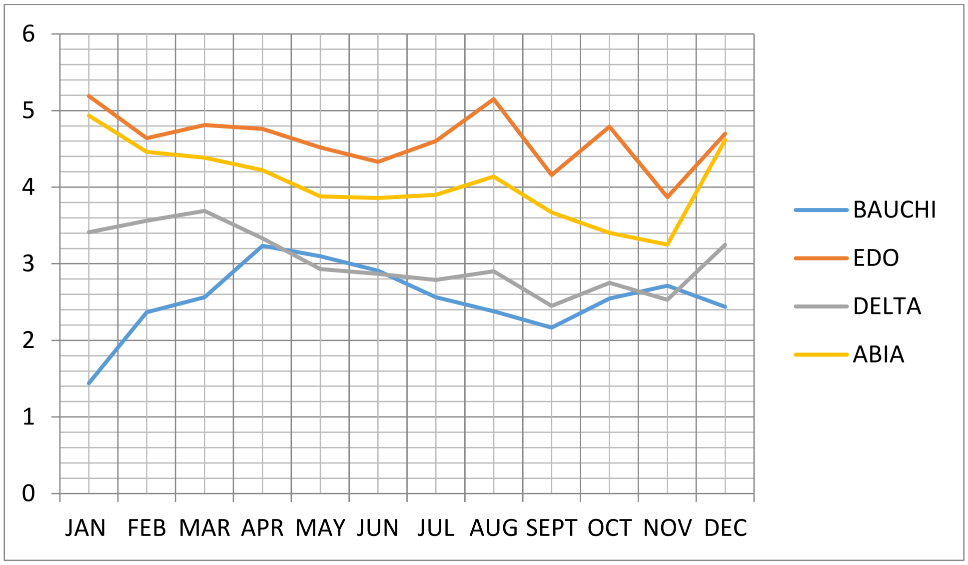

Figure 4.6: Average monthly wind speed at four specific locations

4.3 Wind Direction

Table 4.5: Data collected for Edo

EDO												
MONTHLY MEAN OF WIND DIRECTION												
YEAR	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**
2008	SE	SE	W	SW	W	SW	W	W	SW	W	SW	SW
2009	W	W	W	SW	W	SW	SW	W	W	W	W	SW
2010	SW	W	SW	SW	SW	SW	SW	SW	SW	SW	SW	W
2011	SW	W	SW	W	SW	W	W	W	W	SW	SW	W
2012	W	SW	W	SW	SW	SW	W	SW	W	W	W	W
2013	W	SW	SW	SW	SW	SW	SW	SW	W	SW	W	W
2014	W	W	SW	SW	W	W	W	W	W	W	SW	W
2015	E	W	W	W	W	W	W	SW	W	W	W	E
2016	E	SW	W	SW	W	W	W	SW	SW	SW	SW	SW

2017	SW	SW	SW	SW	SW	SW	SW	SW	W	W	SW	W

Table 4.6: Data collected for Delta

DELTA												
MONTHLY MEAN WIND DIRECTION												
YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
2008	N	E	S	S	S	S	S	S	S	S	S	E
2009	S	S	S	S	S	S	S	W	E	W	N	N
2010	N	S	S	S	S	S	S	S	S	S	S	E
2011	N	S	S	S	S	S	S	W	S	S	N	W
2012	S	S	S	S	W	W	W	W	W	W	W	E
2013	E	SW	SW	S	S	W	S	S	S	S	S	W
2014	E	S	S	S	S	S	S	S	S	S	S	S
2015	E	S	S	S	S	S	S	S	S	S	N	N
2016	N	N	S	S	S	S	S	S	S	S	N	N
2017	N	S	S	S	S	S	S	S	SW	SW	S	N

Table 4.7: Data collected for Abia

ABIA												
MONTHLY WIND DIRECTION												
YEAR	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**
2008	NE	NE	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW
2009	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	NE
2010	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	NE
2011	NE	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	NE
2012	NE	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	NE
2013	NE	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW

2014	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	NE
2015	NE	SW	SW	SW	SW	SW	SW	SW	SW	SW	NE	NE
2016	NE	NE	SW	SW	SW	SW	SW	SW	SW	SW	SW	NE
2017	SW	NE	SW	SW	SW	SW	SW	SW	SW	SW	SW	NW

Table 4.8: Data collected for Bauchi

BAUCHI												
MONTHLY MEAN WIND DIRECTION												
YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
2008	N	N	N	E	S	S	S	S	S	E	NE	E
2009	E	E	E	S	S	S	S	S	S	S	N	NE
2010	N	N	N	N	S	S	S	S	S	S	NE	N
2011	N	N	E	SW	S	S	SW	SW	E	E	E	NE
2012	E	SW	E	E	S	S	S	S	S	SE	E	NE
2013	NE	N	E	E	S	S	S	S	S	E	NE	NE
2014	NE	NE	E	E	S	S	S	S	W	E	E	E
2015	E	E	E	E	E	W	W	W	W	E	E	E
2016	E	E	E	SE	E	W	NW	NW	NW	SE	E	E
2017	E	E	E	E	NW	W	NW	NW	W	SE	E	NE

Table 4.9: Percentage occurrence of wind direction

Location	Maximum Percentage Occurrence
Edo	48% W , 47.5% SW
Delta	67.5% S , 12% N , 11% W
Abia	85% SW , 14% NE
Bauchi	34% E , 28% S

In this study, the wind direction is taken from 16 different directions from the chosen locations, the maximum percentage of occurrence is recorded.

As depicted Edo has 48% wind from the West and 47.5% from the South west. Delta has 67% from the North. Abia has 85% from the South – West and 14% from the North – East. Bauchi has 35% from the East and 28% from the South.

4.4 Parameters of Distribution Function of Wind Power Density at a10m Height

To estimate the distribution parameters and choose the best distribution functions among the ten selected the Maximum like-hood method and Kolmogorov-Smirnov test were used for each location. Tables 4.5-4.8 are the tabulated mean, variance and parameters of each distribution function. Moreover, the fitted PDF and CDF models for each location were presented in Figures 4.7-4.13.Also, Table 4.9 presents the goodness-of-fit statistics in terms of the Kolmogorov Smirnov tests for each distribution function. The distribution function with the lowest Kolmogorov Smirnov value will be selected to be the best model for the wind speed distribution in the studied location. Furthermore, based on the result, Generalized Extreme Value distribution has the lowest value, which is considered as the best distribution function to study the wind speed distribution of all studied sites. Moreover, it is observed that the Rayleigh distribution function cannot be used to analyze the wind potential in the studied Location, as shown in Table 4.10.

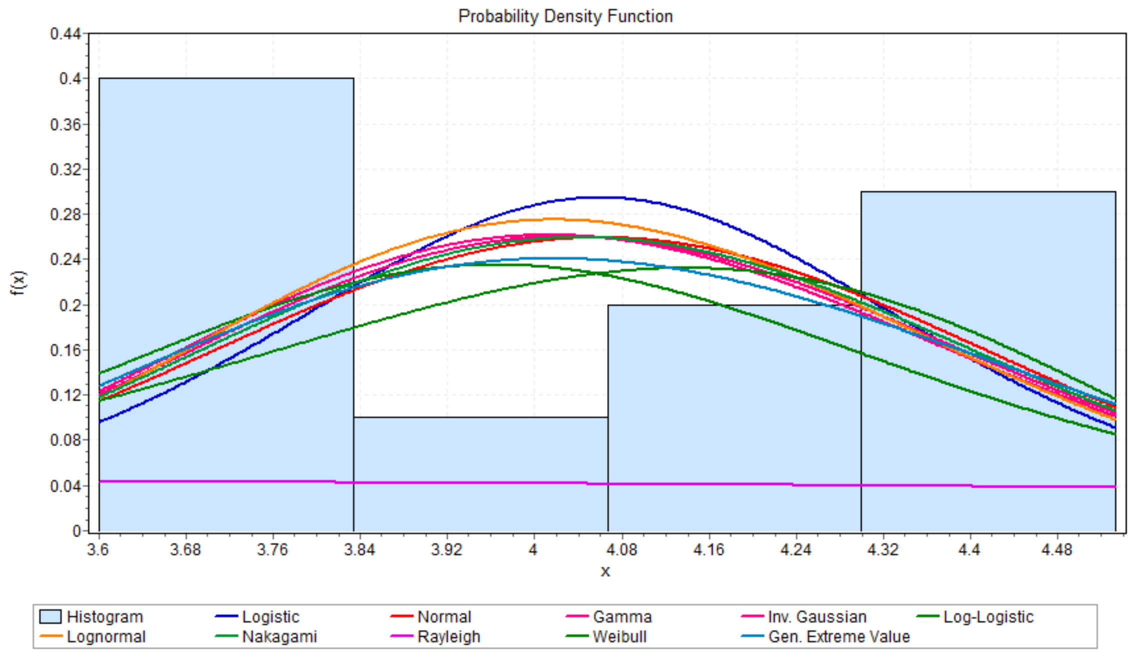

Figure 4.7: Probability density function (PDF) for Abia

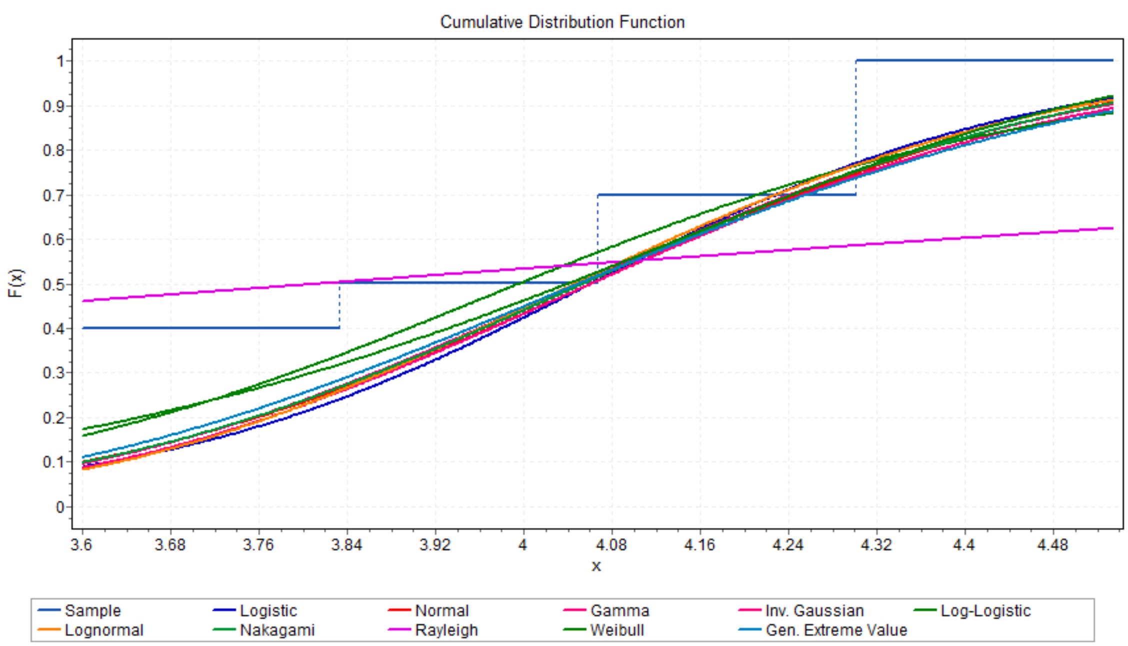

Figure 4.8: Cumulative distribution function (CDF) for Abia

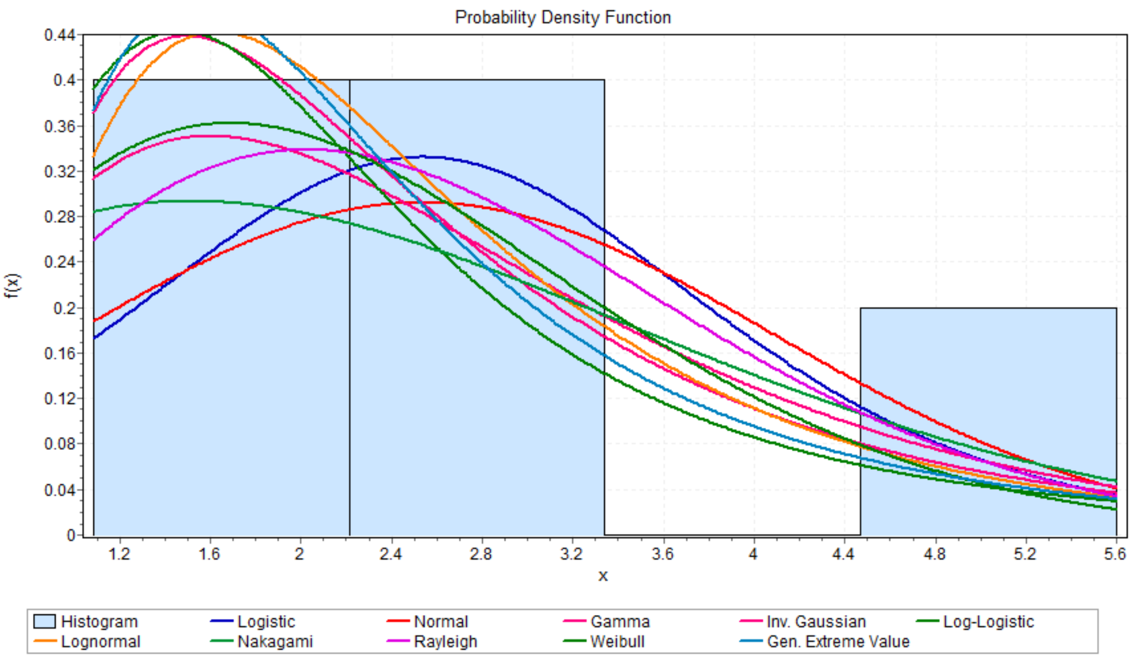

Figure 4.9: Probability density function (PDF) for Bauchi

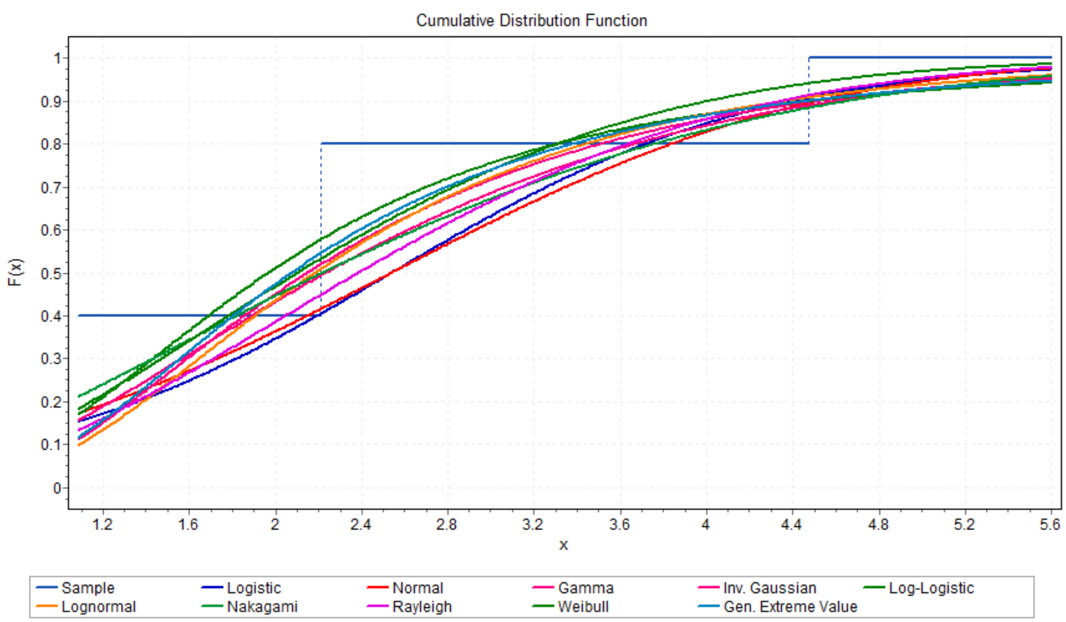

Figure 4.10: Cumulative distribution function (CDF) for Bauchi

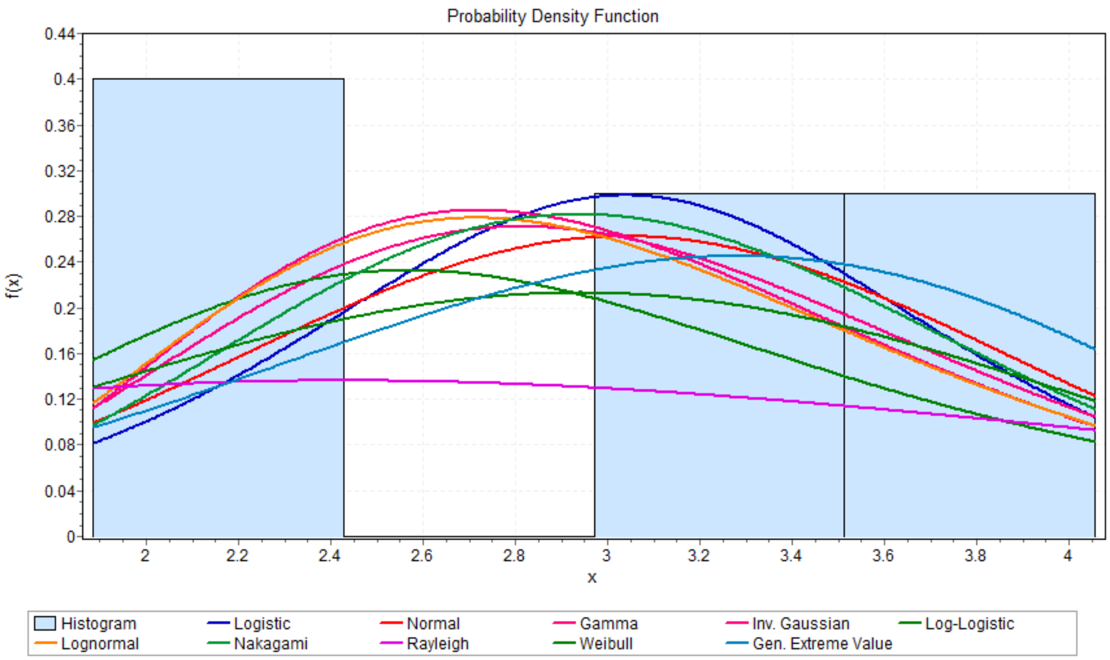

Figure 4.11: Probability density function (PDF) for Delta

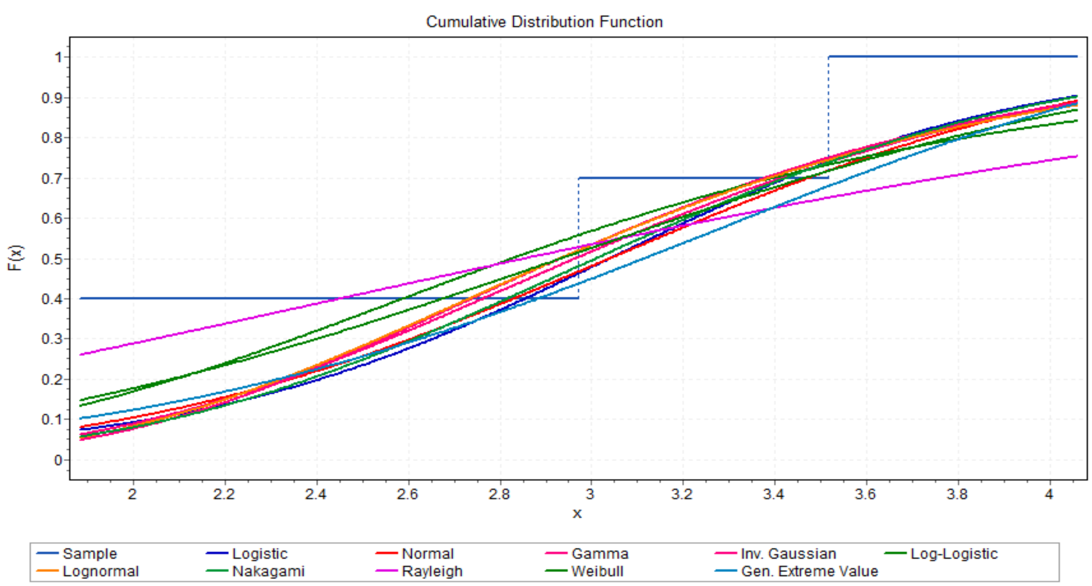

Figure 4.12: Cumulative distribution function (CDF) for Delta

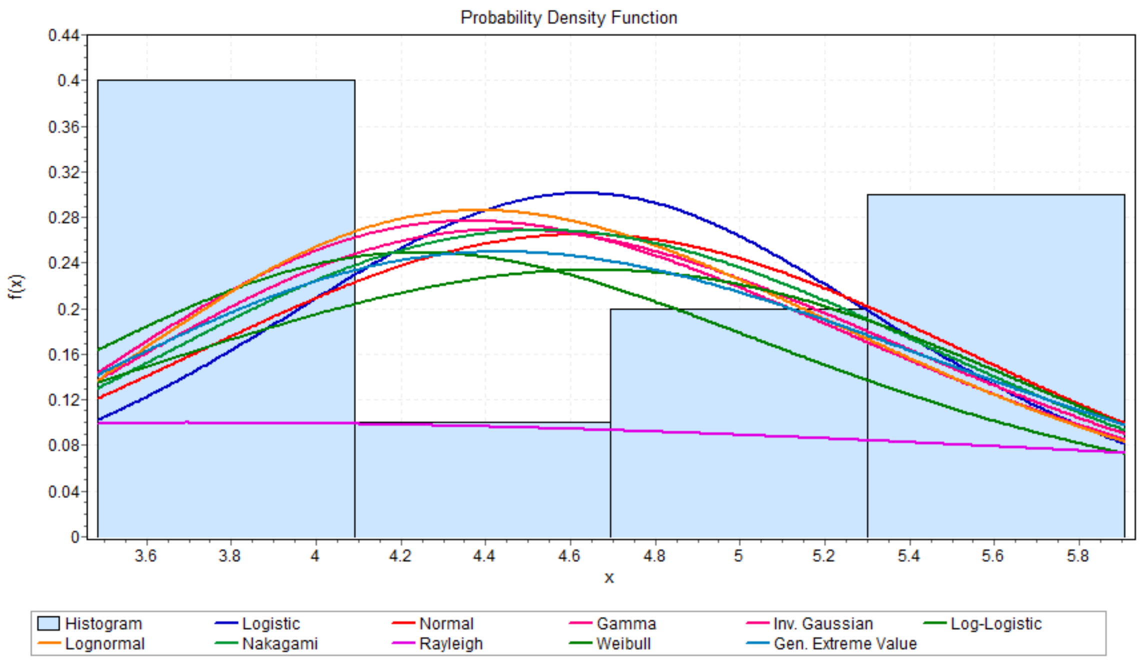

Figure 4.13: Probability density function (PDF) for Edo

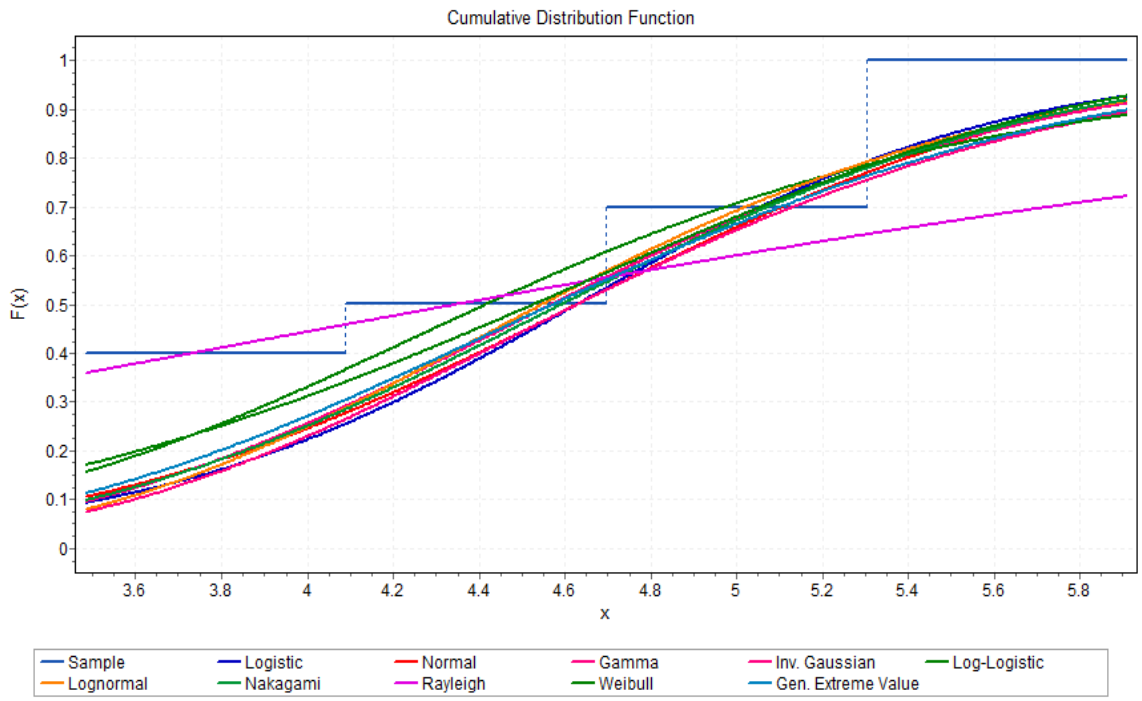

Figure 4.14: Cumulative distribution function (CDF) for Edo

Table 4.10: Annual Distribution parameters for Edo

	EDO										
Distribution Functions	**Year**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
	Actual Mean	4.78333	5.44166	5.05	4.61666	5.76666	5.90833	3.86666	3.66666	3.48333	3.68333
	Mean	4.78333	5.44167	5.05	4.61667	5.76667	5.90833	3.86667	3.66667	3.48333	3.68333
G	Variance	0.88423	0.72342	0.68620	1.86239	0.72828	0.83772	0.48329	0.38129	0.27679	0.78392
	a	25.8759	40.9329	37.1646	11.4443	45.6612	41.6707	30.9357	35.2597	43.8356	17.3065

	b	0.18485	0.13294	0.13588	0.40340	0.12629	0.14178	0.12499	0.10399	0.07946	0.21282
GEV	Mean	4.83649	5.43477	5.09638	4.62573	5.7677	5.91127	3.85857	3.66473	3.47499	3.68196
	Variance	2.10841	0.74019	1.49695	1.70112	0.68986	0.81846	0.45140	0.38032	0.26278	0.71399
	k	0.29442	0.07296	0.24315	0.67238	0.42668	0.54107	0.25766	0.14598	0.17775	0.38806
	sigma	0.60804	0.73119	0.59912	1.41805	0.88211	0.98181	0.66359	0.56203	0.47944	0.88669
	mu	4.239	5.06221	4.56314	4.42262	5.53229	5.70849	3.61353	3.41209	3.27104	3.426
IG	Mean	4.78333	5.44167	5.05	4.61667	5.76667	5.90833	3.86667	3.66667	3.48333	3.68333
	Variance	0.87112	0.72600	0.69285	2.20974	0.76181	0.87344	0.49520	0.38772	0.27965	0.85346
	mu	4.78333	5.44167	5.05	4.61667	5.76667	5.90833	3.86667	3.66667	3.48333	3.68333
	lambda	125.636	221.95	185.88	44.5292	251.723	236.136	116.742	127.143	151.136	58.5517
L	Mean	4.66513	5.37474	5.01617	4.71939	5.75684	5.95042	3.84502	3.62892	3.4585	3.7157
	Variance	1.0017	0.81640	0.87986	1.78925	0.72846	0.93882	0.58337	0.40283	0.34118	0.83420
	mu	4.66513	5.37474	5.01617	4.71939	5.75684	5.95042	3.84502	3.62892	3.4585	3.7157
	sigma	0.551796	0.498155	0.517154	0.737474	0.47056	0.5342	0.4211	0.349924	0.322036	0.503555
LL	Mean	4.71326	5.41505	5.05052	4.84717	5.79909	5.99399	3.88156	3.66263	3.48082	3.78526
	Variance	0.97397	0.82150	0.91882	2.76913	0.77298	1.06068	0.62458	0.41676	0.35101	1.07657
	mu	1.52947	1.67559	1.60217	1.52623	1.74649	1.77646	1.33641	1.28316	1.23323	1.29642
	sigma	0.11251	0.09076	0.10244	0.17714	0.08245	0.09309	0.10956	0.09541	0.09225	0.14473
LN	Mean	4.78796	5.44692	5.05585	4.66056	5.77449	5.91696	3.8727	3.67132	3.48685	3.6989

							8			6
Variance	0.95532	0.79548	0.76113	2.46696	0.83355	0.95851	0.5444 4	0.42483	0.30675	0.9452 6
mu	1.54569	1.68182	1.60587	1.48535	1.7411	1.76432	1.3361 4	1.28504	1.23654	1.2746 5
sigma	0.20205 9	0.16266 2	0.17129 4	0.32798 9	0.15713 3	0.16434 7	0.1888 3	0.17616 1	0.15785 1	0.2584 67

Table 4.10: Annual Distribution parameters for Edo cont.

	Mean	**4.78891**	**5.44331**	**5.05108**	**4.60521**	**5.76576**	**5.90724**	**3.86725**	**3.66767**	**3.48384**	**3.68131**
Na	Variance	0.914659	0.729569	0.68497	1.6637	0.707645	0.811991	0.477706	0.381546	0.276187	0.741318
	mu	6.38607	10.2736	9.4319	3.2979	11.8657	10.8645	7.94591	8.93377	11.1071	4.68534
	omega	23.8483	30.3592	26.1983	22.871	33.9517	35.7075	15.4333	13.8333	12.4133	14.2933
N	Mean	4.78333	5.44167	5.05	4.61667	5.76667	5.90833	3.86667	3.66667	3.48333	3.68333
	Variance	1.05606	0.815379	0.759091	1.6997	0.760606	0.871742	0.526061	0.424242	0.305152	0.792424
	mu	4.78333	5.44167	5.05	4.61667	5.76667	5.90833	3.86667	3.66667	3.48333	3.68333
	sigma	1.02765	0.902983	0.871258	1.30372	0.872127	0.933671	0.7253	0.651339	0.552405	0.890182
R	Mean	4.32787	4.88304	4.53609	4.23832	5.16387	5.29572	3.48157	3.29616	3.1224	3.35052
	Variance	5.1179	6.51513	5.62221	4.9083	7.28609	7.6629	3.31202	2.96866	2.66392	3.06738
	B	3.45314	3.8961	3.61928	3.38169	4.12017	4.22537	2.77789	2.62996	2.49132	2.67333
W	Mean	4.76127	5.42358	5.04891	4.63398	5.76076	5.91671	3.86596	3.65283	3.48104	3.68903
	Variance	1.26062	0.953185	0.788289	1.37083	0.77085	0.796306	0.534308	0.490615	0.323229	0.717232
	A	5.1952	5.82075	5.41133	5.0786	6.12574	6.2881	4.16106	3.93496	3.71543	4.01839
	B	4.84315	6.49829	6.66457	4.48962	7.77325	7.86089	6.16179	6.06864	7.21699	4.98764

Table 4.11: Annual Distribution parameters for Delta

DELTA											
Distribution Functions	Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
G	Actual mean	3.7416	3.325	3.94166	4.05833	3.4166	3.39166	1.833	2.366	2.05	2.2083
	Mean	3.7417	3.325	3.94167	4.05833	3.4166	3.39167	1.83	2.367	2.05	2.2083
	Variance	0.2262	0.13339	0.15115	0.30203	0.4143	1.25956	0.151	0.129	0.54529	0.4732
	a	60.821	82.8794	102.789	54.5309	28.171	9.13285	23.63	32.88	7.70682	10.304
	b	0.0627	0.04011	0.03834	0.07442	0.1212	0.37137	0.05	0.030	0.26599	0.2143
GEV	Mean	3.7408	3.34096	3.94189	4.05891	3.4168	3.38807	1.871	2.364	2.04785	2.2039
	Variance	0.2390	0.28417	0.15497	0.29793	0.4644	1.0901	0.230	0.175	0.46558	0.4240
	k	0.0922	1.15733	0.03555	0.25831	0.0808	0.32896	0.855	0.629	0.33204	-0.274
	sigma	0.4436	0.49324	0.32082	0.53931	0.5574	1.07024	0.471	0.358	0.70040	0.6424
	mu	3.5187	3.37381	3.76764	3.85999	3.1341	3.0416	1.854	2.112	1.82242	1.9711
IG	Mean	3.7167	3.325	3.94167	4.05833	3.4667	3.39167	1.833	2.367	2.05	2.2083
	Variance	0.2323	0.13622	0.14876	0.30958	0.1991	1.4814	0.112	0.136	0.65378	0.532
	mu	3.74167	3.325	3.94167	4.05833	3.4167	3.39167	1.883	2.366	2.05	2.2083
	lambda	225455	269.848	411.65	215.903	94.989	26.3371	41.44	76.30	13.1774	20.237
L	Mean	3.7164	3.33363	3.89431	4.06841	3.3748	3.38262	1.896	2.353	2.05701	2.1934
	Variance	0.2411	0.15529	0.14459	0.30953	0.4453	1.24548	0.746	0.170	0.53347	0.500
	mu	3.7164	3.33363	3.89431	4.06841	3.374	3.38262	1.896	2.353	2.05701	2.1934
	sigma	0.27743	0.217263	0.209645	0.30638	0.37916	0.615288	0.255	0.2313	0.40268	0.390093
LL	Mean	3.73621	3.34603	3.90543	4.09318	3.4148	3.51953	1.9158	2.588	2.15667	2.26911
	Variance	0.24585	0.16367	0.13809	0.33648	0.4614	1.81285	0.2154	0.185	0.883285	0.677822
	mu	1.30943	1.20058	1.35789	1.3995	1.2053	1.19531	0.2286	0.435	0.69003	0.7618
	sigma	0.07240	0.06608	0.05217	0.07720	0.1082	0.19449	0.1775	0.754	0.21677	0.1858
LN	Mean	3.74409	3.32713	3.94294	4.06226	3.4262	3.4272	1.8861	2.636	2.07692	2.224
	Variance	0.25402	0.14903	0.16241	0.33885	0.4075	1.66187	0.7785	0.913	0.74163	0.5949
	mu	1.3112	1.19542	1.36673	1.39158	1.2181	1.16558	0.151	0.496	0.65156	0.7429
	sigma	0.13400	0.11564	0.10194	0.14256	0.147	0.36377	0.2259	0.850	0.39831	0.3368

Na	Mean	3.74238	3.32484	3.94223	4.05827	3.4185	3.38762	1.8273	2.3682	2.04674	2.2081

Table 4.11: Annual Distribution parameters for Delta Cont.

	Variance	**0.235405**	**0.131276**	**0.154625**	**0.297927**	**0.417208**	**1.15323**	**0.145337**	**0.175803**	**0.49254**	**0.445146**
	mu	14.9957	21.1749	25.2503	13.9418	7.12102	2.59529	6.21484	8.09341	2.23115	2.84722
	omega	14.2408	11.1858	15.6958	16.7675	12.1033	12.6292	3.69	5.78333	4.68167	5.32083
N	Mean	3.74167	3.325	3.94167	4.05833	3.41667	3.39167	1.88333	2.36667	2.05	2.20833
	Variance	0.262652	0.142045	0.173561	0.32447	0.468788	1.22811	0.156061	0.198788	0.522727	0.48447
	mu	3.74167	3.325	3.94167	4.05833	3.41667	3.39167	1.88333	2.36667	2.05	2.20833
	sigma	0.512495	0.376889	0.416606	0.569622	0.684681	1.1082	0.395045	0.445856	0.722999	0.696039
R	Mean	3.34436	4.88304	3.51105	3.62893	3.08317	3.14943	1.70239	2.13125	1.91754	2.04425
	Variance	3.05611	6.51513	3.36835	3.59834	2.5974	2.71024	0.791881	1.24111	1.00469	1.14186
	B	2.66841	3.8961	2.80141	2.89547	2.46001	2.51288	1.35831	1.70049	1.52998	1.63108
W	Mean	3.71996	3.32758	3.91626	4.04543	3.40279	3.39625	1.88926	2.35293	2.05373	2.21149
	Variance	0.346074	0.136459	0.260421	0.365581	0.540656	1.11156	0.136753	0.245724	0.46557	0.448319
	A	3.96346	3.48551	4.13174	4.29732	3.69251	3.77037	2.03769	2.54924	2.28897	2.4514
	B	7.47134	10.8874	9.18791	7.93746	5.32893	3.57556	5.93463	5.47834	3.31564	3.67614

Table 4.12: Annual Distribution parameters for Abia

ABIA											
Distribution Functions	Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	Actual Mean	4.50833	4.46666	4.03333	3.78333	3.60833	3.8	3.6	4.14166	4.53333	4.125

G	Mean	4.50833	4.46667	4.03333	3.78333	3.60833	3.81667	3.6	4.125	4.53333	4.125
	Variance	0.4431	0.086612	0.349732	0.336433	0.644014	0.420298	0.157483	0.871273	0.748779	0.610237
	a	45.8701	230.351	46.515	42.5452	20.2171	34.6586	82.2944	19.5296	27.4462	27.8836
	b	0.098285	0.019391	0.08671	0.088925	0.17848	0.110122	0.043745	0.211218	0.165172	0.147936
GEV	Mean	4.50582	4.41048	4.03777	3.78677	3.60592	3.81698	3.60194	4.09838	5.33104	4.11745
	Variance	0.447646	0.29882	0.364465	0.448163	0.590668	0.405257	0.162192	1.28383	Inf	0.588358
	k	-0.11632	-1.37772	-0.7526	0.110626	-0.34814	-0.27756	-0.56173	0.332888	0.778873	-0.17564
	sigma	0.593771	0.438304	0.650103	0.440321	0.794375	0.635965	0.437864	0.411541	0.33863	0.716215
	mu	4.22493	4.48186	3.96837	3.47888	3.35799	3.59048	3.51602	3.66158	3.97104	3.81165
IG	Mean	4.50833	4.46667	4.03333	3.78333	3.60833	3.81667	3.6	4.125	4.53333	4.125
	Variance	0.44569	0.088377	0.37248	0.336027	0.694335	0.438895	0.160157	0.78268	0.709246	0.625617
	mu	4.50833	4.46667	4.03333	3.78333	3.60833	3.81667	3.6	4.125	4.53333	4.125
	lambda	205.596	1008.35	176.153	161.157	67.663	126.675	291.315	89.6783	131.358	112.192
L	Mean	4.46466	4.47914	4.08639	3.73322	3.60123	3.81312	3.60304	3.89632	4.37558	4.08359
	Variance	0.473835	0.092535	0.353848	0.412035	0.695965	0.426807	0.189193	0.602489	0.723818	0.689394
	mu	4.46466	4.47914	4.08639	3.73322	3.60123	3.81312	3.60304	3.89632	4.37558	4.08359
	sigma	0.379511	0.167712	0.327959	0.353898	0.459943	0.360186	0.239808	0.427942	0.469057	0.457767
LL	Mean	4.49594	4.48473	4.1112	3.7571	3.65683	3.85022	3.61555	3.92629	4.40909	4.13164
	Variance	0.4808	0.0949	0.4113	0.4087	0.8060	0.4683	0.1973	0.4440	0.6435	0.7313

		5	85	92	72	37	26	07	45	77	32
	mu	1.49158	1.49833	1.40186	1.30961	1.26833	1.33286	1.27782	1.35373	1.4677	1.39822
	sigma	0.083846	0.037781	0.084784	0.092231	0.130709	0.096187	0.067129	0.091994	0.098378	0.111289
LN	Mean	4.51238	4.46773	4.03963	3.7867	3.62067	3.82315	3.60223	4.11819	4.53387	4.13203
	Variance	0.487829	0.096468	0.407981	0.368482	0.764725	0.481121	0.17522	0.839887	0.772521	0.687577
	mu	1.49499	1.49447	1.38381	1.31881	1.25831	1.32488	1.27485	1.39125	1.49313	1.39903
	sigma	0.153869	0.069436	0.157142	0.159289	0.238111	0.179962	0.115814	0.219854	0.192074	0.198699

Table 4.12: Annual Distribution parameters for Abia Cont.

Na	Mean	4.50939	4.46653	4.03182	3.78445	3.60729	3.81637	3.59991	4.14721	4.54239	4.12616
	Variance	0.44623	0.085127	0.332781	0.33962	0.616662	0.410291	0.155615	1.02147	0.811715	0.605635
	mu	11.5134	58.7125	12.3331	10.6633	5.39176	8.99442	20.9424	4.32375	6.47264	7.1463
	omega	20.7808	20.035	16.5883	14.6617	13.6292	14.975	13.115	18.2208	21.445	17.6308
N	Mean	4.50833	4.46667	4.03333	3.78333	3.60833	3.81667	3.6	4.125	4.53333	4.125
	Variance	0.497197	0.091515	0.349697	0.379697	0.66447	0.445152	0.169091	1.31477	0.975152	0.671136
	mu	4.50833	4.46667	4.03333	3.78333	3.60833	3.81667	3.6	4.125	4.53333	4.125
	sigma	0.705122	0.302515	0.591352	0.616196	0.81515	0.667197	0.411207	1.14664	0.987498	0.819229
R	Mean	4.03995	3.96679	3.60949	3.39341	3.27175	3.42948	3.20944	3.78294	4.10401	3.72119
	Variance	4.4596	4.29955	3.55989	3.14642	2.92484	3.21366	2.8145	3.91022	4.60214	3.78361
	B	3.22342	3.16504	2.87996	2.70755	2.61048	2.73633	2.56076	3.01835	3.27452	2.96908
W	Mean	4.48823	4.47028	4.04502	3.77646	3.60926	3.80788	3.6009	4.08703	4.49437	4.11895
	Variance	0.605176	0.082346	0.28069	0.426481	0.635252	0.471198	0.169203	1.74057	1.32374	0.71037
	A	4.80643	4.59616	4.26863	4.04366	3.92189	4.08707	3.77641	4.54769	4.92973	4.45458
	B	6.76938	19.2867	9.13798	6.78621	5.20405	6.48834	10.5636	3.42363	4.4253	5.65506

Table 4.13: Annual Distribution parameters for Bauchi

Distribution Functions	Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
	Actual Mean	1.16666	1.08333	1.125	2.21666	2.425	1.90833	2.55	2.39583	4.88333	5.6
G	Mean	1.16667	1.08333	1.075	2.21667	2.425	1.90833	2.55	2.55	4.88333	5.6
	Variance	0.332219	0.57718	0.207866	0.344549	0.625997	0.338082	0.95235	0.95235	4.01386	0.90599
	a	4.09703	2.03336	5.55946	14.261	9.39401	10.7717	6.82785	6.82785	5.94116	34.6141
	b	0.284759	0.532781	0.193364	0.155436	0.258143	0.177161	0.373471	0.373471	0.82195	0.161784
GEV	Mean	1.1726	0.975403	1.07608	2.22568	2.42302	1.90389	2.54707	2.54707	4.80233	Inf
	Variance	0.458212	1.39137	0.1557	0.51970	0.74862	0.35633	1.0893	1.0893	1.54635	Inf
	k	0.151737	-1.14778	-0.51908	0.177399	0.060509	-0.02415	0.052567	0.052567	-1.23704	1.22362
	sigma	0.411575	1.09726	0.427105	0.41514	0.61881	0.47985	0.75561	0.75561	1.09734	0.299161
	mu	0.863003	1.04401	0.983099	1.8986	2.0266	1.63812	2.06962	2.06962	4.91293	4.88277
IG	Mean	1.16667	1.08333	1.075	2.21667	2.425	1.90833	2.55	2.55	4.88333	5.6
	Variance	0.394047	0.928789	0.296768	0.345994	0.665212	0.358664	1.04734	1.04734	8.73244	0.884508
	mu	1.16667	1.08333	1.075	2.21667	2.425	1.90833	2.55	2.55	4.88333	5.6
	lambda	4.02988	1.36889	4.18608	31.4799	21.4376	19.3765	15.8319	15.8319	13.3356	198.546
L	Mean	1.18295	1.06608	1.09588	2.14431	2.35825	1.8497	2.42998	2.42998	5.16169	5.44976
	Variance	0.455291	0.603855	0.169694	0.384144	0.764756	0.388802	1.06878	1.06878	0.835569	1.08003
	mu	1.10404	1.06608	1.09588	2.14431	2.35825	1.8497	2.42998	2.42998	5.16169	5.44976
	sigma	0.335212	0.428427	0.227114	0.34171	0.482139	0.343776	0.569973	0.569973	0.503967	0.572965
LL	Mean	1.19685	1.32375	1.171	2.18812	2.43063	1.90197	2.54263	2.54263	5.332	5.48214
	Variance	0.665575	20.8374	0.37655	0.39785	0.91311	0.43484	1.31411	1.31411	3.17628	0.98867

				1	6	1	7				8
	mu	0.026068	-	0.05244	0.74497	0.82211	0.58980	0.85015	0.85015	1.62398	1.68562
			0.139413	7	6	2	8	8	8		
	sigma	0.300886	0.483767	0.25046	0.15154	0.19904	0.17867	0.22281	0.22281	0.17303	0.09807
				9	5	2	9	6	6	1	9
LN	Mean	1.18295	1.16526	1.13484	2.22055	2.43683	1.91662	2.56762	2.56762	5.20545	5.60386
	Variance	0.455291	1.31443	0.15044	0.38108	0.74415	0.39829	1.17332	1.17332	9.50863	0.96957
				7	1	9	3				5
	mu	0.027175	-0.18557	0.07124	0.76053	0.83166	0.59909	0.86108	0.86108	1.49932	1.70825
		2		7	4	3	5				
	sigma	0.530734	0.82282	0.33239	0.27284	0.34360	0.32084	0.40471	0.40471	0.54843	0.17437
				3	4	8	3	6	6	6	9
Na	Mean	1.18042	1.08151	1.06673	2.22278	2.43112	1.91252	2.56413	2.56413	4.77813	5.60439
	Variance	0.323267	0.467005	0.17125	0.35591	0.61547	0.33475	0.94356	0.94356	2.68617	0.93746
				2	9	2	8	8	8		3
	mu	1.1672	0.699678	1.76121	3.58256	2.50767	2.84057	1.84302	1.84302	2.22966	8.49562

Table 4.13: Annual Distribution parameters for Bauchi cont

	omega	**1.71667**	**1.63667**	**1.30917**	**5.29667**	**6.52583**	**3.9925**	**7.51833**	**7.51833**	**25.5167**	**32.3467**
N	Mean	1.16667	1.08333	1.075	2.21667	2.425	1.90833	2.55	2.55	4.88333	5.6
	Variance	0.387879	0.505152	0.1675	0.417879	0.703864	0.382652	1.10818	1.10818	1.82152	1.07636
	mu	1.16667	1.08333	1.075	2.21667	2.425	1.90833	2.55	2.55	4.88333	5.6
	sigma	0.622799	0.71074	0.409268	0.646435	0.838966	0.618588	1.0527	1.0527	1.34964	1.03748
R	Mean	1.16115	1.13377	1.01401	2.03961	2.26393	1.77079	2.43	2.43	4.47669	5.04034
	Variance	0.3684	0.351232	0.28095	1.13667	1.40046	0.856798	1.61345	1.61345	5.47592	6.94165
	B	0.926463	0.904618	0.809063	1.62737	1.80635	1.41289	1.93886	1.93886	3.57188	4.02161
W	Mean	1.17264	1.08436	1.07491	2.2112	2.431	1.90977	2.55656	2.55656	4.82668	5.57993
	Variance	0.344966	0.481713	0.142885	0.452331	0.664719	0.375476	1.0431	1.0431	1.06487	1.2951
	A	1.32397	1.20942	1.20172	2.45176	2.71088	2.12428	2.87487	2.87487	5.23414	6.03339
	B	2.0973	1.59958	3.11234	3.65749	3.28112	3.44674	2.69945	2.69945	5.39121	5.67539

Table 4.14: Fit results of the distribution functions for each location

		ABIA	DELTA	EDO	BAUCHI
	DISTRIBUTION	PARAMETERS			
1	Gamma	α=127.69 β=0.03179	α=13.505 β=0.22498	α=25.665 β=0.18027	α=2.7032 β=0.9379
2	Gen. Extreme Value	k=-0.238 σ=0.368 μ=3.919	k=-0.447 σ=0.919 μ=2.802	k=-0.190 σ=0.911 μ=4.25	k=0.243σ=0.9143 μ=1.721
3	Inv. Gaussian	λ=518.44 μ=4.06	λ=41.032 μ=3.0383	λ=118.74 μ=4.6267	λ=6.8537 μ=2.5354
4	Log-Logistic	α=16.03 β=3.9949	α=4.6067 β=2.8252	α=7.1073 β=4.4144	α=2.667 β=1.9642
5	Logistic	σ=0.19808 μ=4.06	σ=0.45583 μ=3.0383	σ=0.50352 μ=4.6267	σ=0.8502 μ=2.5354
6	Lognormal	σ=0.08399 μ=1.3977	σ=0.27629 μ=1.0748	σ=0.18949 μ=1.514	σ=0.54045 μ=0.77985
7	Nakagami	m=32.097 Ω=16.6	m=4.0528 Ω=9.8467	m=6.7368 Ω=22.157	m=0.68124 Ω=8.5686
8	Normal	σ=0.35929 μ=4.06	σ=0.82678 μ=3.0383	σ=0.91328 μ=4.6267	σ=1.5421 μ=2.5354
9	Rayleigh	σ=3.2394	σ=2.4242	σ=3.6915	σ=2.023
10	Weibull	α=11.235 β=4.173	α=3.3128 β=3.2757	α=4.993 β=4.8697	α=1.8586 β=2.5569

Table 4.15: Distribution function rank in each location

		ABIA		DELTA		EDO		BAUCHI	
		STATISTICS	RANK	STATISTICS	RANK	STATISTICS	RANK	STATISTICS	RANK
1	Gamma	0.1698	3	0.26515	7	0.19271	4	0.21544	6
2	Gen. Extreme Value	0.15268	**1**	0.19476	**1**	0.17576	2	0.15649	**1**
3	Inv. Gaussian	0.17277	6	0.28027	10	0.21866	8	0.18394	4
4	Log-Logistic	0.15864	2	0.27926	9	0.17894	3	0.18077	2
5	Logistic	0.18794	9	0.25224	4	0.21897	9	0.29571	9
6	Lognormal	0.18071	7	0.2767	8	0.20316	7	0.18625	5
7	Nakagami	0.17134	5	0.25637	5	0.19546	5	0.22165	7
8	Normal	0.17116	4	0.2356	2	0.19734	6	0.29623	10
9	Rayleigh	0.46071	10	0.26049	6	0.3593	10	0.25183	8
10	Weibull	0.18316	4	0.25031	3	0.17114	**1**	0.18346	3

Table 4.16: The Mean Power Density (W/m^2) of Edo

	MEAN POWER DENSITY W/M^2									
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
ACTUAL	9.124504	13.43424	10.73721	8.20357	15.98792	17.1954	4.819783	4.109903	3.523728	4.166203
G	9.124485	13.43427	10.73721	8.203587	15.98794	17.19537	4.819796	4.109914	3.523718	4.166191
GEV	9.432096	13.38323	11.03577	8.25198	15.99651	17.22105	4.789569	4.103394	3.498469	4.161544
IG	9.124485	13.43427	10.73721	8.203587	15.98794	17.19537	4.819796	4.109914	3.523718	4.166191
L	8.464641	12.94463	10.52287	8.763446	15.90632	17.56549	4.739288	3.984277	3.4489	4.277
LL	8.729342	13.23807	10.74053	9.494718	16.25911	17.95417	4.875692	4.096344	3.516106	4.521728
LN	9.151006	13.47319	10.77457	8.43979	16.05307	17.27083	4.84268	4.125571	3.534411	4.219454
Na	9.156454	13.44642	10.7441	8.142647	15.98038	17.18586	4.821965	4.113278	3.525266	4.159341
N	9.124485	13.43427	10.73721	8.203587	15.98794	17.19537	4.819796	4.109914	3.523718	4.166191
R	6.758338	9.70707	7.781482	6.347439	11.48004	12.38204	3.51838	2.985672	2.537949	3.13584
W	8.998824	13.30073	10.73026	8.296211	15.93884	17.26864	4.817141	4.063551	3.516773	4.185563

Table 4.17: The Mean Power Density (W/m^2) of Delta

	DELTA									
	MEAN POWER DENSITY W/M^2									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
ACTUAL	4.367296	3.06473	5.10572	5.572633	3.325256	3.252796	0.556928	1.105169	0.718255	0.897865
G	4.367307	3.06473	5.105733	5.572619	3.325266	3.252805	0.556925	1.105173	0.718255	0.897861
GEV	4.364542	3.109075	5.106588	5.575009	3.316544	3.242459	0.560321	1.104851	0.715998	0.892493
IG	4.367307	3.06473	5.105733	5.572619	3.325266	3.252805	0.556925	1.105173	0.718255	0.897861
L	4.279418	3.088656	4.923896	5.614246	3.203027	3.226836	0.565243	1.061834	0.725649	0.879858
LL	4.348216	3.12325	4.966196	5.717417	3.315961	3.634723	0.585752	1.093879	0.836312	0.974056
LN	4.375787	3.070624	5.11067	5.588824	3.33974	3.356106	0.561622	1.108946	0.746924	0.918138
Na	4.369794	3.064288	5.107909	5.572372	3.330612	3.241167	0.556393	1.107066	0.714834	0.897581
N	4.367307	3.06473	5.105733	5.572619	3.325266	3.252805	0.556925	1.105173	0.718255	0.897861
R	3.118576	9.70707	3.608514	3.98431	2.443485	2.604433	0.411334	0.807087	0.587828	0.712228
W	4.291727	3.07187	5.007626	5.519648	3.284905	3.266001	0.562202	1.086036	0.722183	0.901721

Table 4.18: The Mean Power Density (W/m^2) of Abia

ABIA										
MEAN POWER DENSITY W/M^2										
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
ACTUAL	7.639508	7.429643	5.470281	4.514827	3.916853	4.574758	3.889778	5.923014	7.767303	5.851796
G	7.639491	7.42966	5.470268	4.514815	3.916842	4.635228	3.889778	5.851796	7.767286	5.851796
GEV	7.626738	7.15278	5.488353	4.527142	3.908999	4.636358	3.89607	5.739235	12.63145	5.819723
IG	7.639491	7.42966	5.470268	4.514815	3.916842	4.635228	3.889778	5.851796	7.767286	5.851796
L	7.419634	7.49206	5.689011	4.337785	3.893766	4.622306	3.89964	4.931524	6.984321	5.677324
LL	7.576678	7.520145	5.793261	4.421561	4.076915	4.758542	3.940401	5.0462	7.14602	5.8801
LN	7.660098	7.43495	5.495941	4.526891	3.957165	4.658878	3.897011	5.822861	7.770062	5.881766
Na	7.644881	7.428961	5.464126	4.518826	3.913456	4.634136	3.889486	5.946828	7.813949	5.856734
N	7.639491	7.42966	5.470268	4.514815	3.916842	4.635228	3.889778	5.851796	7.767286	5.851796
R	5.497247	5.203972	3.920621	3.257814	2.919831	3.362808	2.756164	4.513419	5.762919	4.295986
W	7.537766	7.447688	5.51797	4.490265	3.919871	4.603277	3.892696	5.691684	7.568743	5.826086

Table 4.19: The Mean Power Density (W/m^2) of Bauchi

BAUCHI										
MEAN POWER DENSITY W/M^2										
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
ACTUAL	0.132390761	0.105999	0.118707	0.908068	1.18892	0.579402	1.382413	1.146534	9.708819	14.64136
G	0.132391896	0.105998	0.103572	0.908072	1.18892	0.579399	1.382413	1.382413	9.708799	14.64136
GEV	0.134420956	0.077369	0.103885	0.91919	1.18601	0.575364	1.377653	1.377653	9.233648	14.64136
IG	0.132391896	0.105998	0.103572	0.908072	1.18892	0.579399	1.382413	1.382413	9.708799	14.64136
L	0.138011882	0.101015	0.109725	0.822016	1.09342	0.52762	1.19626	1.19626	11.4655	13.49427
LL	0.142934308	0.193391	0.133871	0.873435	1.19722	0.573625	1.370461	1.370461	12.63827	13.73623
LN	0.138011882	0.131912	0.121849	0.912849	1.206405	0.586983	1.411268	1.411268	11.75959	14.67166
Na	0.137128267	0.105465	0.1012	0.915602	1.197944	0.583224	1.405521	1.405521	9.094759	14.67582
N	0.132391896	0.105998	0.103572	0.908072	1.18892	0.579399	1.382413	1.382413	9.708799	14.64136
R	0.130521571	0.121504	0.086925	0.70739	0.9674	0.462933	1.196289	1.196289	7.479772	10.67571
W	0.134434713	0.106301	0.103546	0.901366	1.197767	0.580712	1.39311	1.39311	9.374818	14.4845

Table 4.20: The Mean Power Density (W/m^2) of selected locations

	EDO	**DELTA**	**ABIA**	**BAUCHI**
ACTUAL	9.130246	2.796665	5.697776	2.991261
G	9.130248	2.796668	5.696696	3.013334
GEV	9.187362	2.798788	6.142685	2.962655
IG	9.130248	2.796668	5.696696	3.013334
L	9.061686	2.756866	5.494737	3.01441
LL	**9.342581**	2.859576	5.615982	3.222991
LN	9.188457	2.817738	5.710562	3.235179
Na	9.12757	2.796202	5.711138	2.962218
N	9.130248	2.796668	5.696696	3.013334
R	6.663425	2.798487	4.149078	**2.302474**
W	9.111653	2.771392	5.649605	2.966967

4.5 Parameters of Distribution Function of Wind Power Density at a 30m Height

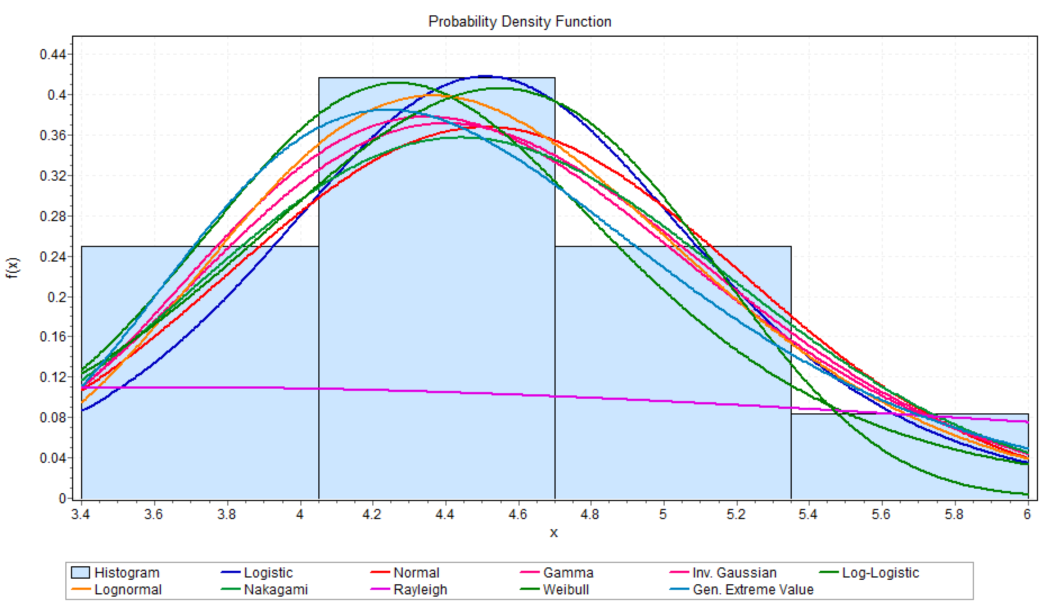

Figure 4.15: Probability density function (PDF) for Edo

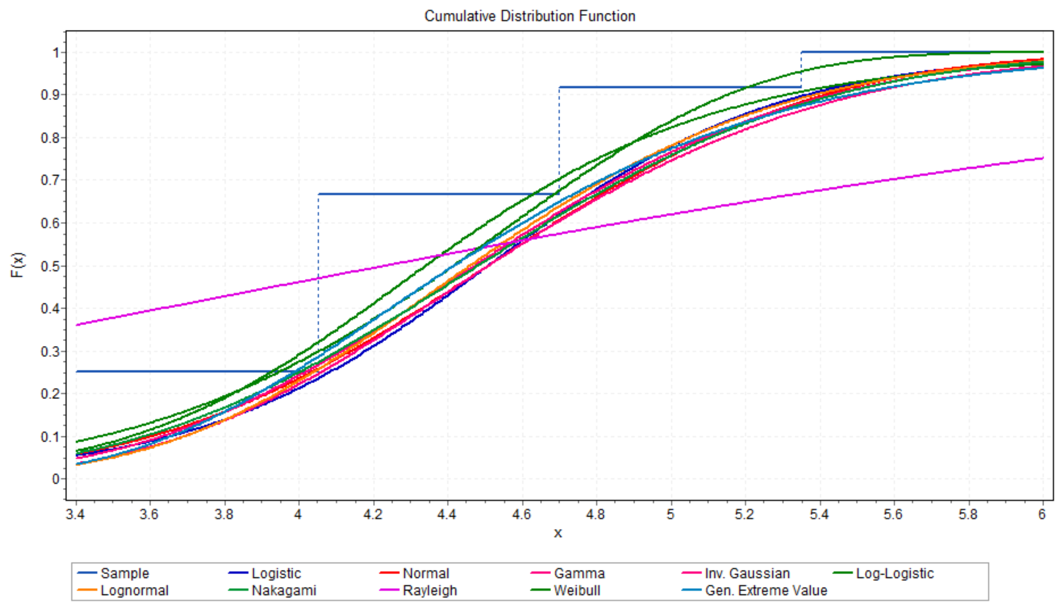

Figure 4.16: Cumulative distribution function (CDF) for Edo

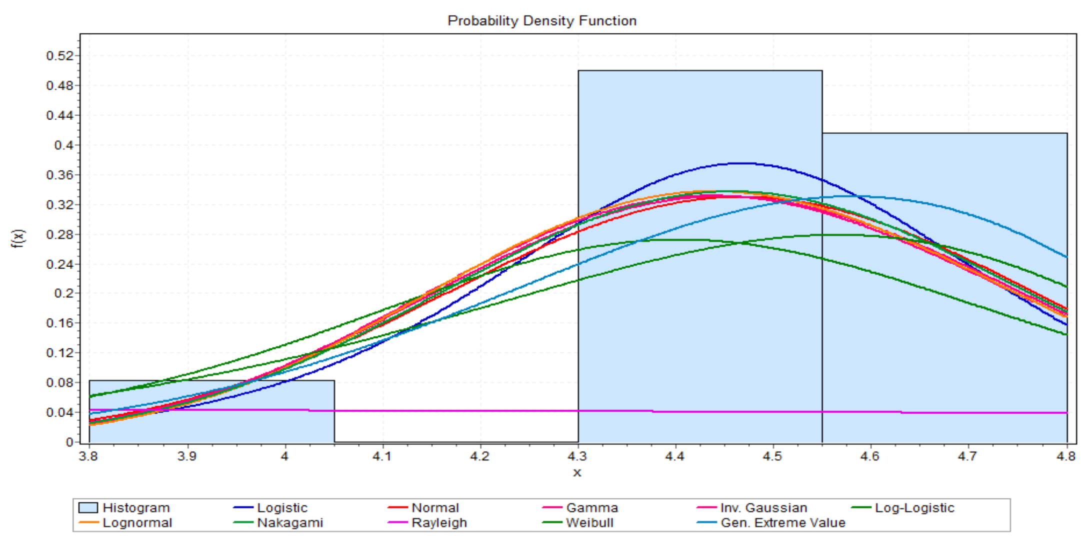

Figure 4.17: Probability density function (PDF) for Delta

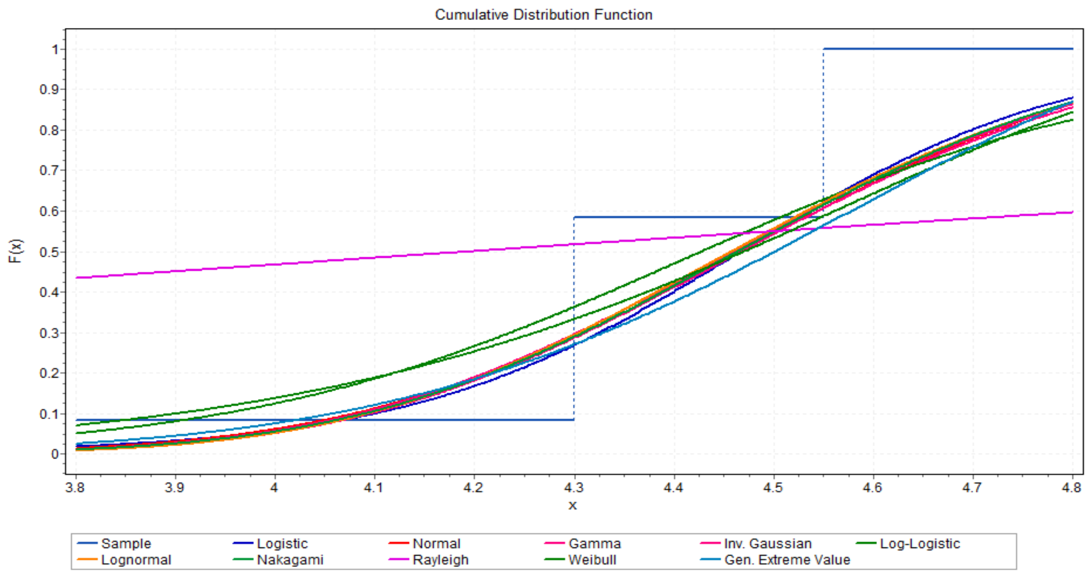

Figure 4.18: Cumulative distribution function (CDF) for Delta

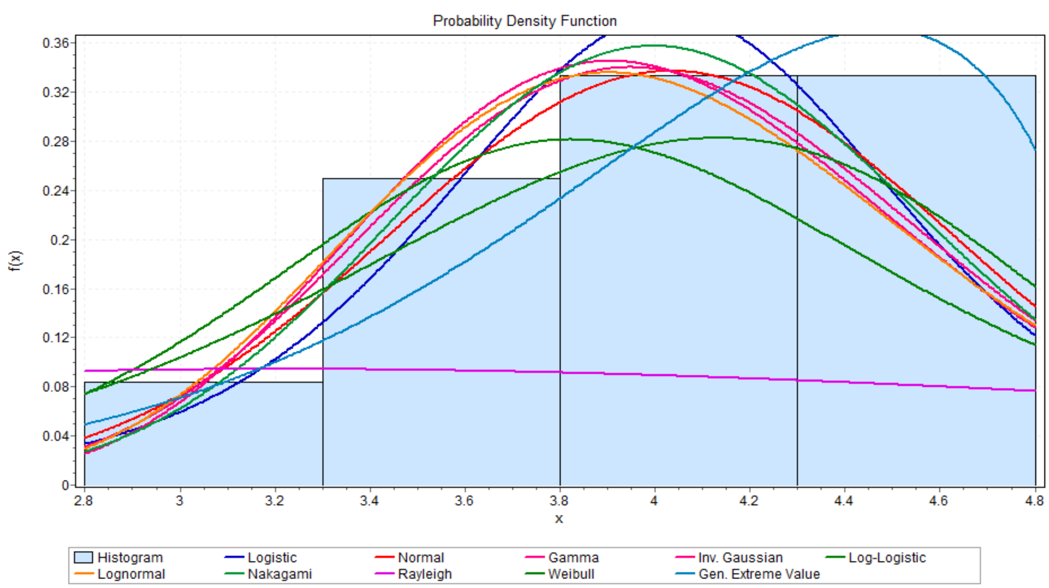

Figure 4.19: Probability density function (PDF) for Abia

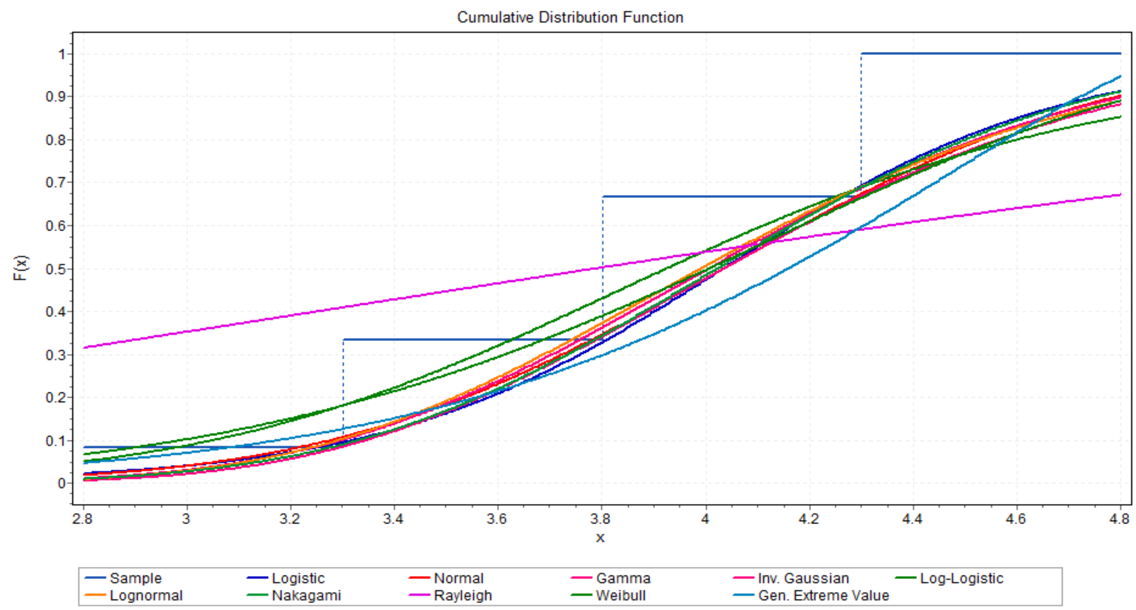

Figure 4.20: Cumulative distribution function (CDF) for Abia

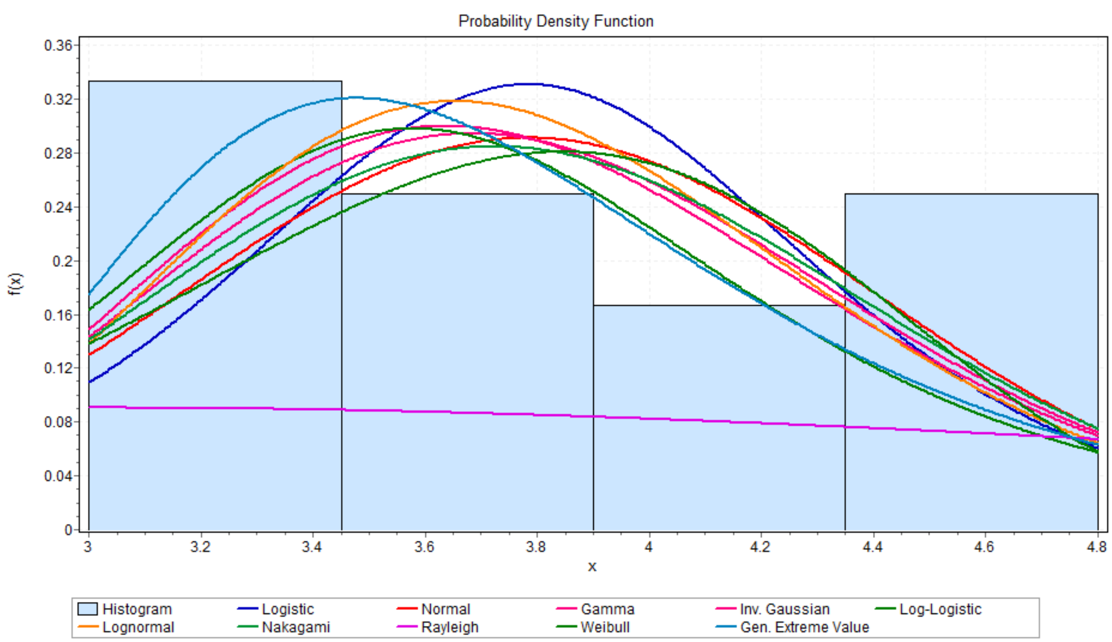

Figure 4.21: Probability density function (PDF) for Bauchi

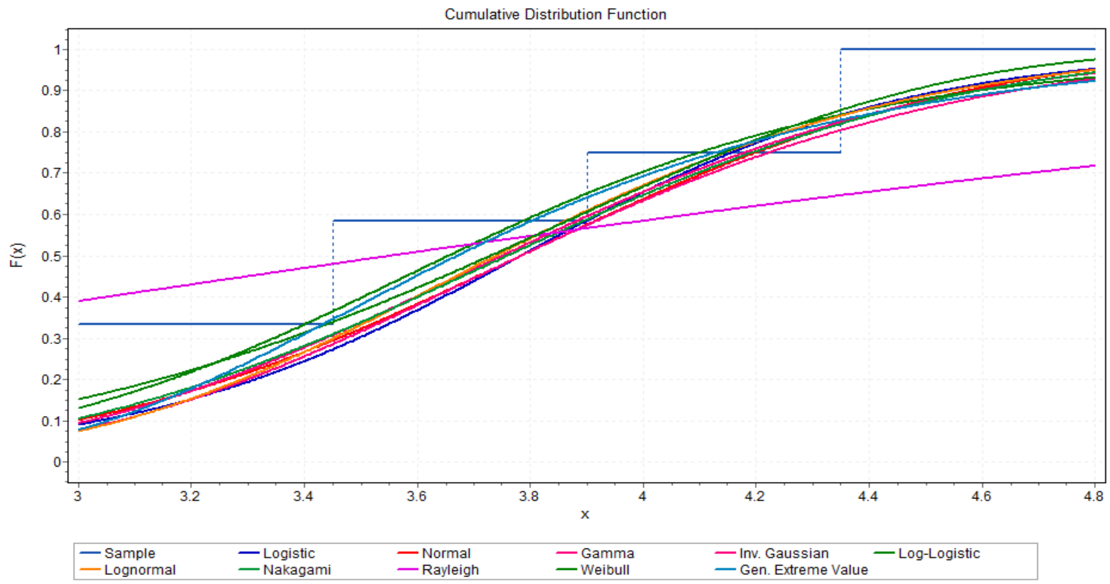

Figure 4.22: Cumulative distribution function (CDF) Bauchi

4.6 Parameters of Distribution Function of Wind Power Density at a 90m Height

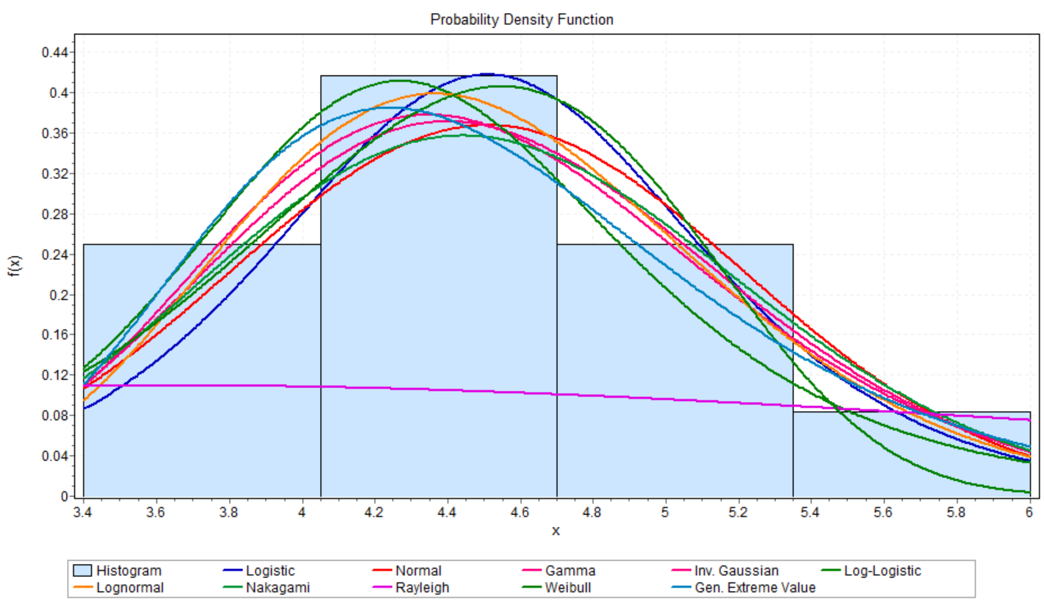

Figure 4.23: Probability density function (PDF) for Edo

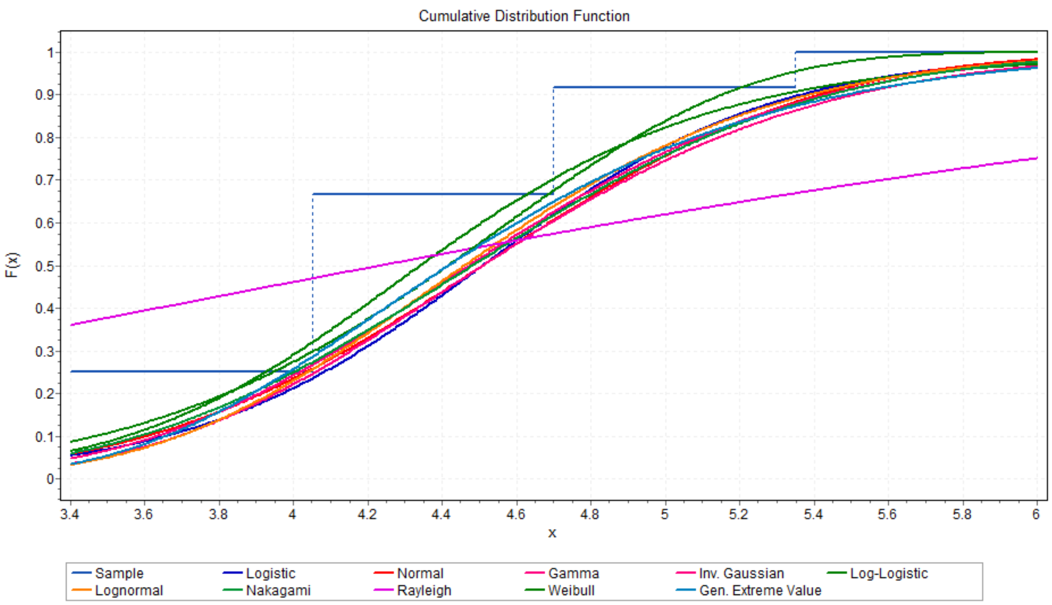

Figure 4.24: Cumulative distribution function (CDF) for Edo

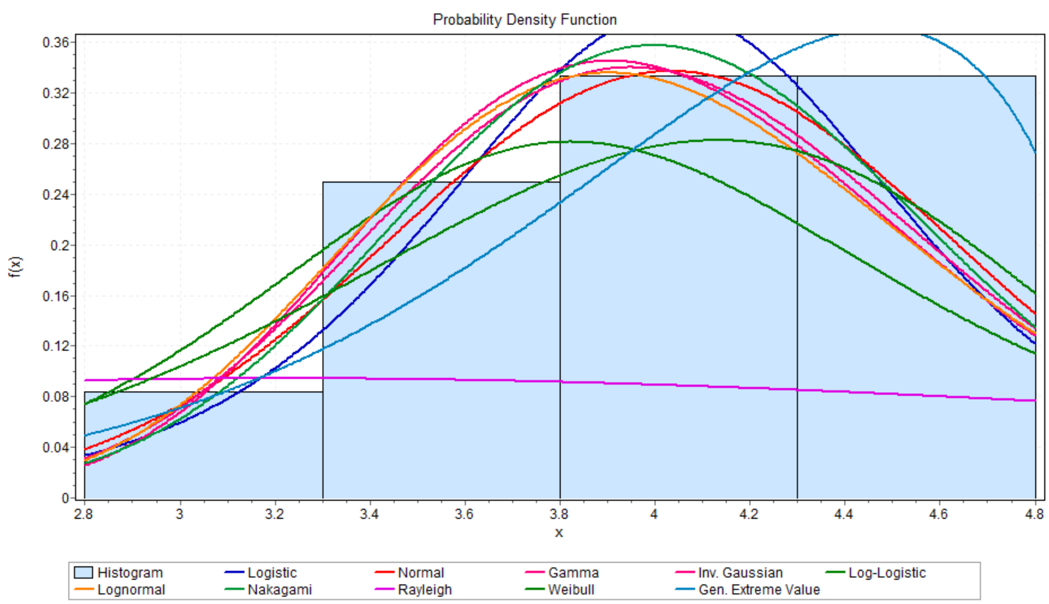

Figure 4.25: Probability density function (PDF) for Delta

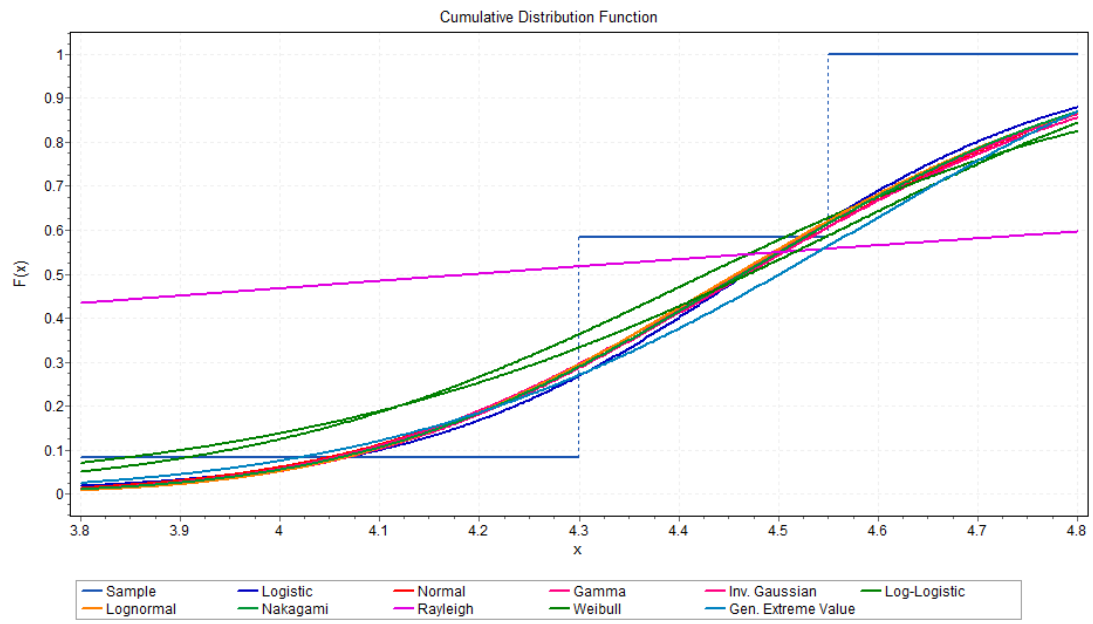

Figure 4.26: Cumulative distribution function (CDF) for Delta

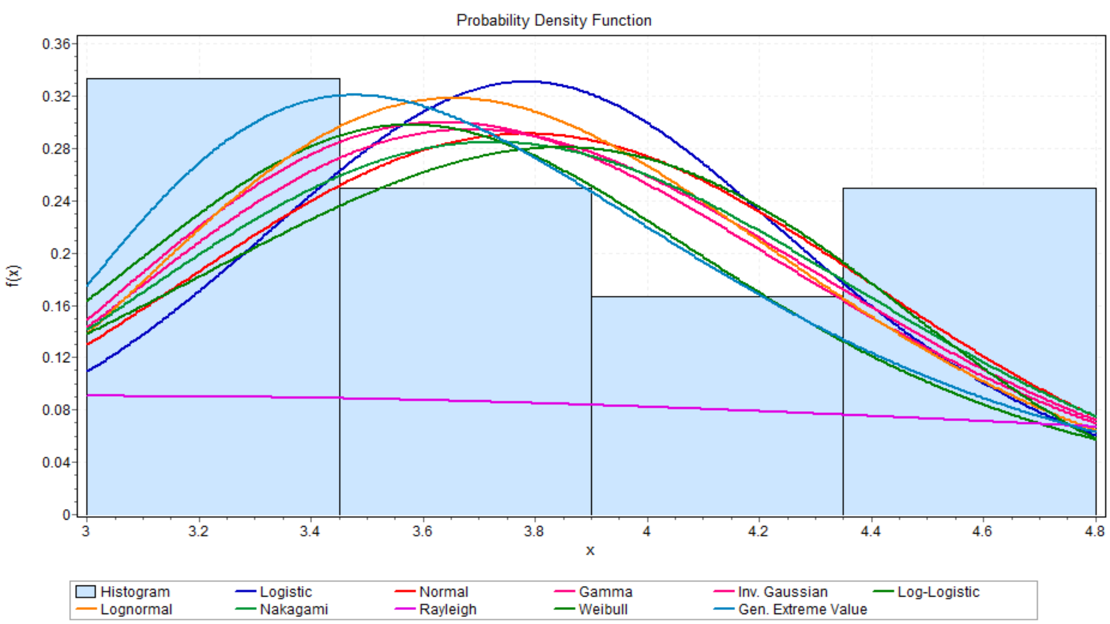

Figure 4.27: Probability density function (PDF) for Abia

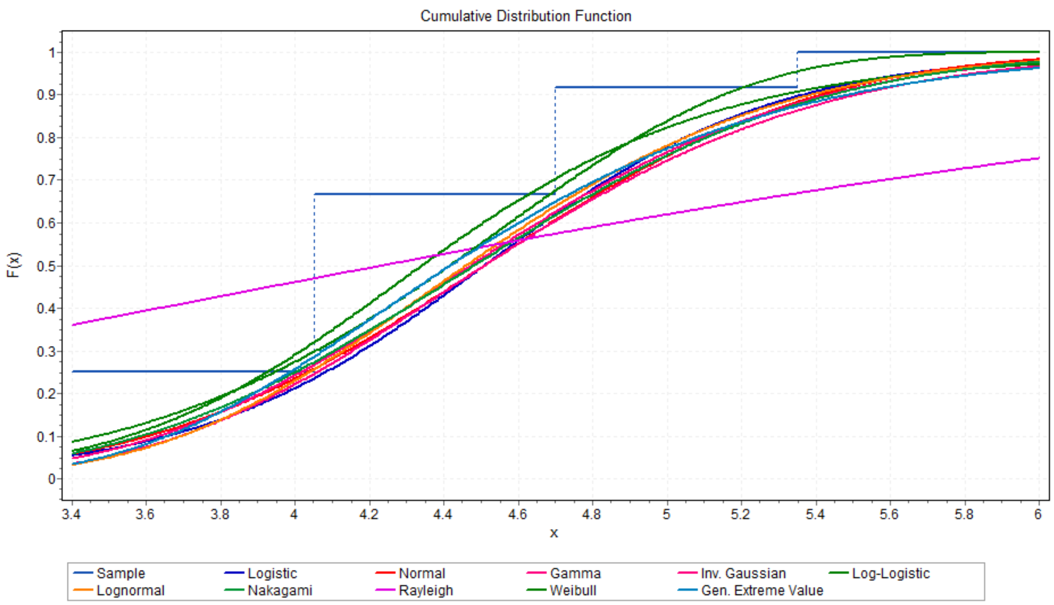

Figure 4.28: Cumulative distribution function (CDF) for Abia

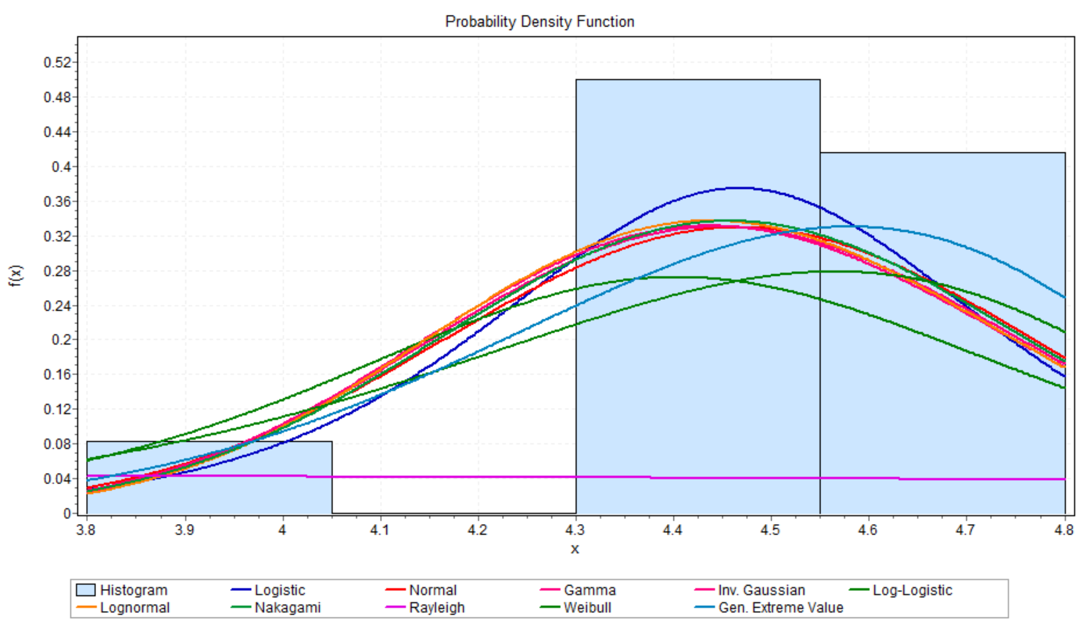

Figure 4.29: Probability density function (PDF) for Bauchi

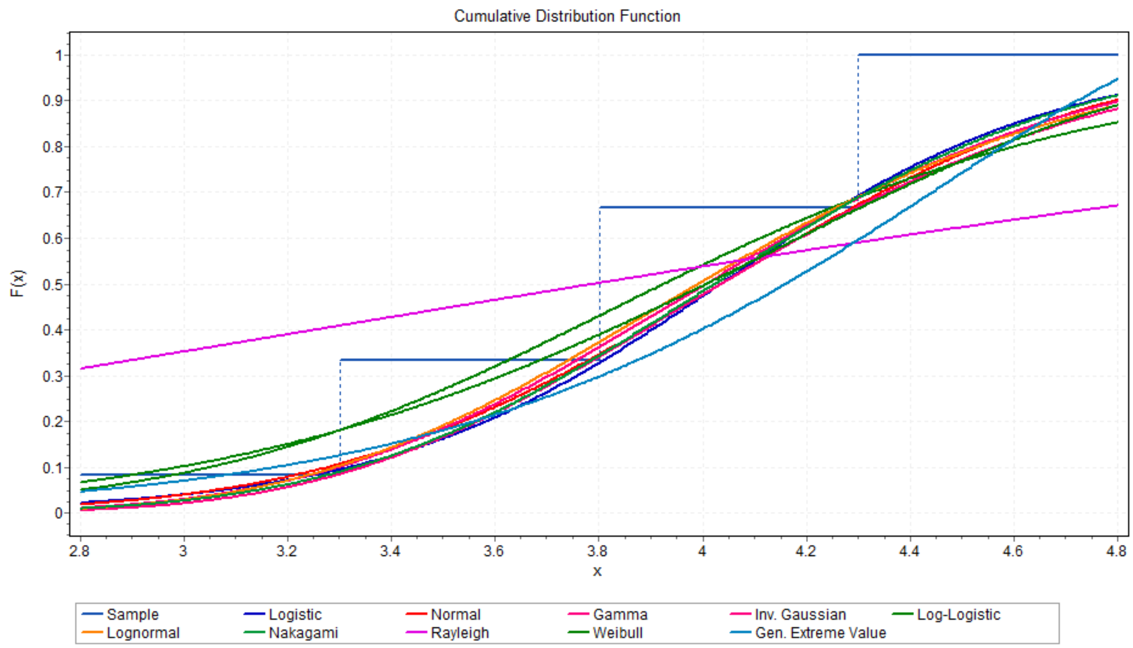

Figure 4.30: Cumulative distribution function (CDF) Bauchi

4.7 Economic Analysis of Electricity Generation Potential

In this thesis, the performance of the HAWT was evaluated. In a general case, the HAWT is used mostly for generating electricity. VAWT are usually used for low wind speeds, but VAWT are purely evaluated here because the wind speed data is relatively low. The description of the medium and large-scale wind turbines that have been evaluated in this work is presented in Table 4.21.

Table 4.21: Characteristics of the selected wind turbines

No.	Type	Model	P_r[KW]	Hub height [m]	v_{ci}[m/s]	v_r[m/s]	v_{c0}[m/s]
1	**HAWT**	**ATLANTIS Windkraft**	0.6	12	3	10	-
2		**Aircon10**	10	12/18/24/30	2.5	11	32
3		**Passaat**	1.4	12/24	2.5	16	-
4		**Windspot**	3.5	18	3	12	30
5		**Montana**	5.6	18	2.5	17	-
6		**Finn WindTuule C 200**	3	27	1.9	10	-
7		**Bonus -33**	300	30	3	14	25
8		**Aelos-H**	3	36	3	12	25
9		**Bonus -54**	1000	50	3	15	25
10		**Vestas -V47**	660	55	4	15	25
11		**Vestas -80**	2000	67	4	16	25
12		**YDF-1500-87**	1500	75	3	10.2	25
13	**VAWT**	**Winddam**	4	Site-dependent	2.5	12	-
14		**WS-12**	8	Site-dependent	2	20	-
15		**WRE.060**	6	Site-dependent	2	14	-
16		**Eurowind**	5	Site-dependent	3	12	28
17		**WRE.030**	3	Site-dependent	2	14	-
18		**AWT(2)2000**	4	Site-dependent	2	12	-
19		**Ecofys**	3	Site-dependent	3.5	14	20
20		**WS-4B & 4C**	8	Site-dependent	2	20	-
21		**WRE.007**	0.75	Site-dependent	2	14	-
22		**Turby**	2.5	Site-dependent	4	14	14
23		**Venturi 110-500**	0.5	Site-dependent	2	14	-
24		**WW2000**	2.9	Site-dependent	4	10.5	20

The annual Energy production power in kWh and capacity factor were calculated with equations (2.6) and (2.8) respectively.

Table 4.20 shows the wind turbine models, their various hub heights for HAWT and VAWT is site dependent, tables 4.22 to 4.25 shows the annual energy production for both HAWT and VAWT From the table, it is observed in the Delta station that vesta- 80 has the smallest annual energy production with a value in the negative and also has the second lowest capacity factor with a value in the negative. The turbine with the lowest capacity factor is Atlantis Windkraft with a capacity factor of -7%. So therefore, these turbines cannot be recommended for this region.

However, from the Table 4.22, the wind turbine YDF-1500 can be observed to be the best performing wind turbine because it has an annual energy production of 92430KWh and has a capacity factor with a value of 16%, which is fair. For this reason, the YDF-1500 is selected to be the appropriate recommended wind turbine for the Edo station.

Furthermore, the same analysis was conducted for all station, and again it can be observed from the table that VESTAS V42 and VESTAS -V47 both have negative values for the annual energy production and positive capacity factors, therefore these wind turbines cannot be used in this station. While the Finn WindTuule C 200 has the second capacity factor with a value of 10%. Therefore the tFinn WindTuule C 200 is the recommended wind turbine for Edo and probably Abia stations.

Table 4.22: Annual Energy production of HAWT

	Annual Energy production [kWh]			
Model	ABIA	BAUCHI	DELTA	EDO
ATLANTIS Windkraft	-7.847785	-14.59522	-16.41688	3.692512313
Aircon10 (12 m)	-34.70566	-123.8875	-147.9646	117.8240553
Aircon10 (18 m)	-0.427601	-112.5649	-144.3336	184.7821123
Aircon10 (24 m)	29.58063	-102.2445	-140.8904	241.9710291
Aircon10 (30 m)	56.767168	-92.61046	-137.5804	292.8441177
Passaat (12 m)	-2.232418	-7.968979	-9.517723	7.578952744

Passaat (24m)	1.902754	-6.576805	-9.062679	15.56462295
Windspot	-20.66054	-54.02139	-63.47259	34.43934509
Montana	-0.09718	-25.58239	-32.8024	41.99504346
Finn Wind Tuule C 200	39.188545	-11.1056	-26.05792	119.4002811
Bonus -33	-225.5563	-2975.463	-3803.317	4120.40575
Aelos-H	3.2839478	-38.89005	-51.86504	68.89379029
Bonus -54	3498.4671	-7048.994	-10423.48	19447.27986
Vestas -V47	-3347.151	-10931.83	-13386.15	8027.371518
Vestas -80	-5050.051	-27371.96	-34767.14	27857.94655
YDF-1500-87	26752.623	-18235.18	-33341.46	**92430.39168**

Table 4.23: Capacity factor of HAWT

	Capacity factor [%]			
Model	ABIA	BAUCHI	DELTA	EDO
ATLANTIS Windkraft	-3.583464	-6.664485	-7.496293	1.686078682
Aircon10 (12 m)	-0.95084	-3.394178	-4.053825	3.228056309
Aircon10 (18 m)	-0.011715	-3.08397	-3.954346	5.062523626
Aircon10 (24 m)	0.8104282	-2.801218	-3.860011	6.629343262
Aircon10 (30 m)	1.5552649	-2.537273	-3.769325	8.023126513
Passaat (12 m)	-0.436872	-1.559487	-1.862568	1.483161007
Passaat (24m)	0.3723589	-1.287046	-1.773518	3.045914472
Windspot	-1.617264	-4.22868	-4.9685	2.695839146

Montana	-0.004754	-1.251584	-1.604814	2.054552029
Finn Wind Tuule C 200	3.5788625	-1.01421	-2.379719	10.90413526
Bonus -33	-0.205987	-2.717317	-3.473349	3.762927626
Aelos-H	0.2999039	-3.551602	-4.736534	6.291670346
Bonus -54	0.9584841	-1.931231	-2.855747	5.328021879
Vestas -V47	-1.389436	-4.537911	-5.556723	3.332242224
Vestas -80	-0.691788	-3.749584	-4.762621	3.816157062
YDF-1500-87	4.8863238	-3.330626	-6.089765	**16.88226332**

Table 4.24: Annual Energy production of VAWT

	Annual energy production Kwh			
	ABIA	BAUCHI	DELTA	EDO
Winddam	-15.8486667	-42.64660116	-49.7265	30.70871
Windside (WS-12)	2.064879625	-16.57863288	-21.5042	34.45517
WRE.060	3.19411067	-25.64507274	-33.2643	53.29785
WS-12	-49.5477207	-83.72749361	-92.7577	9.834487
WRE.030	1.597055335	-12.82253637	-16.6321	26.64892
AWT(2)2000	2.920329756	-23.44692365	-30.413	48.72946
Ecofys	-37.1230769	-52.19007882	-56.1707	-10.9464
WS-4B & 4C	2.064879625	-16.57863288	-21.5042	34.45517
WRE.007	0.399263834	-3.205634092	-4.15803	6.662231
Turby	-46.5803953	-59.39781011	-62.7841	-24.3121
Venturi 110-500	0.266175889	-2.137089395	-2.77202	4.441487
WW2000	-103.193491	-131.5889947	-139.091	-53.8606

Table 4.25: Capacity factor of VAWT

	Capacity factor %			
	ABIA	BAUCHI	DELTA	EDO
Winddam	-1.08552511	-2.92100008	-3.40593	2.103336
Windside (WS-12)	0.070715056	-0.5677614	-0.73644	1.179972
WRE.060	0.145849802	-1.171007888	-1.51892	2.433692
WS-12	-2.7149436	-4.587807869	-5.08261	0.538876
WRE.030	0.145849802	-1.171007888	-1.51892	2.433692
AWT(2)2000	0.200022586	-1.605953674	-2.08309	3.337634
Ecofys	-3.39023533	-4.766217244	-5.12975	-0.99967
WS-4B & 4C	0.070715056	-0.5677614	-0.73644	1.179972
WRE.007	0.145849802	-1.171007888	-1.51892	2.433692
Turby	-5.10470085	-6.509349053	-6.88045	-2.66434
Venturi 110-500	0.145849802	-1.171007888	-1.51892	2.433692
WW2000	-9.7490308	-12.43164806	-13.1404	-5.08839

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusions

This study shows the wind speed characteristics and wind power potential of four locations in Nigeria: Edo, Delta, Abia and Bauchi forten year duration. Furthermore, to examine the capabilities of a vertical axis wind turbine to generate power at the locations.

- The annual mean wind speed for the four locations in this study is ranges from 1.2 to 2.4 m/s at a 10 m, this indicates the locations have low wind energy potential.
- The GEV proved to be the best fit to the wind speed data for the locations of Delta, Abia, and Bauchi, while Weibull analysis for Edo.
- It was observed that Edo has the highest winds and its wind power analysis is the best location for collecting wind energy.
- The annual wind power values ranged from 2.30W/m^2 to 9.34W/m^2 at 10m height. These values shows that the wind power potential of these locations could be possible to exploited using small-scale wind turbines at the locations.
- It was concluded that VAWT with a comparable rated output would produce more power in the locations than a HAWT due to less noise and more efficient.
- Subsequently, with a power rating of 4kW the Winddam had the lowest energy production cost among the considered vertical axis wind turbine.

5.2 Future Work

This study should explore rural areas (selected stations). Nigeria has a lot of untapped potential so studies should be carried out at the coast region for better wind speed data like Ondo, Imo, Akwa Ibom, Bayelsa and other regions with better wind speed data to work with better suited turbines. This is because these locations are also exposed to the south trade wind from the Atlantic.

Due to the varying roughness and the drag exerted by surface-mounted obstacles. The prognosis of wind speed is hard on the flow, which reduces the wind speed close to the ground in locations with conventional buildings. The evaluation of potential locations for the installation of small-scale wind turbines in urban areas can be studied by using Computational Fluid Dynamics (CFD). It is reasonable to say that there is a lack of accurate ways for the assessment of wind speed in urban areas. An interesting area for future study is Computational Fluid Dynamics (CFD), which can be used to predict the wind speed in urban environments.

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APPENDIX

CATALOGUE OF EUROPEAN URBAN WIND TURBINE MANUFACTURERS