JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING

POSTGRADUAT IN SUSTAINABLE ENERGY ENGINEERING

WIND ENERGY POTENTIAL INVESTIGATION AND EVALUATION OF TURBINE PERFORMANCE FOR SPECIFIC LOCATIONS.

Case study: Debrebrehan, Enewari and Mehalmeda

A Thesis Submitted to the School of Graduate Studies of Jimma University Institute of Technology in Partial Fulfillment for the Degree of Masters of Science in Energy Engineering

By Girma Zenebe

June, 2019

Jimma, Ethiopia

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Declaration

Declaration I hereby declare that this research paper entitled " Wind Energy Potential investigation and Evaluation of Turbine Performance for Specific Locations" is my original work carried out under the supervisions of Prf.Venkata Ramaya and Mr. Dawit Kebede

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LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

A	Area
B	Number of blades
AEP	Annual energy production
C	Weibull scale factor (m/s)
Cd	Drag coefficient
Cl	Lift coefficient
Cf	Capacity factor
CP	Power coefficient
Ct	Truest coefficient
EEPCo	Ethiopian electric power corporation
F	Tip lose coefficient
F(v)	Probability of observing wind speed
F(V)	Cumulative distribution function
GIS	Geographic information system
h	Height (m)
IEC	International electronic Technical commission
HAWT	Horizontal Axis Wind Turbine
K	Weibull shape parameter or factor
Kw/kwh	Kilowatt / kilowatt-hour
N	Number of observation
NACA	National Advisory Committee for Aeronautics
NMSA	National Metrology Service Agency
NREL	National renewable Energy laboratory
P	Power of wind per unit area (w/m^2)

R	Blade radius
r	Radius at span wise locations
VAWTV	Vertical Axis Wind Turbine
V	Wind velocity
V_m	Mean wind speed
WTCS	Wind turbine conversion system

Greek symbol

α	Angle of attack
a	Axial induction fact
á	Tangential induction factor
β0	Tip pitch angle
βt	Twist angle
λ	Tip speed ratio
λr	Local tip speed ratio
ρ	Air density
φ	Angle of relative wind to rotor plan
μ	Dynamic viscosity ($Pa{\cdot}s$)
ρ	Density (kg/m3)
Ω	Angular velocity (rad/s)
δ	Standard deviation

ABSTRACT

In the present situation, the demand for energy was ever-growing, worries over restricted fossil-fuel resources and limited ecological regulations have made renewable energies very attractable. Among all renewable energy sources, wind energy has played important roles in addressing clean, affordable, harmless, and competent energy in sustainable enlargement. The leading issues were that most all these papers mainly concerned the assessment of wind energy potential, site suitability analysis, choice and performance evaluation of existing wind turbines with the optimum interaction of wind regime. The primary task of this study, wind characteristic, and wind energy potential were analyzed using the wind speed data collected from the national meteorology agency using the two Weibull parameters such as, the shape parameter k (dimensionless) and the scale parameter c (m/s). The annual mean wind speed and power densities are 7.38 m/s and 267.5 W/m^2 *for Debrebrehan, 9.12m/s and 419.6 W/m*^{2} *for Enewari, 8.03m/s and 317.25W/m*^{2} *for Mehalmeda at 70-meter height. The results indicate that Enewari has a better potential for using wind energy than the other two areas. In order to assess the most suitable area for wind farm placement, ArcGIS software was applied. Among twelve sets of alternatives, two wind turbines with generating capacities 2000 kW for Enewari and Mehalmeda wind sites and 1500 kW for Debrebrehan wind site are chosen and examined, and the annual energy output and annual capacity factor of the selected wind turbines are calculated for each study area, which are 4314.2MWh and 37.8%, 7285.2MWh and 44.8%,6243.2MWh and 39.6% respectively. The most significant component of wind energy extraction is the wind turbine and its aerodynamic characteristics of the blade airfoil. Therefore, predicting wind turbine performance by using the "blade element moment" theory, the results of power coefficient for both selected wind turbine indicates that 0.47 and 0.448 respectively. and the prediction of aerodynamic characteristics of the desired airfoil by the varying angle of attack is essential, among the two airfoil types s818 can achieve the maximum lift to drag coefficient ratio at an angle of attack 5 degree. Finally, the CFD simulation was done over a two-dimensional S818 airfoil, by predicting the contour plot of velocity and pressure distribution to describe the characteristics of a particular wind turbine.*

Key words: wind speed, wind power density, horizontal axis wind turbine, annual energy production and blade element moment theory.

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CHAPTER ONE

INTRODUCTION

Energy, one of the imperative necessities of a human being plays a key role in the socio-economic growth of developing countries like Ethiopia. Conventional energy (natural gas, coal, oil) have considered as the main energy source in the world. Nearly, 35% of the world's primary energy consumption comes from natural gas [1]. Recently, the demand for energy was ever-growing, worries over restricted fossil-fuel resources and more limited ecological regulations have made renewable energies very attractable [2]. Among all renewable energy sources, the combined use of wind and solar is becoming ever more attractive and being broadly used as an alternative to fossil-fuel energy. Which have important roles in addressing clean, affordable, harmless and competent energy in the sustainable enlargement. Another important support of renewable energy is for global CO_2 discharges drop to be appreciated, power generation should mightily depend on exploiting renewable energy schemes, especially in growing countries [3][4]. In a similar way, wind energy is just one of the fastest developing, furthermost commercially good-looking and frequently used sources of renewable energy for generating electricity [5]. In the past few decades, different researches have been carried out and an enormous potential of wind energy has been discovered across the globe. This worldwide wind energy potential is approximated to be about 278,000 TWh per year of which about 39,000 TWh supply per year could be sustainably used in the long run. This figure is more than double of the current global electricity demand. In recent years, many countries have installed large wind farms and are enjoying the benefits of it [6].

In precisely, it has expected a considerable extent of attention in its viable and financial practicality, eco-friendlies, and free obtainability at a worldwide scale [6]. In Ethiopian, was electrified with hydropower, which has not to access full capacity throughout the year because of water resource depends on seasonal behavior [7]

To massively develop wind energy resources and carry out energy development strategies, it shall firstly get familiar with the spatial and temporal distribution of wind energy resources and then calculate the distribution variations, area and reserves of the exploitable resources so as to provide the most fundamental information support for energy development. The main objective of this study is to asses wind potential resource by using reliable method, select a proper type of wind turbine and examine it based on site wind characteristics [8].

The statistical analysis of historical wind measurement is also adopted in commonly used the Weibull probability distribution function, employed to calculate the wind power density and energy for the regions at10-meter height. The Weibull parameters, shape (K) (dimensionless) and scale(C) m/s have been valued mathematically and graphically. It was applied to model the wind behavior using actual meteorological data in the form of hourly mean wind speed and wind direction [9]. As far as wind energy is concerned, the most crucial characteristics are its potential based on wind speed as well as its direction and the situation of the degree of variation with a given location for a given period of time. Those parameters are strongly dependent on geographical location, time of the day, climate condition as well as the season of the year for the particular proposed potential site. The relationship between wind speed and its ability to generate power is amplified by a cube rate [10]. This shows the very high sensitivity of power production to wind speed variation for three locations in Ethiopia to a recent successive five years. Such as Debrebirehan, Enewari, and Mehalmeda.

Another one important outcome of this thesis will be the ability to integrate wind resource potential assessment to site suitability analysis used to wind energy development by Appling effective and efficient tools of arc GIS and specified criteria to eliminate redundant computational processes and save time [11].

To utilize the maximum possible output of power for a given site, it should be understood properly pairing between the performance parameters of wind turbine conversion system and the wind speed characteristics of each site can increase the wind energy captured considerably and reduce the cost of the generated energy. The power generation of a wind turbine is relating to the interaction between the rotor and the wind. This study has exposed those points of wind turbine performance significantly impacted by aerodynamic forces produced by wind. Additionally, horizontal axis wind turbine aerodynamic characteristics with wind power (P), power coefficient (CP) and tip speed ratio (λ) are strong-minded as a purpose of the performance analysis. [11]

The aerodynamic analysis encompasses the selection of aerofoil family and optimization of the chord and twist distributions. The variation of thickness to chord ratio along the blade also has to be considered, but this ratio is usually set at the minimum value permitted by structural design of selected wind turbine, as this minimizes drag losses. The selected of wind turbine blades can be viewed as a both aerodynamic and structural consideration.

Generally, wind energy is a genuinely promising source of energy and it is one of the few green energy systems having an everlasting nature. As a result, proper use of the resource with well integration of wind turbine through sustainable project designs would significantly contribute in solving the energy crisis.

1.2 Statement of the Problem

Ethiopia is a developing country and its major primary energy conception had largely converted by biomass and imported fossil fuel. These types of energy sources also its own impacts specifically for the customer health and quality of leaving; furthermore, deforestation, endangering biodiversity, and erosion are under consideration. Current traditional energy use patterns bounded to have a highly negative consequence for the rural economy as well as environmental and ecosystem balance in particularly.

Even though Ethiopia has been investing a lot in electricity generation. Electricity access in Ethiopia is one of the lowest in Africa, around 57.1% of the population does not have access to electricity; 30 % of those without electricity live in village centers and 70% shortage of power source [12]. However, the country endowed different renewable energy resources such as hydropower, wind, solar, geothermal and bioenergy. For the most power, the generation is mostly dependent on hydropower resources. Yet, the power shedding that the country faces is due to the lack of energy resource mix. Therefore, to explore the opportunity for a wider energy mix. In the future wind energy will be one of the better possible options.

The country has set goals of becoming an industrial economy and a hub of electric energy in the region. In the process, the local demand for energy is predicted to meet with the surplus put up for sales. Accordingly, there is a bright future for electrification in the country as renewable energy takes center stage in fulfilling the surging demand for energy as pointed out earlier, Therefore, efforts towards electrification call for the expansion of free and affordable renewable energy source like wind energy.

The broad contribution of this research, to aggressively develop another clean source of energies to mitigate the risk of over-reliance on hydropower. By involving the private sector and preparing a transparent, competitive procurement agenda for government and private sector investments. As well as drastically increasing economic and environmental benefits by improving lighting services, reducing energy costs, improving health and education quality

1.3 Objective

The General objective of this study is to investigate wind energy potential and performance evaluation of selected wind turbines for a specific location**.**

1.3.1 Specific Objective

- Wind speed data collection and characterization
- Wind power/energy density analysis by using Weibull distribution method
- Site suitability analysis
- Selection of existing and suitable wind turbine model based on specific wind characteristics
- Evaluate the performance of the selected wind turbine on the base of the technical parameter.

1.5 Scope of the Study

A number of researchers worldwide have been investigating the assessment of wind energy potential as well as different capacity wind turbine design and performance analysis by using deferent parameters and techniques. However, the wind is intermittent behavior by its nature, the variation is occurring with respect to time and geographical changes. As far as, wind turbine selection and performance examination subjected to specific load and stress due to this, difficult to handle similar outputs from different sites. For this reason, wind site and wind turbine mating study should be conducted detail site-specific analysis. For this research mainly cover the analysis of wind speed and direction from given meteorology data and then investigation of wind energy potential by using Weibull statistical methods, generate site suitability map using GIS, selecting wind energy conversion system (WECS) from existing wind turbine and evaluate wind turbine energy extracting performance. However, some tasks are not incorporating for this research like economic analysis, design, and modeling of any wind machine and wind farm.

1.6 Significance of the study

This study mainly impressed to promising wind energy project in Ethiopian wind farm master plan and encouraging forgoing to layout for project allocation as well as looks surrounding more competitive for suitability and potential attractive sites. The objective of this work is taken into consideration, helps to promote renewable attention by the government and investors. How the wind energy can be used to solve the lack of electrification access by efficient affordable and sustainable models of electricity power generation from the clean and renewable energy source in the environs of the study sites by which comparable cost/kWh of electricity generation. To promote the expansion of renewable energy sources, highly contributed to a well understanding of ratifying sustainability hence, reduced the environmental challenges and security of national energy cries.

1.7 Thesis outline

The thesis starts with a general introduction of the topic in **chapter one:** which presents an overview of the wind energy potential assessment and turbine performance evaluation in a specific location of Ethiopian, the objective of the research, significance, and scope are described in this chapter.

Chapter two: mainly cover the literature review of related works including an overview of recent wind energy potential capacity and assessment techniques inexperienced country including Ethiopia, an overview about the energy situation of Ethiopia, basics of wind energy, classification of wind turbine and general research gap are discussed in detail.

Chapter three: deals with the materials and methods to facilitate the thesis work by including relevant data and related to simulation software, such as the study area, where the data are obtained, the data collection method, methods of data analysis and performance evaluation technique of wind turbine under specific location.

Chapter four: focuses on the analysis of wind speed characteristics basically height and time variation with the effect of altitude difference and the direction of wind speed as well as deals with the power density of the candidate sites. **Chapter five:** selection and evaluation of site matching wind turbines

Chapter six: Result and Discussion: Discusses the analysis result of wind energy potential turbine selection and performance evaluation with regard to the site-specific available resource. **Chapter seven**: Conclusion and Recommendation: This summarizes the main findings of the thesis work and recommends those who want to use it as a base either for further study or as an input for information. Appendixes: describe specifications of selected wind turbine

CHAPTER TWO

LITERATURE REVIEW

2.1 Introductions

An inclusive literature review, have carried out many numbers of research paper published in the international journal, official report and article published by organization and energy sector. They have been reviewed for the current situation of global as well as local wind power generation capacity; provide the accurate practice for the estimation of wind energy potential and an updated wind energy technology.

2.1 Global cumulative wind power installed capacities

In the last decade, wind power has achieved mainstream status and risen to dominate the international energy research agenda in recent years for a different perspective, as wind potential as well as wind energy conversion system based on this attention to installing great capacities of wind energy potential in a global scale. According to the worldwide statistics the global wind installed capacity reached 254000MWat the end of June 2012 hence drastically increasing at the end of 2012 up to 273000MW besides those values becoming rapidly increasing a significant share of the world's electricity supply.[10][13] Global capacity stood at around 432.680 GW at the start of 2015, and also at the end 2017around 539.581GWas illustrated in the figure below[14] [11].

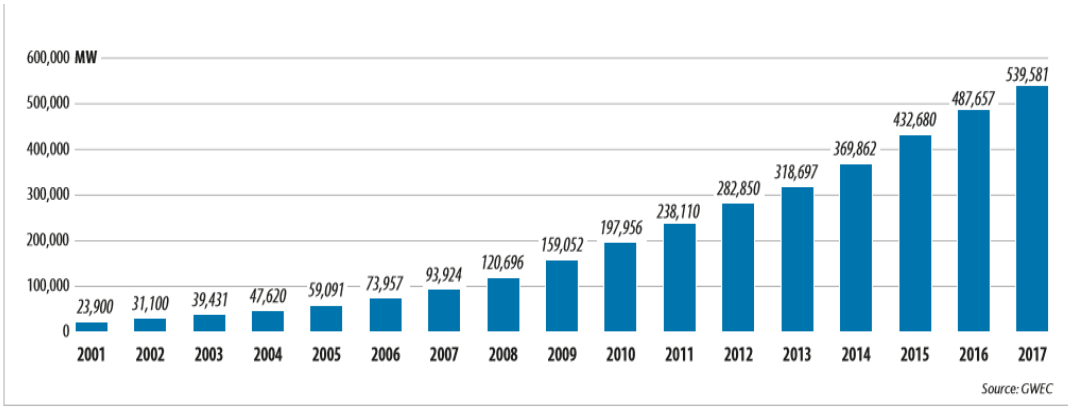


Figure 1:Global cumulative installed wind capacity 2001-2017: [13]

The general, robust development of wind power near the world that goes hand in hand with further geographic divergence is very hopeful. The regions such as Latin America and most recently Africa are playing an important role in this self-motivated growth. Obviously, the European Union and its member states should immediately reinforce their efforts to install wind power as part of an inclusive renewable energy strategy and to work out a roadmap for a 100% renewable energy future [11]. With regard to this, Asia and Europe are actively participating to maximize renewable energy potential specifically installed capacity of wind energy.

At the end of 2009 up to 2017, Europe has installed wind power capacity of 147,771 MW, Africa, and the Middle East3289 MW, North America 88,744 MW, Latin America and the Caribbean 12,220 MW, Asia 175,573 MW and the Pacific region432,419 MW. Asia has the highest growth capacity, while Africa and the Middle East have the lowest growth capacity at the end of 2015 despite high wind potential in Africa. There is a significant gap between the potential and the level of implementation [13]. This raises concerns regarding the development of wind farm projects on the continent. The detail compression analysis is shown in fig 2.

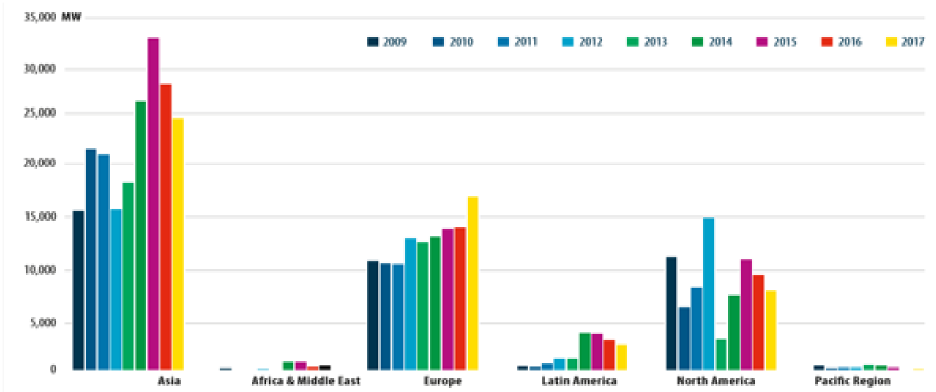


Figure 2: individual wind installed capacity of contents [13].

In comparison to the rest of the world, Africa possesses tremendous unexploited wind energy potentials. Recently, some African countries have already installed wind farms currently; South Africa, Morocco, Egypt, Tunisia, and Ethiopia have the largest wind power capacity in the continent as well as respective installed values as follows the next table [13].

Table 1:wind power installed capacity in Africa[15]

Africa middle east	End of 2016 (MW)	New 2017 (MW)	Total 2017(MW)
South Africa	1473	621	2094
Egypt	810	-	810
Morocco	787	-	787
Ethiopia	324	-	324
Tunisia	245	-	245
Jordan	119	-	119
Others	159	-	159

2.2 Status of Wind Power Generation in Ethiopia

Large electricity generation systems by wind turbines are installed in Ethiopia, such as Adama and Ashegoda wind farms are the most important ones[15]. The total installed capacity of Adama I wind farm is 51MW, and 34 Goldwind GW77 wind turbines with a unit capacity of 1.5MW are installed, the annual energy output is 162.7Gwh, the average equivalent full load operation hours is 3189h. The annual average wind, speed of the Adama/Nazret Wind Park site at 65m height is 9.45m/s, as well as the annual wind power density, is 613.4W/m2. and the other Ethiopian larger wind farm located in ashegoda near to Mekelle in the Tigray region which have 84 WTG units 120 generates MW electric energy. It is a fearless and direct driven 3 reinforced fiberglass blade rotor permanent magnet synchronous generator with full power converter [16]. The height of the tower is 65m, 70m rotor diameter, 34m blade length, the swept area is 3886$\boldsymbol{m^2}$and a unique feature of the gold wind 1.5MW wind turbine generator is air-cooled. The Cut in wind speed is 3.25 m/s and cut out wind speed is 25m/s [17]. The control system for, this particular wind turbine generator is the Yaw system and Pitch system convertor [16]. The height of the tower is 65m, 70m rotor diameter, 34m blade length, the swept area is 3886$\boldsymbol{m^2}$and **a** unique feature of the gold wind 1.5MW wind turbine generator is air-cooled. The cut in wind speed is 3.25 m/s and cut out wind speed is 25m/s [17]. The control system for, this particular wind turbine generator is yaw system and pitch system.

Table 2;The current Ethiopian wind farms and their installed capacity[16]

Site name	Installed capacity in (MW)	Capacity factor 2016/17	No. Turbines	Location	Current status
Adama I	51	0.30	34	Adama	Operation
Adama II	153	0.32	102	Adama	Operation
Ashegoda	120	0.21	84	Hintalo	Operation
Ayisha I	120	0.34	80	Ayisha	Under construction.
Ayisha II	120	0.41	48	Ayisha	Under construction

Total capacity	564.8	-	-		-
Total operation	324	-	-		-

2.4 Ethiopia energy potential opportunities

Ethiopia has enormous potential for hydropower growths, next to the Democratic Republic of Congo in Africa with generating a capacity of about 45,000 MW [20]. Hydropower plants are very reliable in their nature. However, depending fully on hydropower has associated risks, as the output energy from the turbines is directly dependent on the amount of water in reservoirs and speed of water flow, which in turn might vary seasonally. Climate changes or the absence of rainfall could also have a severe impact on these energy systems. Consequently, constructing other alternative renewable energy systems, such as wind and solar, could be of great importance to complement hydropower plants [20]. In the case of Ethiopian, the dry and long summer season is the most favorable time to generate peak energy from wind and solar energies while dams and rivers are at their maximum potential during the rainy season. The seasonal fluctuating of hydropower potential can successfully supplement by wind energy in Ethiopia. The figure below shows how wind energy increases the security of the system during the dry, low water season. As can be seen in the figure, while the hydropower potential significantly drops in the period December through June, the wind energy potential peaks and during the rainy season and the following few months, July through November, the water levels are higher and the wind potential drops. As a result, well-studied projects that could combine these energy systems can deliver a regulated and constant output power to the grid throughout the year [20].

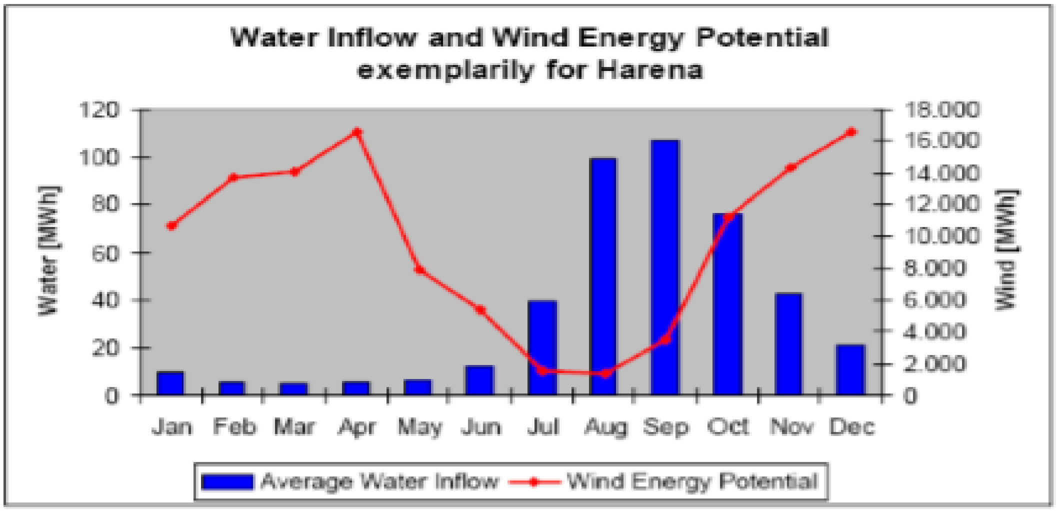


Figure 3: Wind and Hydro are complementing each other [20]

2.4 Wind energy basics

The wind energy is one of the oldest natural resources exploited by mechanical systems. However, in the last century, the wind power technology had developed and wind turbines were constructing in order to generate electrical power. Hence, how this wind turbine is becoming too functional? Should we consider some fundamental facts, which was starting from the initial deriving force of this manner? The kinetic energy of the moving air particles up to the basic aerodynamic force of lift to produce a net positive torque on a rotating shaft. resulting first in the production of mechanical power and then in its transformation to electricity in a generator [21].

After understanding the basics of how a modern wind turbine works, it is vital to bring up an important question; how much energy is available in the wind and how much can be converted to mechanical energy?

$$P = \frac{1}{2}\rho A V^3, \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad (2.1)$$

This formula is the basis of this analysis in order to obtain the theoretical wind power potential.

The air density, which was taking1.225kg /m^{3}and V, is monthly mean wind speed in m/s. Any wind machine cannot totally extract this available power.

The maximum extractable power from any wind machine is limited by famous Betz relation [Betz, 1942] which assigns power co-efficient C_p =16/27 for the maximum performance of a wind machine.

$P_w = \frac{1}{2} C_P \rho_a \, A \, V^3$ ……………………………………………………………………(2.2)

Then, the input energy undergoes several conversions before it made available as useful Energy demand for particular. Finally, the available power of the system expressed as:

$P_m = \frac{1}{2} \eta C_P \rho_a \, A \, V^3 P_w$ ………………………………………………………………… (2.3)

2.5 Wind turbine Technology

A wind turbine is a rotational engine that generating of power from a fluid stream (the wind) by means of aerodynamically designed blades and transform it into valuable mechanical power, which used to produce electricity, water lifting and stone grinding machine frequently called a windmill. In other ways, the machine could be altered mechanical energy to electricity, which is called a wind generator[22].

In recent years, sites with low annual average wind speeds have started to be considered for the development of new wind farms in order to the gradual upscale of wind turbine machines [23]. Based on the rationale for better land exploitation, the cost of energy from wind has dropped and past funding growth programs pushing towards the development of big-scale machines. On the other hand, a stabilizing trend is noted during the recent years that have put an end to the exponential increase of the tower height and rotor diameter met in the first two decades [24]. The gradual change of wind turbine technology starting from 25m tower height and 15m diameter could generate 50 kW power and becoming the recent largest onshore wind turbine was 164m diameter and 7.0MW power could be generating [24].

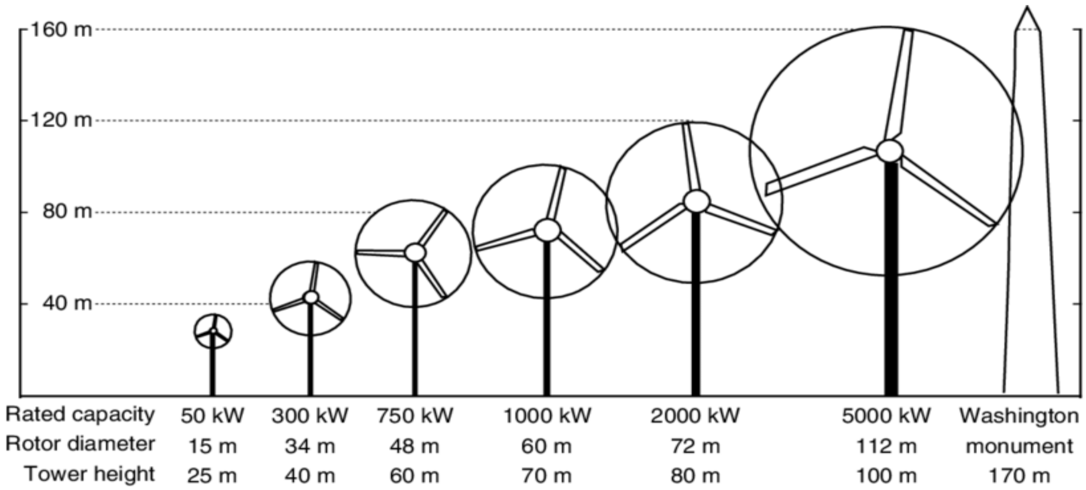


Figure 4: progressive change of wind turbine blade size and hub height[24].

2.6 Application of wind energy

The accessible kinetic energy of the wind used to generate electric power in wind turbines. In addition, its application for water pumping, grain grinding, and other agricultural claims like energy conversion systems was widely known as windmills. These days the wind is used predominantly for power generation with the help of wind turbines [25].

2.7 Wind Turbine Classification and Energy conversion system

Modern wind turbines have three basic configurations based on the axis of the rotating Shaft or technological status. Hence, Conventional wind turbines are classified in the following ways [26].

- Based on the orientation of the rotor, these are classified as.

  a) Horizontal axis wind turbine (HAWT
  b) Vertical axis wind turbine (VAWT)

- Based on the positioning of the turbine to flow direction, they are classified as.

  a) Upwind positioned wind turbine b
  b) Downwind positioned wind turbine

- Based on the number of blades on the rotor,

  a) Single-bladed wind turbine

b) Multi-bladed wind turbine

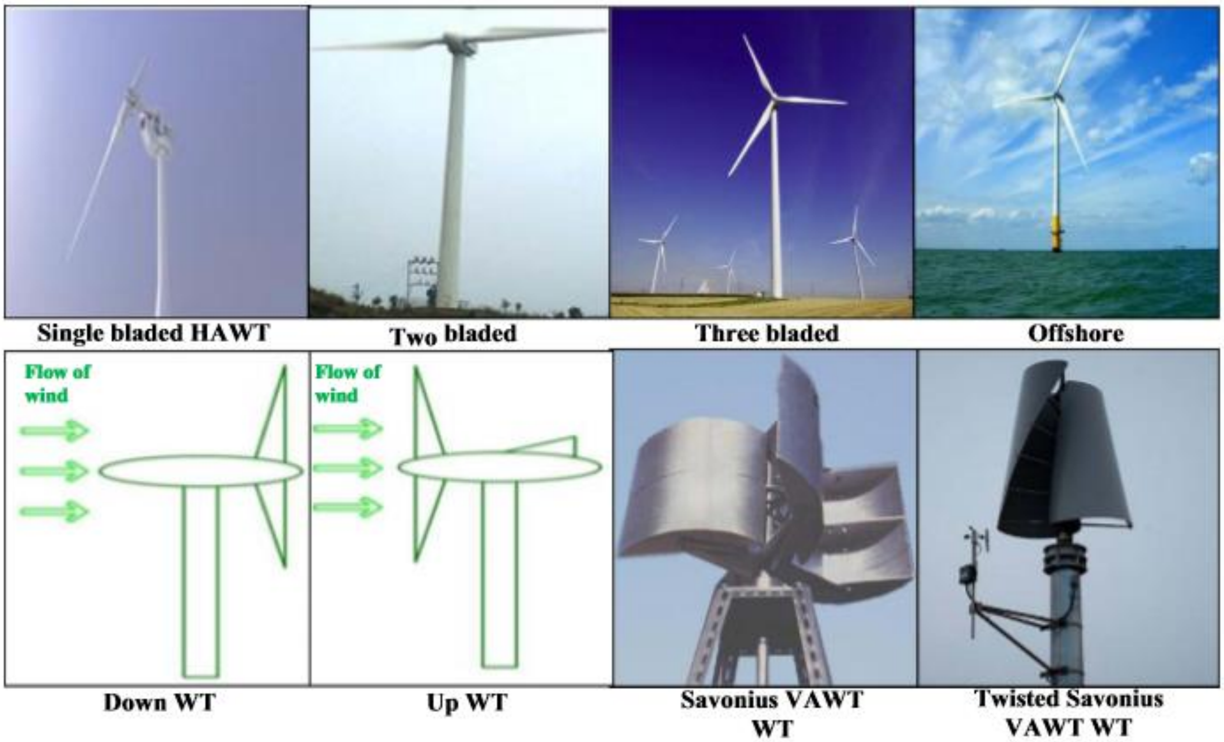


Figure 5:Various technologies in large scale HAWT and small scale Savonius VAWT [27].

Horizontal axis wind turbine: most modern wind machines use today are the horizontal axis type due to their high performances compared to the vertical type of wind turbine. Horizontal axis wind Machines have blades like airplane propellers. And predominantly have 2 or 3 blades, or a larger number of blades are available the latter described as used to the different applications [27]. **Vertical axis wind turbine**: Vertical axis wind turbines (VAWTs) have blades that go from top to bottom. The most common types of these turbines are savoinius and one of the most popular in the world market; the Darrius wind turbine. These turbines can harness winds from any direction without the need to reposition the rotor when the wind direction changes but they are less performance[27].

After all the three-bladed HAWT is, the optimal low solidity design and better stability for aerodynamic loading will be relatively uniform. Most of the present commercial Turbines used for electricity generation have three blades. Horizontal axis machines have some distinct advantages such as low cut-in wind speed and easy furling and high power coefficient. Due to those advantages, three-blade HAWT have selected for commercial-scale wind turbines.

2.8 Reviews of wind resource assessment technique

The availability of Wind throughout the world over, however their strength and energy content in them differs from place to place due to the nature of wind. In order to carry out wind resource assessment at any given location, one needs to figure out the strengths of wind at that location over an adequately long period to make a long-term assessment of electricity that can be generated using recent wind turbines. Adopted a definite method of wind distribution analysis by Weibull and Raleigh distribution with some power-law models. Since all the procedures can follow when the preliminary analysis of wind potential have to investigate. [28]. To give the priority of many numbers of researcher's wind energy potential and feasibility of wind farm to escape investment risk as well as maximize system efficiency with specific locations.

In order to use wind energy competently, it is essential to evaluate the potential and practicability of wind energy in a specific location by knowing the wind characteristics. With regard to this, the recent studies and practice have been conducted in different countries such as Jordan [29], Chad [30], Malesia [31], Algeria [32] and Nigeria [33][34], etc. encompassing in different techniques and methodologies aggressively involved in the development of wind power projects.

Most of wind energy potential researchers suggest a novel, globally feasible approach assess the local wind energy potential as well as to locate the areas with high suitability for placing wind farms like meteorological reanalysis data are applied to obtain long-term low-scale wind speed data at specific turbine locations and hub heights[35]. Model the relation between wind data and energy production by using different widely acceptable statistical tools, found that the Weibull and Rayleigh distribution methods can be used to describe the wind variations [36].
The researchers have been studded the quality of wind energy potential and feasibility analysis of optimum future utilization by investigating the influence of wind distribution and determine wind speed class, direction and frequency have been done. optimal farm layout on the wind resource potential at a site [35].

2.9 Wind Energy Resources Assessment in Ethiopia

Particular studies on the wind energy resource assessment at national level as well as in specific location of Ethiopia were conducted to estimate wind energy potential of the country those studies are reviewed below.

The first national level wind energy potential estimation had been done theoretical analysis with only very few ground data measurement stations by Italian company CESEN-ANSALDOG roupinmid 1980s [37]. Another wind potential assessment was conducting by the Ethiopian National Energy Commission in 1986 using data from 39 different stations. For the period of 1971-1978 with three wind measurements per day taken at the hours of 06:00, 12:00, 18:00. The report was criticizing in details by not implemented spatial wind analysis techniques. and also for not attempting to examine seasonal or monthly wind speed and energy patterns in terms of their spatial representation, appreciable wind potentials were identified [38] .Consequently, United Nations Environmental Program sponsored national level study of wind energy resource in the country was conducted in 2007 by Solar and Wind Energy Resource Assessment (SWERA) [37]. For some of the currently ongoing wind farm projects.; the German Agency for Technical Cooperation (GTZ) has conducted a number of studies for reanalysis of wind resource assessment [39]**.** Mainly developed around in East African Great Rift Valley areas of the country have investigated. twenty areas of wind energy and solar energy photovoltaic power generation project, including resource condition in the plant, topographic condition, road construction condition, power grid access condition and population distribution and environmental condition etc. the wind master plan determines the wind power capacity is 6,820MW and there are 51 recommended construction areas for wind farm, February, 2012 [39].

Numerous studies have been done concerning the wind energy potential in Ethiopia, different region of the specific location has been largely discussed in the literature: Bekele & Palm [40] have been given considerable results regarding the wind energy potential in the country by investigative the wind regimes. Those studies were having the same parameter and methods. Such as type of data used, methods of data collection, periods in which the data was observed and the location in which the data was observed and resource characterized technique conducted using the daily average wind speeds measured at the anemometer height of 10m over a period of 4-6 years obtained from the NMSA [41]–[43]. However, the researchers hadn't to detail studded about site-specific wind turbine performance and site suitability for those potential areas and other competitive new wind energy potential promising sites.

2.10 Recent studies for wind turbine performance evaluation

Now a day various researchers call for performance evaluation of wind turbines offered at past and future time intermissions. Due to these current studies were carried out the viability of the wind turbine for power generation were evaluated based on different perspective mainly involved in optimization of wind turbines by using vortex lattice method for predicting wind turbine Performance. to design site mating wind turbine, optimize airfoil thickness and blade shape using the genetic algorithm code of MATLAB [44]. Power performance validation by improve wind turbine power curve for elaboration of artificial neural network (ANN) modeling technique [45] while surveying of wind turbine energy extracting efficiency mainly challenged by blade deflection and performance under aerodynamic loads, and the vibrational response within near wake experiments and investigate both CFD and FE modeling method [46].

Generally, in the past few decades, different researches have been carried out whether the potential of wind energy or wind turbine activity has been discovered across the globe and to some extent in Ethiopia however, no substantial development has been seen in these energy generation systems so far. The detailed review of the literature related to the topic aforesaid is providing in table 4

Table 3 :Reviews of several previous studies

S. no	Author	Tittle	Gap/problem	Method	Result
1	S.H. Pishgar-Komleh. [2017] [13]	Evaluation of wind energy potential for different turbine models In , Iran	Determine wind available site and examine wind energy potential with different wind turbine in specific region of Iran	Wind speed and direction collected from NMSA at 10 m. and 3 hour interval then analysis have been done by using Weibull and Rayleigh method	Average wind speed at 50m hub height 6.5 m/s and power density 424 W/m^2 and wind energy density were 3720 kW.h. $/m^2$ for suitable wind turbine mode based on max. AEO. EWT DW52-900 model and EWT DW52-500 is cost efficient model
2	Vladislovas Katinas,	investigation of wind power density	Uncertainties related to wind energy	Wind characteristics are measured by new equipment in NMSA	Variation of capacity factor in case of large-

	Giedrius Geceviciu s [2017] .[47]	distribution at location with low and high wind speeds	output due to different wind conditions in different location of near the Baltic Sea of morocco	recorded every one hour and entered in the database then have been calculated all wind variations	scale wind turbines Cp.= 0.19 for the low wind speeds and Cp ≅ 0.35 high wind speeds case of small-scale wind turbines Cp varies from 0.075 to 0.18 finely decide to high wind speeds can be used successfully installation
3	Farivar Fazelpour , Elin Markarian , Nima Soltani [2017] [48]	Wind energy potential and economic assessment of four locations in Sistine & Baluchistan province in Iran	Effects of the wind speed distribution quality for output power and economic feasibility of locations	NMSA wind data, were collected and investigate wind variations for used to Weibull distribution then wind power and energy density of the sites have been calculated and finally economic assessments are performed	All studied sites in Iran were Zabol, Zahak, Zahedan and Mirjaveh mean power density are 284.97, 269.02,144.49 and 138.64 W/m2 resp. energy densities are 2495.36, 2355.69, 1265.2 and 1214.01 kWh/m2/year resp. and energy cost 0.0341, 0.0502, 0.0970 and 0.1655 $/kWh, resp. Zabol and Zahak & DW61-900 kW were suitable site and turbine resp.
4	Tiaon Aukitino [2014] [49]	Wind energy resource assessment for Kiribati with a comparison of different methods of	Misleading of potential estimation with currently available wind turbines	34 m height anemometer wind speed and direction were recorded then wind resource map and sites suitability obtained using Wind Atlas Analysis and	Tarawa site has 5.355 & Abaiang site has 5.4575 m/s at 34 m above ground level wind direction predominantly East-North-East

		determining Weibull parameters		Application Program (WAsP) software and using more accurate method of weibull parameter	turbulence intensity 10% 275 kW rated power is suitable turbine at both sites and economic analysis is perform payback period 5.42 to 8.74 years
5	Getachew Bekele , Björn Palm [2009] . [40]	Wind energy potential assessment at four typical locations in Ethiopia	Investigation of new wind potential site based on geographical gap	Wind speed data, obtained from NMSA. & NASA. For 3 years at 10 m height and 5 times a day. analysis are done by using Weibull parameter in four sites	Wind potential in Debrezeit, substantially lower than others do. it is insufficient wind energy potential however the left three sites are feasible for wind power plant investment
6	Sajid Ali, Sang-Moon Lee [2017] [9]	Techno-Economic Assessment of Wind Energy Potential at Three Locations in south Korea	Reliability of long term data and feasibility of wind farm	Meteorological data like wind speed and wind direction Collecting at 10m height and 1h. interval then using Weibull parameter assessed wind distribution according to the wind conditions (IEC) guidelines, a set of five different wind turbines and evaluated it	Studied at three location. Of north Korea 1).Deokjeok-do 10 years Ava. Wind speed =3.8m/s 2).Baengnyeong-do, 15 years Ava. wind speed =4.6 m/s and 3).Seo-San also 19 years Ava wind speed =5 m/s Wind S134/3000 wind turbine is the most suitable for site 1&2 model HJWT 87/2000 is the most suitable wind turbine for site 3 based on technically and economically concern it is the most feasible one

7	Nitin Tenguria [2013] [50]	The Performance Test of Three Different Horizontal Axis Wind Turbine (HAWT) Blade	Efficient energy harnessing problem of wind turbine	using NACA airfoils Blade geometry is obtained calculated theoretical optimum chord and twist distribution Optimal rotor theory is used	changes in performance diameter taken is 82 m which is VESTAS V82-1.65MW and also CP&CF are under taken from manufacturer data
8	Natei Ermias, Ashenafi Abebe [2016] [51]	Evaluations of Wind Speed Distribution and Wind Power Potential over Ethiopia (ambo)	Maximizing wind farm profitability by implement accurate wind energy potential assessment technique	Wind speed data from NMSA in 6-year & 10 m. height by using statistically analyzed	wind speed of 3.2m/s at 10 m height (5.0 m/s and 6.2 m/s) at extrapolated 30 and 50 m. heights, respectively power density 26.0, 97.3 and 179.2 W/m^2 res .not suitable for electric generation but suitable for water lifting
9	A.Chermittia, M.Benchentrifa, Z. Nakoul (2014) [52]	Assessment parameters and matching between the sites and wind turbines(Algeria)	Differentiate available wind class in specific location and Uncertainty with pairing between the sites and wind turbine	wind data collecting from NMSA at 10 m high and by analysis of Weibull probability density function then assessing different model of wind turbine and select suitable model based on available potential	mean speed at 10 m are between 6.96 and 7.2m/s at 24 m =7.61 and at 70m= 8.18 m/s these sites can have typical could be installed a medium and big size wind turbines rated power values of up to 1500 to 2000kw sites are suitable
10	Oumer Yissa Dawde [2013] [41]	Wind Resource Data Analysis in Tigray regional state, Ethiopia	Geographical gap	wind resource data analysis by using Excel, MATLAB & wa$_s$p software data collecting from wind mast of 50m height	average wind speed of 7 m/s &wind density of about 287 W/m^2
11	Satyanara	Wind energy	Feasibility	wind speed data were	Three commercial wind

	yana G. and Shiva Prashanth Kumar Kodicherl a [43]	potential and cost estimation of wind energy generation of Tigray region (Ethiopia	analysis of wind farm based on electricity generation and economic viability	captured at 10 m height by a cup-generator anemometer then Weibull distribution function has been used to assess wind power potential, finally cost analysis have been done	turbines were selected for eight potential sites. from those sites the highest capacity factor and minimum cost per Kwh. obtained 7.873 % using VESTAS V110-2.0 and 0.0011$/kWh using VESTAS V110-2.0 resp.at Mekele

2.11 Research gap from literature survey

According to the better understanding of those articles which are addressing for the above survey have been focused on the assessing of wind resource as well as design and optimization of the wind turbine in each individual for different perspectives. Wind energy potential and wind turbines are the main elements of the wind power plant so it needs to well integration and capacity proportions of each other to minimize the capacity defect and performance compromise. With regard to these challenges, several articles were investigating due to improving wind assessing technique and different parts of wind turbines more of the time after implementation of a wind power plant. However, it is not economical, before any farther processing to install wind plants. It needs special attention for wind potential site, compatible wind turbine and the relation between them. In the Ethiopian context, the main problem of those studies was not examined and discussed in relation to the local wind characteristics and performance analysis of a commercial-scale wind turbine its expected performance for the specific location before its implementation. especially in this selected study area did not detail study for the data has used to first perform analysis and characterization of the wind conditions existing at the site over a full year even only one of the sites means Debrebrehan is already studied by gtz on seven-month wind data. However, not select and examine compatible wind turbine type and the remaining two sites are new for computing to the previous gtz recommend sites. The significance of energy conversion performance examination with specific location wind characteristics, to determining the capacity defect of the wind turbine in sites, it gives preliminary result for the efficient planning and effective implementation of any wind power project and longsuffering for the performance of the Wind Energy Conversion System.

CHAPTER THREE

MATERIALS AND METHODS

This chapter describes how the research was conducted and which type of techniques and materials are directly or indirectly incorporating for this research, such as brief discussion of the study area, where the data are obtained, data collection method, methods of data analysis and performance evaluation technique of wind turbine under specific location by available wind resource.

3.1 Methodology

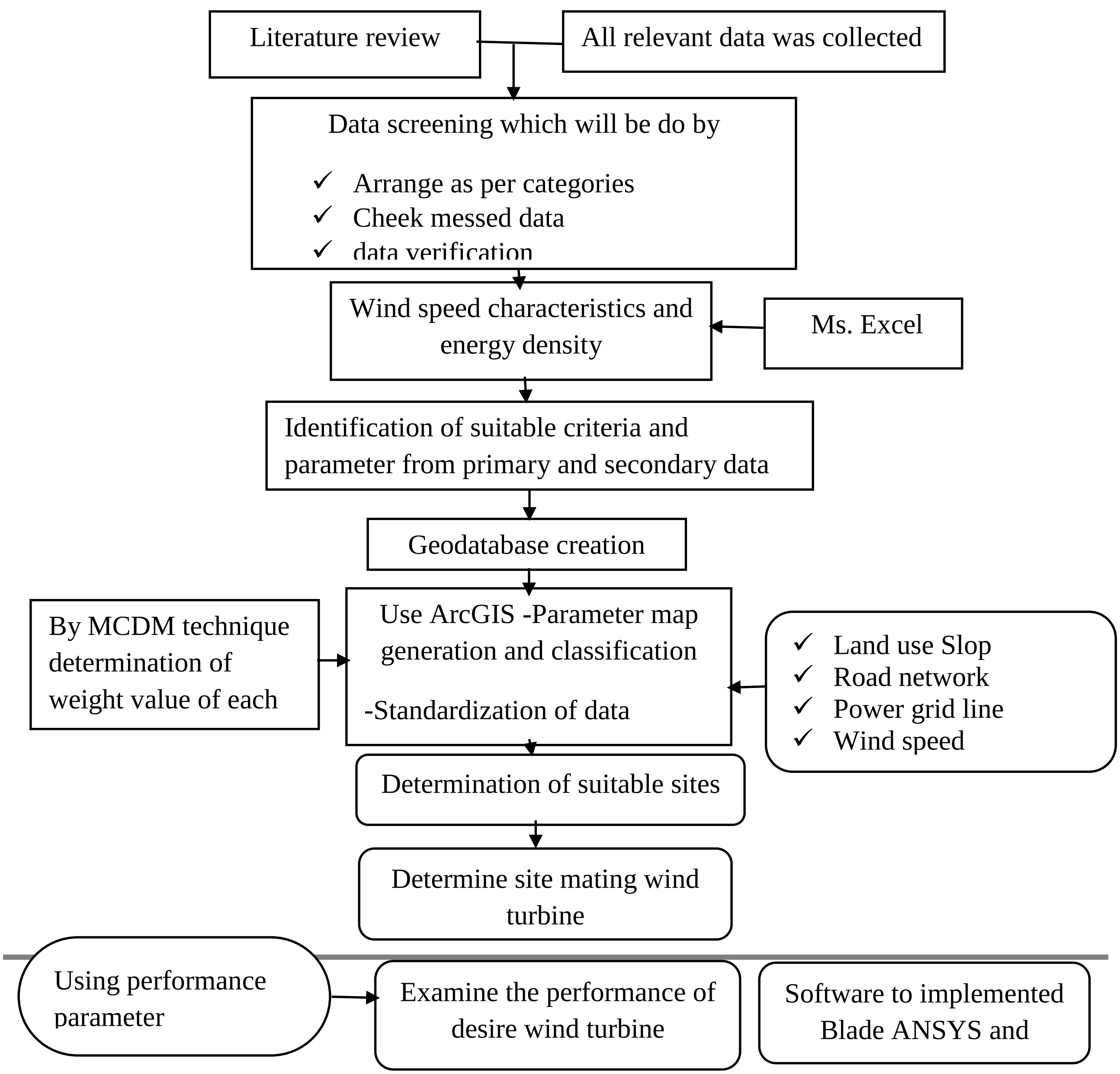


Figure 6: total research workflow

3.2 Description of the Study Area

3.2.1 Location

The wind sites are located in Ethiopia, Amhara regional state, north Shewa zone, northeast district. The zone is comprised of 22 rural woreda and one administrative zone town combined together. Total population of 2,733,616, of whom 1,640,169 are men and 1,093,446 women; with an area of 15,936.13 square kilometers while 214,227 or 11.66% are urban inhabitants. The highway from Addis Ababa to Dessie crosses part of the zone. The topography dominated by chain of hills and rouged mountains with some low lands. The altitude ranges from 1500 to 3100 meters above sea level and about 45.65 % of Zone is rugged type mountain [53]. Three administrative towns located in north Shewa zone; Debrebrehan, Enewari and mehalmeda, have selected for this research.

3.2.2 Debrebrehan

Debrebrehan town is located about 120 km north of Addis Ababa, and coordinated between 9°40'46.34" N 39°31'57.43" E for the altitude 2,816m above sea level (26). The town has a total population of 65,231, of which 31,668 men and 33,563 females. The town serves as an important economic and political center for the surrounding rural communities before and after the restructuring of the administrative zones in 1992.Debreberhan blanket factory and water, bottling Dashen and Habesha breweries are major energy intensive industrial level employers for the urban residents. Service sector economic activities and wholesale/ retail agricultural commodities trading are the main livelihood activities (25For the following section provides a brief description of the site that considered in this study that include where are Debrebrehan, Enewari and mehalmeda all sites are located the central part of Ethiopian in north Shewa zone[53].

3.2.3 Enewari

Enewari was a rural village under rural peasant kebele administration, coordinated between 9°35'35" N 41°51'58" E. distance from Addis Ababa 107 km and distance from Debrebrehan 46 km in the west direction and covers an area of 661.16 square kilometers with an elevation of ~2,652m for the total population of this woreda is 92,937. A total of 21,281 households were counted for the result in an average of 4.37 persons to a household [54].

3.2.4 Mehalmeda

Mehalmeda is the administrative center of Menz Gera woreda in the Amhara region of Ethiopia. It partly named after the northern district for the former domain of Menz. it is located at the eastern edge of the Ethiopia highlands in the north Shewa zone and also its geographical coordination is 10° 18' 00" North, 39° 40' 00" East placed 176 km distance from Addis Ababa with elevation of 3132 meter and the total populations are 89245 with an area of 549.55 square kilometers[54].

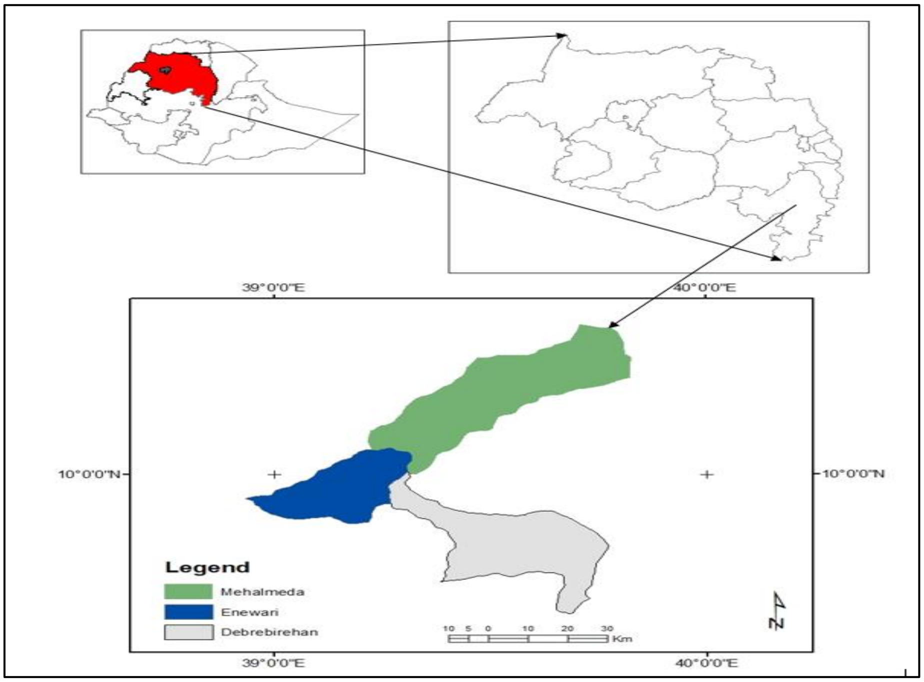


Figure 7 :Location map of study area

3.3 Reason for selection of study area

The main reason, for the selection of these study areas when the review of a similar study for locating potential sites. To consider the German technical coordination of (GHz) in [12] mainly developed around in East African Great Rift Valley areas of the country have been investigated 20 areas of wind energy power generation project. For example, Debrebrehan was one of those recommended sites. However, due to the expansion of urbanization and industrialization the site has not stayed freely which means recently the site covered by other institutions and settlements of the local population. The other reason also during the study time the researchers have taken only 7-month data. It was also not much enough to determine effective available wind resources because of the intermittent character of wind speed. The other very important things but the researchers did not incorporate the site suitability analysis in detail by using special geodatabase. Because of this have to investigate other, potentially attractive, available free land and moderately suitable sites.

3.4 Data Source and Data Collection

Wind data resource was obtained from Ethiopia national meteorology service agency and south wollo meteorological branch Office, Kombolcha station. The data obtained represents the magnitude of hourly mean wind speed for five consecutive years from 2013 to 2017 and it measured at 10 m above the ground.

3.4.1 Materials and Software’s used for the research

The materials and software's used for the study have been selected based on the capability to work on the existing problems in achieving the predetermined objectives are the following listed below in the tables.

Table 4: Materials and software’s have used.

Software/material	Purpose	Remark
ArcGIS	Factor map development. The factors that are input for multi-criteria analysis should be preprocessed in accordance with the criteria set to develop wind energy potential	Version 10.5
MATLAB	To evaluate the performance of the wind turbine	2016

Solid work	Modeling of aerofoil by importing of its coordinate value	2014
ANSYS	To evaluate the performance of aerofoil	2016
Q blade	This simulation software is used for the development of aerofoil shapes	2015
Mendley	This software is used for documentation propose	2014

3.5 Method of Data Analysis

From relevant data sources, large quantities of wind, data in the form of wind speed and geographic parameter were collected. Having some ways to summarize the data in a compact form so that one could evaluate the wind resource or wind power production potential of a particular site is statistical techniques. This parameter is very important to identify the characteristics of wind and the potential of wind energy. This statistical study involves identifying the prospective site as well as the easiest and efficient way to apply Weibull Probability distribution for a wind energy assessment for the specific locations based on the following wind characteristics like,

- ✓ Daily, monthly, annual average wind speeds and standard deviation
- ✓ Wind direction

3.5.1 Weibull probability distributions

The variations in wind velocity characterized by the two functions.

- The probability density function and
- The cumulative distribution function

The general form of the Weibull probability density function is mathematically expressed by [49]:

$$F(V)=\left(\frac{K}{C}\right)\left(\frac{V}{C}\right)^{K-1}\exp\left[-\left(\frac{V}{C}\right)^{K}\right](K>0,V>0\&C>1 \ldots\ldots(3.1)$$

The parameters k and c can be estimate by the linear regression of the cumulative Weibull distribution given by:

$$F(V) = 1 - \text{Exp.}\left[-\left(\frac{V}{c}\right)^{K}\right] \quad \ldots\ldots (3.2)$$

Average wind speed (v): for wind energy calculations, the velocity have to weigh for its power content while computing the average.

$$V_m = \frac{1}{n}\sum_{i=1}^{n} V_i \quad \ldots\ldots (3.3)$$

Standard deviation (σ_u)

One of the measures for the variability of velocities in a given set of wind data is the Standard deviation. Standard deviation tells us the deviation of individual velocities from the mean value. Lower values of σ_u indicate the uniformity of the data set. Thus

$$V_m = \frac{1}{n}\sum_{i=1}^{n} V_i \quad \ldots\ldots (3.4)$$

For analyzing a wind system following the Weibull distribution, the Weibull parameters k and C must be estimate by the following method.

Among the different methods, both the graphical and the standard deviation, which provides very close to the field observation widely accepted and extensively used for wind resource analysis methods, are discussed in the following section.

a) Graphical method

In the graphical method, the cumulative distribution function transformed in to a linear form, adopting logarithmic scales. The expression for the cumulative distribution of wind velocity $1 - F(V) = e^{-\left(\frac{v}{c}\right)k}$

Taking the logarithm twice yields:

$$\ln\{\ln[1 - F(V)]\} = k\ln(V) - k\ln(c) \quad \ldots\ldots (3.5)$$

Plotting the above relationship with $ln(V)$ along the X-axis and $\ln\{\ln[1 - F(V)]\}$ along the Y-axis, nearly a straight line is obtaining. From Eq. 3.5, k gives the slope of this line and – k ln a represents the intercept. If you generate the regression equation for the plotted line and compare it with Eq. 3.5, the values of k and c can be determined.

a) Standard deviation method

Estimating of the Weibull factors k and c form the calculated value of mean and standard deviation of wind data, factor k, can be computed by dividing standard deviation with mean velocity given in Eq. 3.6, and from these equations can be related as

$$\left(\frac{\sigma v}{Vm}\right)^2 = \frac{c\tau\left(1+\frac{1}{k}\right)}{(\tau)^2\left(1+\frac{1}{k}\right)} - 1 \ldots\ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots\ldots\ldots \ldots\ldots\ldots \quad (3.6)$$

Once and are calculated for a given data set, then k can be determined by solving the above expression numerically.

Once k is determined, c given by the following formula

$$c = \frac{Vm}{\tau\left(1+\frac{1}{k}\right)} \quad 1 \ldots\ldots\ldots\ldots\ldots \ldots\ldots\ldots\ldots\ldots\ldots \ldots\ldots\ldots .. (3.7)$$

Where Γ(x is the gamma function, which is calculated

$$\Gamma(x) = \int_0^\infty e^{-u}u^x - 1\, du \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.8$$

Further integration value simplified as follows.

$$\Gamma(x) = \sqrt{2\pi x}\ \ (x^x - 1)(e^{-x})\ \ [1 + \frac{1}{12x} + \frac{1}{288x^2} + \frac{1}{51840x^3} + \cdots]$$

In a simpler approach, an acceptable approximation for k and c are

$$K = \left(\frac{\sigma v}{Vm}\right)^{-1.086} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .(3.9)$$

Similarly, c can be approximate from

$$C = \frac{2Vm}{\sqrt{\pi}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.10)$$

However, for calculating c using Eq. 3.11 is a more accurate approximation than using Eq. 3.9, C can be determined from the expression.

$$C = \frac{V_m K^{2.66745}}{0.184x0.816K^{2.7385}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.11)$$

In this study, to estimate the Weibull factors k and c, the standard deviation method shall be because of widely accepted and extensively used for wind regime analysis.

3.4.2 Rayleigh probability distribution

The existing data in the form of the mean wind velocity over a given time period (for example daily, monthly or yearly mean wind velocity), under this situations, Rayleigh distribution is a simplified case of the Weibull distribution can be derived by assuming the shape factor value is taking= 2.

$$Vm = c\tau\left(\frac{3}{2}Vm\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.12)$$

Rearranging the above expression

$$C = \frac{2Vm}{\sqrt{\pi}}$$

Substituting for C in eq. 3.12 is given

$$F(v) = \frac{\pi}{2}\frac{v}{Vm^2}e^{-\frac{\pi}{4}(\frac{V}{Vm})^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.13)$$

Similarly, the cumulative distribution given by

$$F(V) = 1 - e^{-\frac{\pi}{4}(\frac{V}{Vm})^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.14)$$

Considering both the Weibull and Rayleigh models to estimate the energy potential of a wind regime based on the above indices were discussed.

3.4.3 Energy Estimation of Wind Regimes

Assessing the energy available in the wind system prevailing at a site is one of the preliminary steps in the planning of a wind energy project. Wind energy density and the energy available in the system over a period, usually taken as the yardsticks for evaluating the energy potential. It is available in the wind system for a unit rotor area and time as a function of the velocity and distribution of wind at the site.[47]

a) **Weibull based approach**

$$E_D=\int_0^\infty pv\, F(v)dv \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.15)$$

Substituting for PV and f (V) in the above expression and with the standard gamma integral, it gives

$$E_D= \frac{\rho a c^3}{2}(\frac{3}{k})\Gamma(\frac{3}{k})\text{.. (3.16)}$$

Available energy density over a period of time (EI) can calculate as follows.

$$E_I=EDT = \frac{\rho a c^3}{2}\Gamma(\frac{k+3}{k})n\Delta t\text{.. (3.17)}$$

Where T is the time

The most frequent wind velocity in the regime by VF_{max}

$$Vf_{max} = C\left(\frac{k-1}{k}\right)^{\frac{1}{k}}\text{..(3.18)}$$

The velocity contributing maximum energy to the regime (VE_{max}) given by

$$V_{Emax}= C\left(\frac{k+2}{k}\right)^{\frac{1}{k}}\text{.. (3.19)}$$

For this study, the Weibull based approach has selected to evaluate the velocity contributing maximum energy to the regime as very close to the rated wind velocity of turbines.

b) Rayleigh based approach

The wind energy density at the site to be express as:

$$E_D=\int_0^{\infty} pv\,F(v)dv = \int_0^{\infty}\frac{\pi}{4}\frac{\rho}{Vm^2}V^4e^{-\frac{\pi}{4}(\frac{V}{Vm})^2}\,dv\text{..(3.20)}$$

Rearranging and energy density at the site:

$$E_D= \frac{3}{\pi}\rho V^3\text{..(3.21)}$$

The most frequent wind velocity represented by at the site V_{fmax} given by

$$V_{F\,max}= \sqrt{\frac{2}{\pi}}Vm\text{..(3.22)}$$

The velocity contributing maximum energy to the regime to be express as:

$$V_{E\,max}= 2\sqrt{\frac{2}{\pi}}Vm\text{..(3.23)}$$

3.4.4 Wind direction

Moreover, to conduct wind energy research it is significant to determine wind direction. The wind direction illustrated in polar diagrams and it can measure in clockwise direction. The cycle is divided in 16 sectors, each of 22.5 degree[27].

3.4.5 Variation of Wind Profile with Height

A proper feasibility analysis for a precise estimation of a specific site and its characteristic is rather than, collection and analysis of wind data, analysis of the prevailing wind directions, surface roughness, topography, upwind obstacles such as trees or buildings, intensity of turbulence and wind shear profile shall be understood in detail [27][55].

3.4.6 Extrapolation of wind data

The variability depends on distance from the ground and roughness of the terrain. The most common expression accepted to describe the vertical variation of wind speed is expressed by a power law [56].

$V = V_o\left(\frac{Z}{Z_o}\right)^a$ ……………………………………………………………………………(3.24)

3.25

$a = \frac{0.37 - 0.088\ln(\text{Vref})}{1 - 0.088 ln\left(\frac{Zref}{10}\right)}$, Wind shear correlation value

Where: a = wind shear (or power law) exponent.

Due to the boundary layer affect, the wind speed increase with height which can be expressed as with the log law pattern:[56]

$$V(Z_R) = V_z \frac{ln\left(\frac{Z_R}{Z_O}\right)}{ln\left(\frac{Z}{Z_O}\right)} \quad \text{……………………………………………………………… (3.25)}$$

V = Wind velocity at height z above ground level,

$V_{o=}$ freestream velocity

V_{ref} = Reference velocity, a wind velocity at height z_{ref},

z = Height above ground for the desired velocity, V,

Z_o= Surface roughness length of the site,

z_{ref}= Reference height, i.e. the height where the exact wind velocity V_{ref} known

Table 5:friction coefficient value[31]

land scape type	friction coefficient
lakes, ocean smooth hard ground	0.1
grass land (ground level)	0.15
tall crop, hedges and shrubs	0.2

heavily forested land	0.25
small town with some tree and shrubs	0.3
city area with high rise building	0.4

Table: landscape and roughness values [31]

train	land scape type	roughness class	roughness value zo(m)
Flat	beach, ice snow land scape, ocean	Zo	0.005
Open	law grass, airport, empty crop	Z1	0.03
	land ,high grass law crop	Z2	0.1
Rough	tall raw crop, law woods	Z3	0.25
very rough	Forests	Z4	0.5
Closed	Villages	Z5	1
Town	town center, open space in forests	Z6	2

3.4 **Fluid flow obstacles**

Flow over flat terrain with man-made and natural obstacles has been studied extensively such as buildings, trees, woods and forests, tree lines and rock formations can significantly change the wind speed and direction [27].

Then based on all the wind resource characteristics data the following activities were undertake.

3.5 Selection of wind turbine class as per international standard

According to IEC 61400-1, wind turbine classification with respect to their ability to withstand the extreme wind speed at 50m hub height, mean wind speed and turbulence intensity.

Table 6: Classification of wind turbine as per std. IEC. 61400[41].

S.No.	Classification of WT		IEC 1 High wind	IEC 2 Medium wind	IEC 3 low wind

1	Annual wind speed		10 m/s	8.5 m/s	7.5 m/s
2	Extreme Ws (50 year gust)		70 m/s	59.5 m/s	52.5 m/s
3.	Turbulence (I_{ref})	Class A	18%	18%	18%
		Class B	16%	16%	16%

A designates the category for higher turbulence characteristics,

B designates the category for medium turbulence characteristics

I_{ref} is the reference turbulence intensity at a wind speed of V_m m/s.

3.6 Evolution of wind turbine performance based on site wind characteristics

Determine the effect of non-typical environment on the forecast efficiency and operation of the turbine [57]. For the efficient planning and effective implementation of any wind, power project longsuffering for the performance of wind Energy Conversion System (WECS), at the proposed site, is essential.

3.6.1 The performance curves.

The performance of a wind turbine can be characterized by the manner in which the two main indicators.

- ✓ Power coefficient
- ✓ Tip-speed ratio

3.6.2 Power coefficient

The power coefficient is an important parameter as it describes a wind turbine's aerodynamic efficiency in converting kinetic energy in the wind into electrical energy mathematically recall that the power available in the wind can be expressed as,

$$P=\frac{1}{2}\rho a A v^3 \qquad (3.26)$$

Where ρ is the density of the air, A is the capture area, and V is the wind speed.

The power output of a wind turbine for directly related to the swept area by the rotor blades:

$$A = \pi * (\frac{1}{2}D)^2 \quad \text{……………………………………………………………… (3.27)}$$

The power actually captured by the wind turbine rotor, P_R, is some fraction of the available power, defined by the coefficient of performance, Cp, which is essentially a type of power conversion efficiency [2].

$$Cp = \frac{2PR}{\rho a A v^3} \quad \text{……………………………………………………………… (3.28}$$

CHAPTER FOUR

WIND SPEED DATA COLLECTION AND POTENTIAL ANALYSIS

4.1 data collection

For this study assessing the wind energy potential of the proposed location, the wind speed data have been collected from Ethiopian National Meteorological service Agency (NMSA) every 3 hours at a 10 m height for 5 years from 2013 to 2017. All raw wind speed and wind direction data are check and verified. Those dates used to evaluate the resource of wind energy potential and wind characteristics in representative years for a particular location. Furthermore, the wind speed at higher heights can be calculated using the power law, which is the vertical (extrapolated) profile of the wind speed and the assessment of potential wind power.

4.2 Analysis of Site Wind Resource

4.2.1 Characteristics of wind speed in the study area

Investigation of the wind energy potential on specific locations, involves analyzing the wind characteristics, the distribution of the measured wind speed and direction, the maximum wind speed, the wind variability and seasonality variations of the wind speeds. For this portion should be done the analysis of the atmospheric motion of vary both timely (hours to years) and spaces from (10m to 70m) hub height. As this moment should have presented the comparisons of the natures of the wind speeds at 10m height of wind measuring from national meteorology service agency in selected sites built on the Variations of wind speed in time can be divided into the following categories such as, diurnal or (short term), monthly and annual long term variations.

Diurnal**,** due to latitude difference, some wind variations also can occur on a diurnal or daily time scale. This type of wind speed variation is happening due to the differential heating of the earth's surface during the daily radiation cycle[55]. Hence, the detailed understanding of these variations was very important to identify the characteristics of wind and helps to later, well estimation of wind energy potential. Short-term wind speed variations of interest include average hourly, daily, monthly and yearly wind speed. Speed and direction of the wind change rapidly with time. In these changes, the power and energy available from the wind also vary. The different wind variations based on hours of a day, days of a month and months of a year at a 10 m height demonstration as follow. The analysis result shown in fig 10, can determine the mean hourly wind speed fluctuation for all study areas.

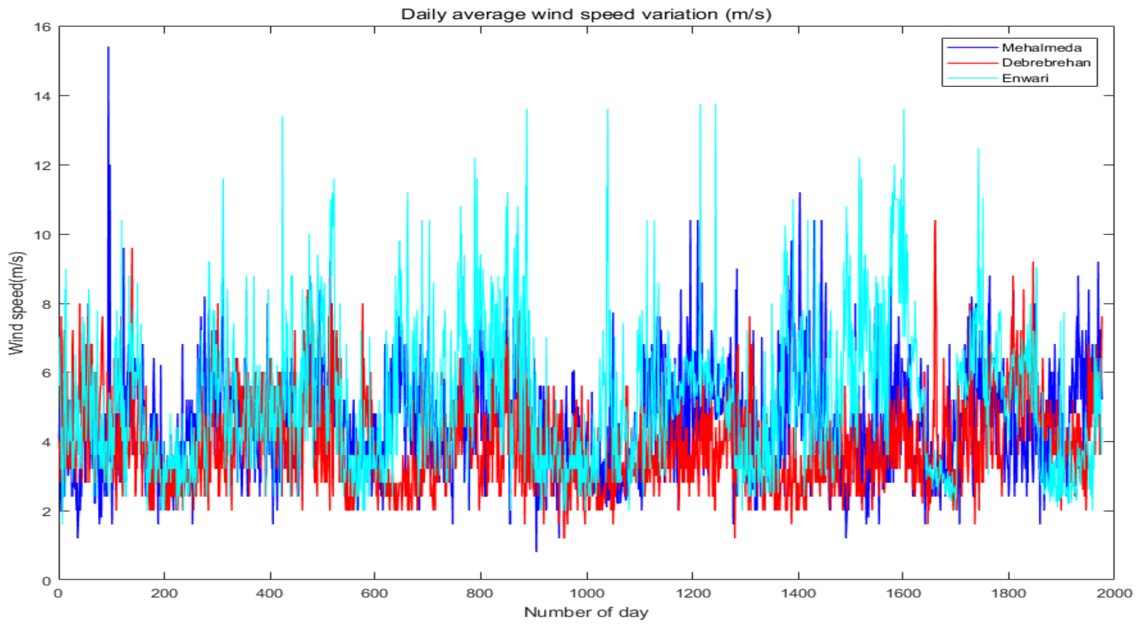
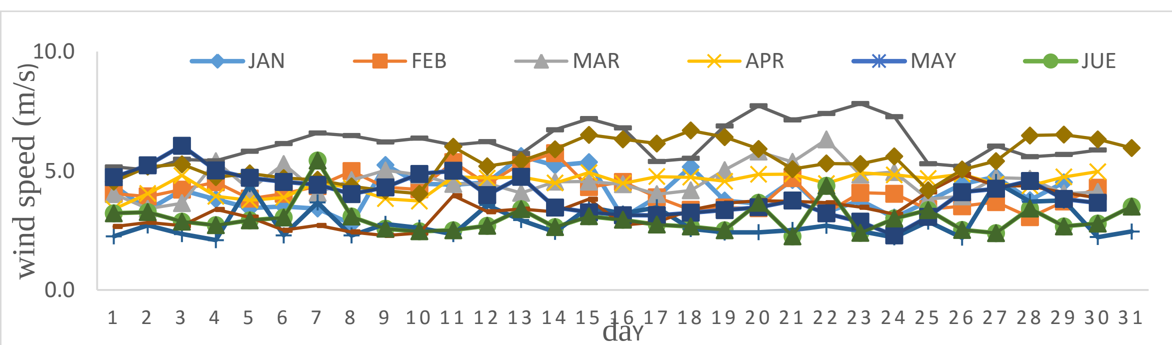
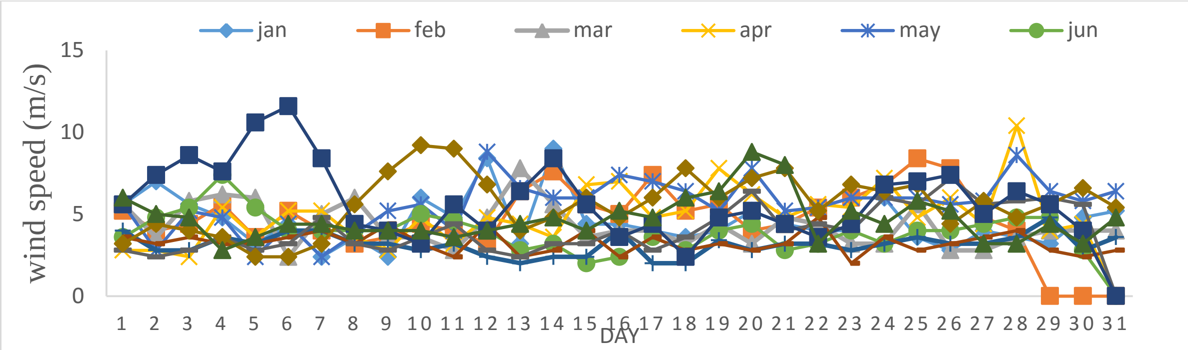


Figure 8: day per hour mean wind speed variations in all respective sites at 10m height.

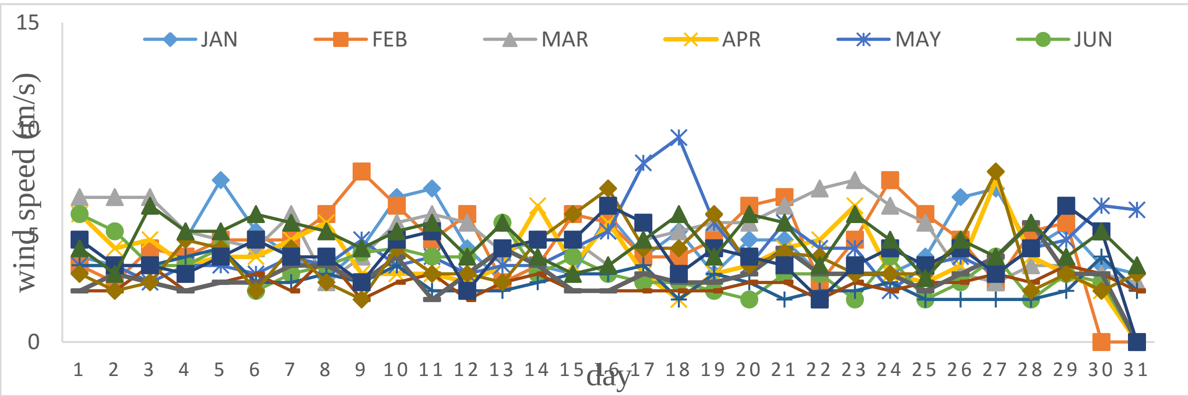
Hourly maximum, minimum and mean wind speed variations for sites of Debrebrehan, Enewari and Mehalmeda for the period of 2013 to 2017 fluctuates between 1.5 and 10.5 m/s for Debrebrehan, 1.2 and 15.5 m/s for Enewari, 2 m/s to 14.5 m/s for Mehalmeda. According to the raw measured data, the most frequent occurrence for 10-meter height is 4 to 5 m/s with 15% to 30% occurrence and 90% of wind speeds are below 10m/s for all respective sites.



Daily wind speed variation in Debrebrehan site



Daily wind speed variation in Debrebrehan site



Daily wind speed variation in Mehalmeda site

Figure 9: Daily per month mean wind speed variations in all respective sites at 10m height

The daily wind speed manners in the sites of, Debrebrehan, Enewari and Mehalmeda respectively shown in Fig. 11 respectively. The result of these variations becoming to close relative to the hourly average. All three site keeps minimum at 2m/s and at maximum 7.8m/s, 12m/s and 10m/s at 10m height respectively.

4.2.2 Wind Direction

Wind direction is mostly describing by the graphical tool in order to plot frequencies of wind in different directions and wind speed of the site. These graphical tools used to determine and quickly indicate the dominant wind directions. Fig. 12 illustrates that the prevailing wind direction in the following three candidate locations of study areas.

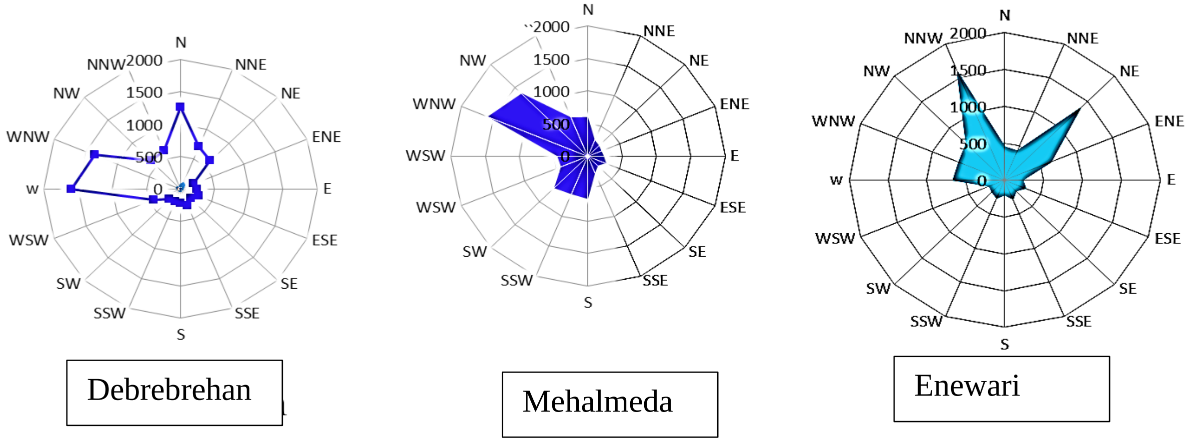


Figure 10: The prevailing wind direction for three respective sites

From relevant data, source large quantity of wind data collected in the form of wind speed under different ranges. Since, this wind speed range used to understand which is frequently occurring on the study area. This maximum frequent wind speed range have dominated contributes to site wind power density. Having one ways to summarize the data in a compact form by the following plots.

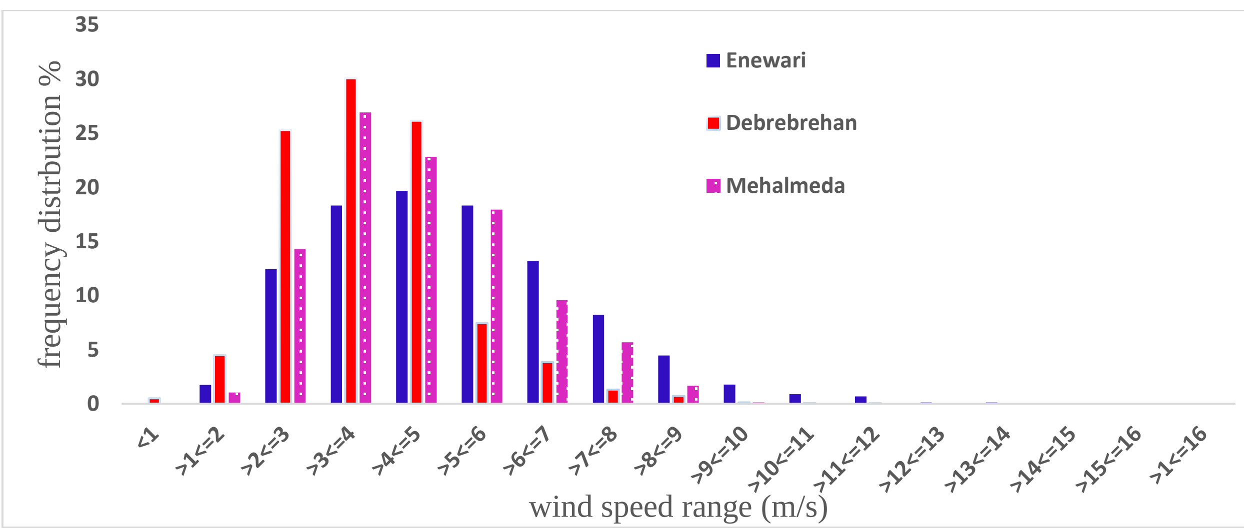


Figure 11: wind speed variation by measured data at 10meter height

Based on meteorology-measured data the wind speed frequency has seen from fig.13 for Debreberhan site, wind speed from 3 to 4 m/s frequently happens for 30%. Enewari wind site also the frequent occurrence wind speed exists 18% from 4 to 5 m/s and the last site Mehalmeda has maximum frequency 25% at a wind speed range of 3 to 4 m/s at 10 m height.

4.2 Weibull parameters and wind frequency analysis

The Weibull distribution function is the most widely used function for modeling the wind speed around the globe. In this, portion the most important thing to analyze the wind variation for the typical sites. Besides, the basic input parameter should be calculated by using its Owen formula which is referred to as the previous chapter such as the scale factor (c) of the Weibull distribution is related to the average wind speed at 10m heights and is calculated using the standard deviation method. Similarly, the Weibull (k) value is the dimensionless shape factor of the Weibull distribution. Then after could be analysis the Weibull frequency distribution and cumulative distribution each responding sites by using eq.3.1 and eq.3.2 respectively

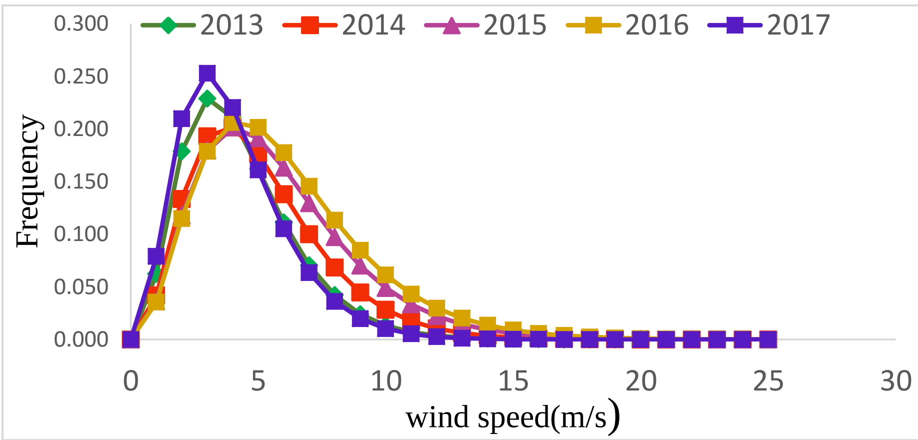


Figure 12:five years' average wind speed frequency in Debrebrehan site

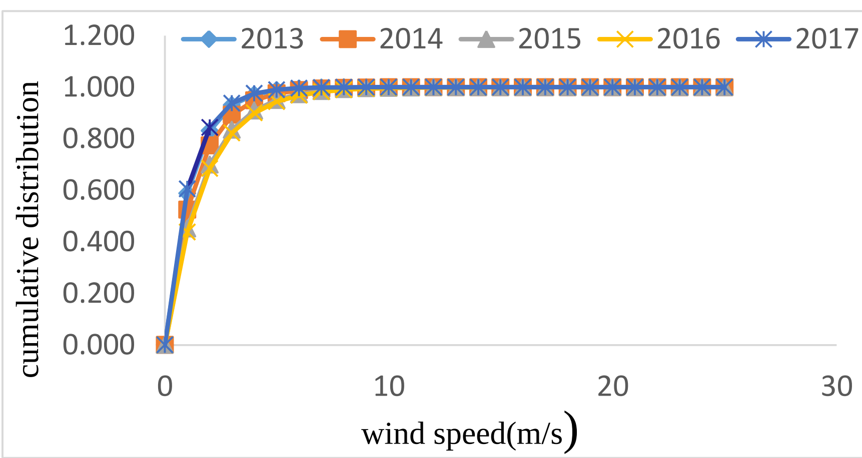


Figure 13: five years average cumulative wind speed distribution Debrebrehan

In figure 14 to 15 Illustrates the synthesized Weibull probability density cumulative wind speed distribution, according to this figure the frequent occurrence of wind speed for 10m height varies from year to year with 18 % up to 25 % in five years. In cumulative result above 97% of wind, speeds are below 10m/s.

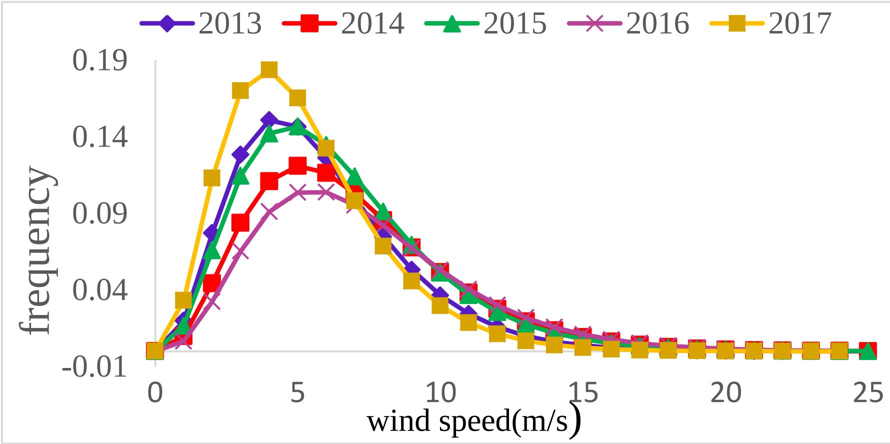


Figure 14:five years' average wind speed frequency on Enewari

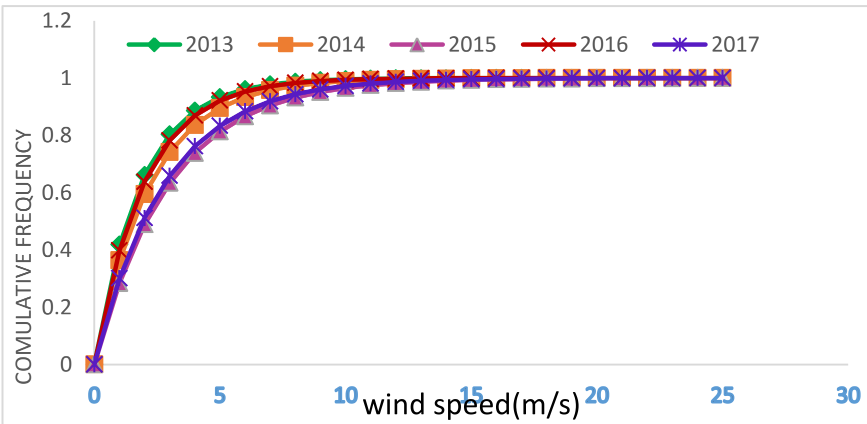


Figure 15: five years average cumulative wind speed distribution Enewari

With regard to Enewari wind speed data, the Weibull probability distribution and cumulative distribution are shown in fig 16 and 17. The synthesized Weibull probability density indicates the most frequent occurrence for 10m height are ; 8% to 18 % on 2013 -17. In addition, the cumulative distribution result shows averagely 89% blow 10m/s at 10m height.

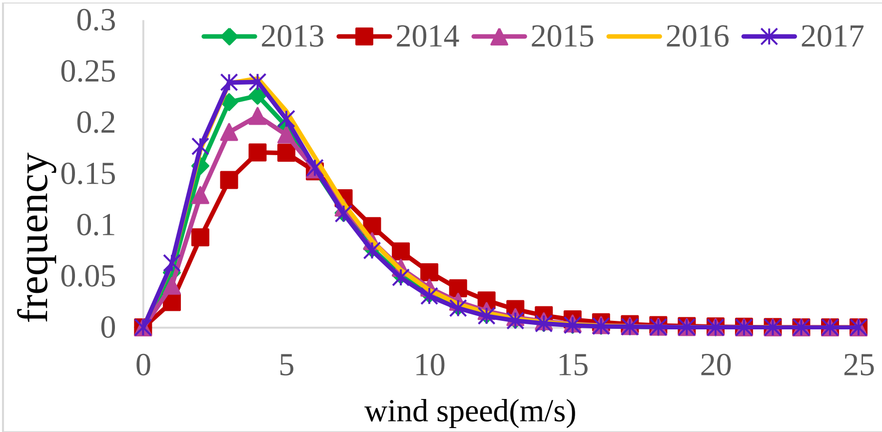


Figure 16: five years' average wind speed frequency on Mehalmeda site

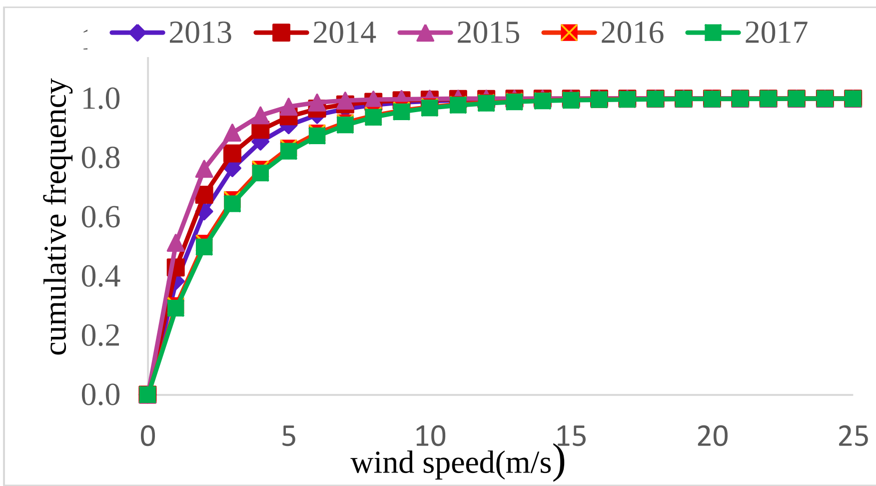


Figure 17: five years average cumulative wind speed distribution Mehalmeda

Weibull probability density and cumulative distribution analysis result in the study area of Mehalmeda illustrated by fig: 18 and 19, the frequent occurrence for 10m height varies from 15.5% to 25% with the corresponding wind speed of 3.5 m/s to 5 m/s and the cumulative wind speed distribution result shows 92% under 10m/s.

4.2.3 Wind speed analysis for the desire wind turbine height by extrapolation

Considering the fact that rotors of the actual wind turbines are placing at heights more than 10 m. in order to choose the suitable height of the wind turbines, it is necessary to know the variations of wind speed with altitude. Extrapolating wind speed data collected at anemometric height to the *required* height is the first step to use these data in calculating and assessing wind energy within the designated location in the site. Thereby, the data collected at the measured 10 m height were extrapolating to 70m heights using power law in the previous chapter Equation 3.24. At those heights the annual average of wind speed 7.38m/s, 9.17m/s and 8.03m/s as per respective study sites.

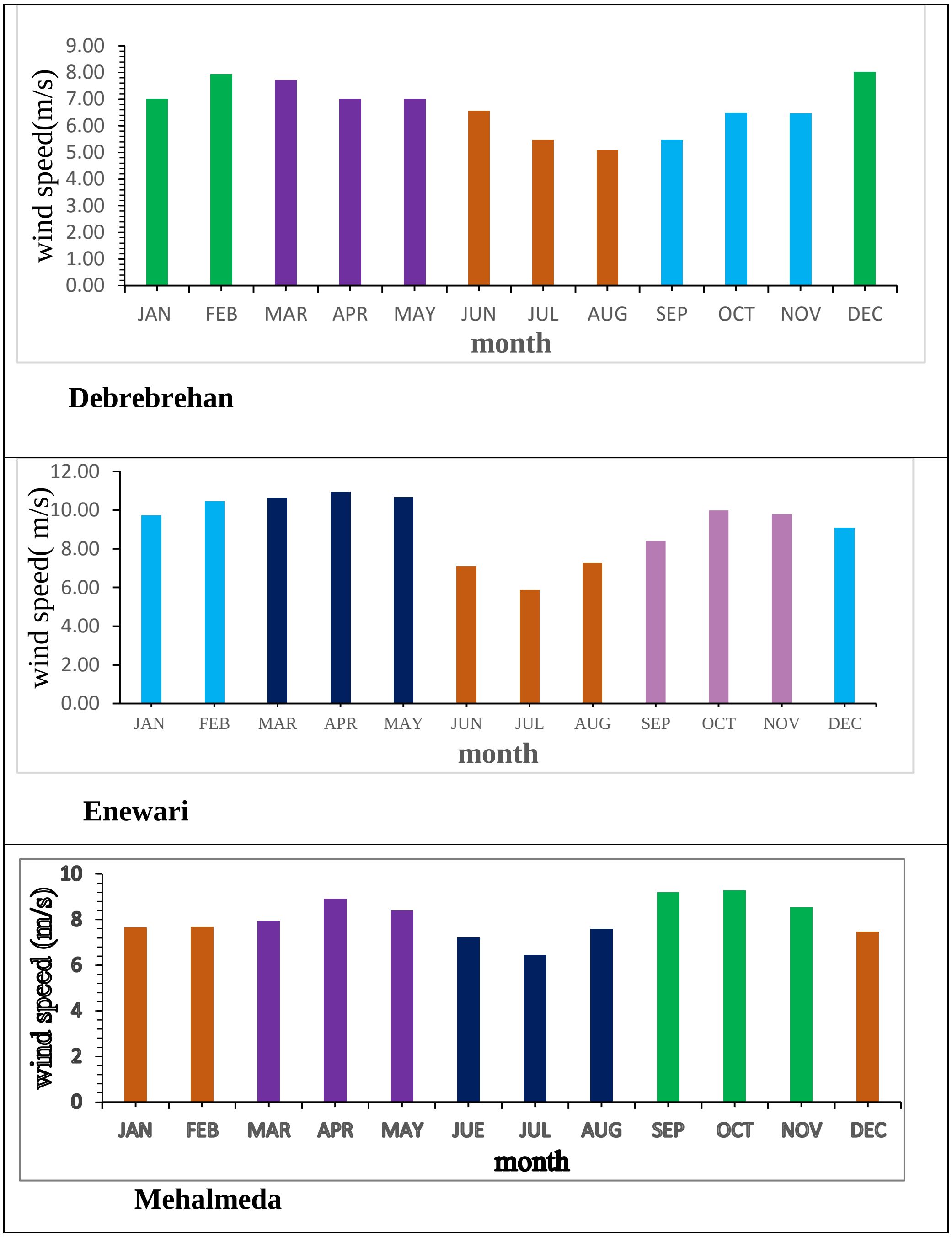


Figure 18: monthly average wind speed variation with three selective sites

The monthly pattern of the wind speed can see in Fig 20. For the first wind site showing that the wind reaches it is the most maximum in February and its most minimum in August. For second wind site shows that the monthly average wind speed is close to the maximum value for much of the year except June, Juley, and August when the wind comes the most maximum and minimum April and July respectively. The last wind site shows the months where the maximum and minimum average wind speed value was observed in April and July respectively.

Annual; -annual variations in wind speed occur over time scales greater than one year have a large effect on long-term wind turbine production. The ability to estimate the annual variability at a given site is almost as important to estimating the long-term mean wind at a site [55].

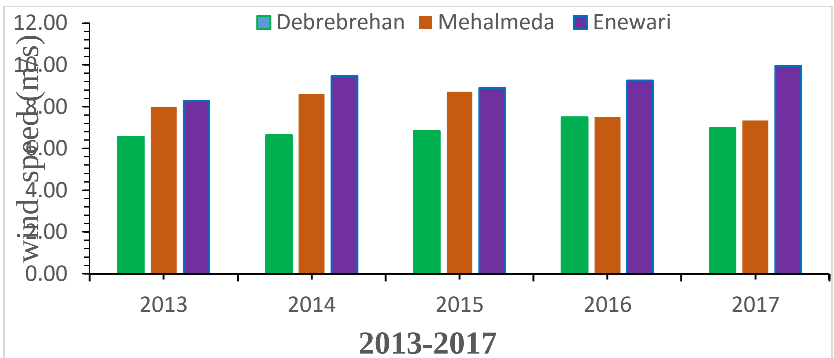


Figure 19: inter annual average wind speed value.

The annual wind speed at 70 meters above ground level (AGL) was illustrating fig 21. The leading maximum value of wind speed was existing in Enewari site in all representative years as well as the next relatively comparable value was obtaining from Mehalmeda and the last comparable wind speed value getting from Debrebrehan windy site.

4.2.4 Wind shear

Extrapolations from 10m above the ground up to the desired wind turbine hub height with the corresponding wind speed assessments which affecting by naturally available terrain like forests, bushes, crops, buildings, and other related structures. Generally, the rate of reduction on wind speed depends on the on-site terrain type; the roughness class or roughness height by log law and power-law exponent commonly represents it. The choice from the above approaches depends on the interest of the users, however, for its simplicity of analysis researchers mostly preferred to use the second approach, which is power low analysis technique.

For the candidate site, as was dominantly covered by a relatively flat surface with short vegetation as well as rural shelters and agricultural cropland over the different direction sectors.

Whole study sites were reasonable where there are no obstacles close enough to an appreciable effect rather than fewer and far away from that location [25]. While giving wind shear averages under 0.0001 to 1 in different wind site classes. However, according to the site situation shear coefficient bounded by 0.20 up to 0.30 but in this analysis taken the highest value of wind shear coefficient of 0.30 then after can calculate wind speed value with the corresponding desire height shown in the below fig below

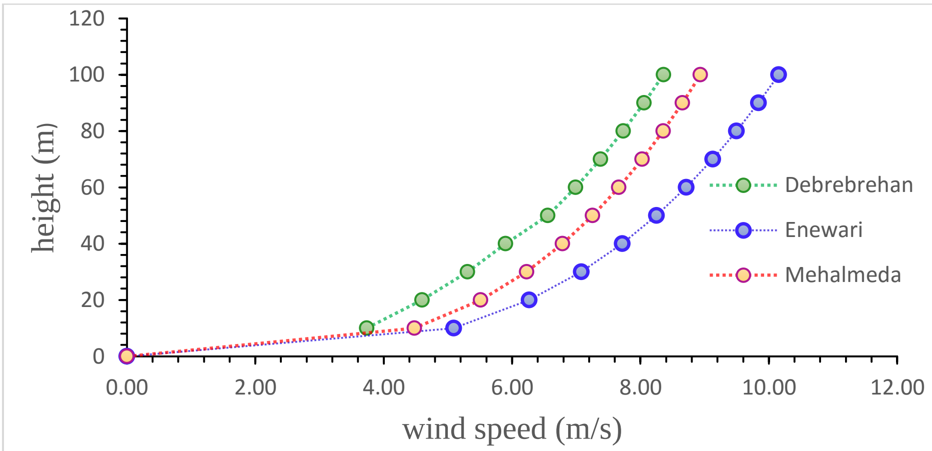


Figure 20: wind speed variation with different height.

4.4 Analysis of wind energy density

In evaluating the wind resource potential of the prospective site determining the available, as well as extractable power/energy density in addition to wind speed, are important parameters. The wind energy density (ED) is the energy available in the regime for a unit rotor area and time[58]. Besides estimating its power generation potential it needs to know and differentiate the most frequent wind velocity (VF-max) and the velocity contributing to the maximum energy (VE-max) to the regime. The peak of the wind speed probability density curve represents VF-max whereas it can be read from the peak of the energy probability density curve. At this portion mainly focused on the analysis of the variation of wind energy density by using Weibull probability density function eq.3.17 as per respective sites, by Raleigh method Eq.3.21 and at the same time could be calculating V_{Emax} and V_{Fmax} by using both methods[58].

Table 7: sites energy and power density analysis value from 2013 to 2017

year	site	parameter	Weibull method /Unit	Raleigh method/unit
2013	Debrebrehan	Power density	279.48 W/m2	322.59W/m2
		Energy density	2449921.68 wh/y	2827823.94 Wh/y
		VF_{max}	6.31 m/s	5.8 m/s
		VE_{max}	8.26 m/s	11.6 m/s
	Enewari	Power density	343.97W/m2	630W/m2
		Energy density	3050305.02 wh/y	5522580 Wh/y
		VF_{max}	7.14 m/s	6.6 m/s
		VE_{max}	8.94 m/s	12.6 m/s
	Mehalmeda	Power density	328.3 W/m2	570 W/m2
		Energy density	2877877.8wh/y	4996620 Wh/y
		VF_{max}	6.49m/s	5.82m/s
		VE_{max}	8.5 m/s	11.65m/s
2014	Debrebrehan	Power density	283.04 W/m2	333.74W/m2
		Energy density	2481128.64wh/y	2925564.84 Wh/y
		VF_{max}	6.3m/s	4.69 m/s
		VE_{max}	7.33m/s	9.38 m/s
	Enewari	Power density	417.65 W/m2	898.06 W/m2

		Energy density	3661119.9 wh/y	7872393.96 Wh/y
		VF_{max}	7.33m/s	6.48 m/s
		VE_{max}	9.3m/s	12.5m/s
	Mehalmeda	Power density	354.22 W/m2	530 W/m2
		Energy density	3105092.52 wh/y	4645980 Wh/y
		VF_{max}	7.26 m/s	6.86 m/s
		VE_{max}	8.7 m/s	13.7 m/s
2015	Debrebrehan	Power density	252.09 W/m2	365.74 W/m2
		Energy density	2209820.94wh/y	3206076.84 Wh/y
		VF_{max}	5.28 m/s	4.8 m/s
		VE_{max}	7.76 V	9.6 m/s
	Enewari	power density	397.99 W/m2	715.79 W/m2
		Energy density	3488780.34wh/y	6274352.16 Wh/y
		VFmax	5.96 m/s	7.1 m/s
		VEmax	8.74 m/s	14.2 m/s
	Mehalmeda	power density	357.97 W/m2	530 W/m2
		Energy density	3136387.14wh/y	4645980 Wh/y
		VF_{max}	7.36 m/s	6.95 m/s
		VE_{max}	8.44 m/s	13.89 m/s
2016	Debrebrehan	Power density	280.42 W/m2	481.01 W/m2
		Energy density	2458161.72 wh/y	4216533.66 Wh/y
		VF_{max}	6.19 m/s	4.26 m/s
		VE_{max}	7.47 m/s	8.53 V
	Enewari	power density	440.12 W/m2	830.85 W/m2

		Energy density	3858091.92wh/y	7283231.1
		VF_{max}	7.15 m/s	7.38 m/s
		VE_{max}	8.75 V	14.77 m/s
	Mehalmeda	Power density	306.08 W/m2	415.2 W/m2
		Energy density	2683097.28wh/y	3639643.2 Wh/y
		VF_{max}	5.21 m/s	5.84 m/s
		VE_{max}	9.75 m/s	11.69 m/s
2017	Debrebrehan	Power density	280.52 W/m2	412.8 W/m2
		Energy density	2459038.32wh/y	3618604.8 Wh/y
		VF_{max}	6.32 m/s	6.49 m/s
		VE_{max}	7.31 m/s m/s	12.98 m/s
	Enewari	Power density	495.33 W/m2	927.28W/m2
		Energy density	4342062.78wh/y	8128536.48Wh/y
		VF_{max}	6.12 m/s	7.95 m/s
		VE_{max}	9.39 m/s	15.87 m/s
	Mehalmeda	Power density	276.17W/m2	219.54W/m2
		Energy density	2420906.22wh/y	1924487.64 Wh/y
		VF_{max}	4.81 m/s	5.99 m/s
		VE_{max}	9.83 m/s	11.98 m/s

4.5 Site suitability analysis

Besides, the wind resource itself, there are a number of environmental and economic criteria that limit the suitable areas for wind energy development. These criteria are classifying numerous ways in the literature, but this thesis will focus on two basic categories were approached simple and dynamic criteria:

Simple criteria are to exclude unsuitable sites based on basic physical, administrative, and geographical constraints like distances of National Parks, National Forests, National Monuments, state and local parks, wetlands, water bodies, military installations, populated places, airports, and areas considered critical habitat for wildlife or vegetation were exclude.[59]

Table 8: simple criteria for suitability determination[59]

Factor	Criteria	Constraint
Economic, safety	Populated place	restricted
Environmental	Wetland	restricted
Environmental	Water bodies	restricted
Environmental	Critical habitat	restricted
Administrative public use	National park and forest	restricted
Infrastructure safety	Airport	restricted
Infrastructure safety	Military	restricted

Site selection criteria that have a fluctuating geographical dependence on some aspect of the input features. Each of the above criteria may have thresholds for exclusion, but they also have a graduated range of suitable values based on spatially dependent relationships with the features used to represent them that defines their level of suitability [59].

Dynamic criteria are also to identify a suitable area for a large scale wind energy development by scores are calculated based on assigned grading values given to the range of suitable value that graded the input values or value ranges on a scale to determine not suitable or optimal. Criteria and model constraints are shown in the table below.

Table 9:dynamic Criteria and model constraints[59]

Factor	Criteria
Physical, wind resource	Wind power class
Physical	slope
Environmental, economic	Land use
infrastructure, economic	distance to grid
infrastructure, economic	distance to the road network

By using the common practice in potential modeling of wind energy, the multi-criteria decision study was choosing for forming with data alteration and reclassification. All of the nominated criteria have transformed into the raster data construction with a resolution of 200 m and then reclassified into ordinal suitability scores of 0–4. With 4 being the most suitable and 0 unsuitable. The score rating system was established based on an appraisal of associated published studies[60].it helps to eliminate redundancy, save time easy to evaluate by reclassification scale.

Table 10: suitable wind map modeling standard criteria [60]

	suitability score				
criteria	high 4	medium 3	low 2	lowest 1	unsuitable
WSC. m/s at 10m	6 - 6.4	5.6 -6	5.1 -5.6	4.4 -5.1	<4.4
land use	agriculture/barren	grassland	shrub land	forest land	water body
distance to road	0 - 1000	1000-2500	2500-5000	5000-10000	>10000
distance to grid	0 - 5000	5000-10000	10000-15000	15000-20000	>20000
Slope in degree	0-7	7-16	16-30	30-40	>40

According to this suitability, the standard can grade the input value or value range. Hence, one of these input value, wind speed getting from meteorology office including with surrounding of study area then interpolate it and generate wind speed map. The other important parameter of this study are Land use and slop classification data from Ethiopian geospatial instate. The remaining input data are road network and electric grid line data from zone administrative office specifically transportation and Ethiopia electric power corporation branch office.

Then after, by using those input data and GIS tools to generate the initial parameter map. This map is included in the Appendix. Reclassified by using table 11 criteria standards.

5.4.1Reclassified available wind speed

The basic term for wind farm suitability analysis is the availability of wind speed, which, is the most important geographical dependent criteria. The data should organize into class-based mean annual value. The greatest weight for all other criteria with regard to this site map shown the magnitude of the existing wind speed as follows.

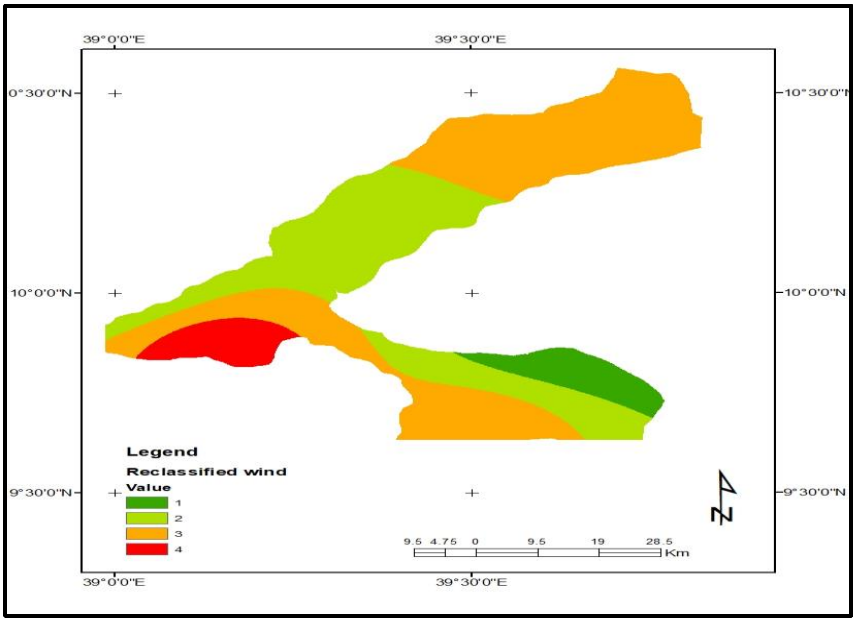


Figure 21: Suitability according to availability of wind speed

4.5.2 Reclassified Land Use

Land use is one of the influential factors for this site suitability analysis. It is difficult to purely determine for the area of nothing for the local population and wind. However, this researcher should follow some technical classifications such as farmland, grassland, and bushland, forestland and water body of the study area. Based on these classifications can be understood for equal or important for other criteria. Those criterions were representing the environmental impact of the wind farm.

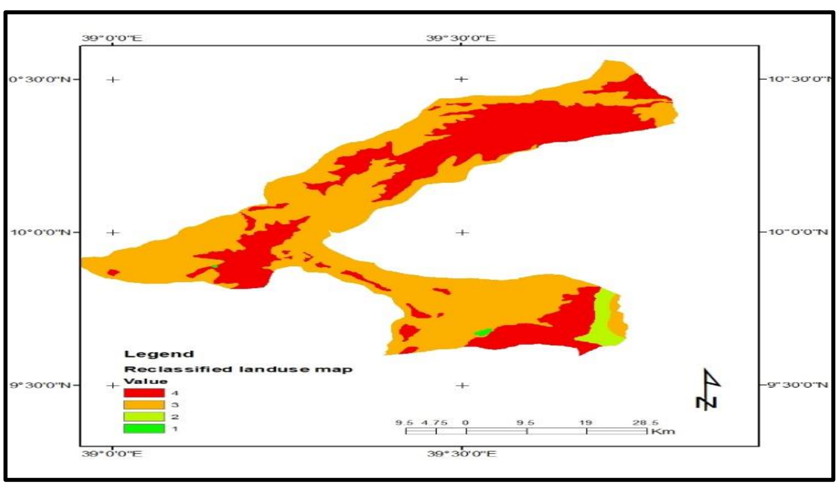


Figure 22: Reclassified Land use map showing land use type suitability for wind farm

4.5.3 Distance to Roads

The study area is suitable to implement wind turbine should be considered the more appropriate distance from roads because the candidate site is far from the suitable range of road distance difficult to transport wind turbine and gadgets so it must be keeping the moderately suitable range of road distance.

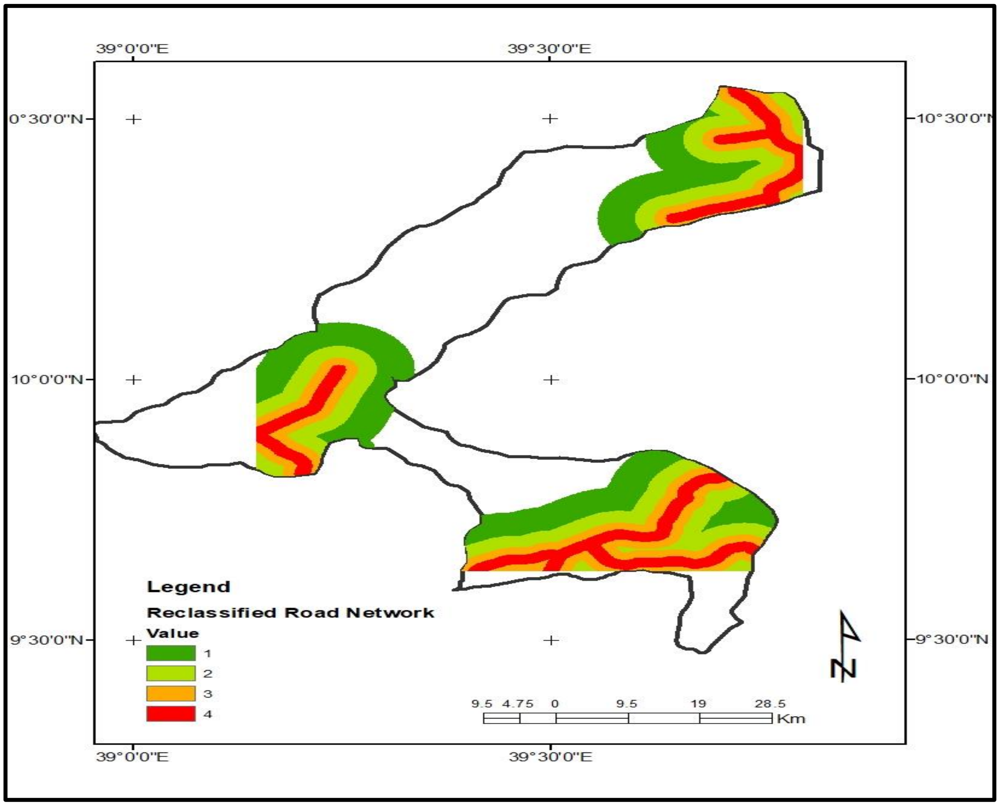


Figure 23: Suitability according to distance from roads

4.5.4 Distance to Gridlines

Any other very important factors of selecting suitable wind site electric gridline which has significant roles for the cost of wind installation in case of minimizing constriction and transmission cost by the matter of over long distance away from new contraction sites.

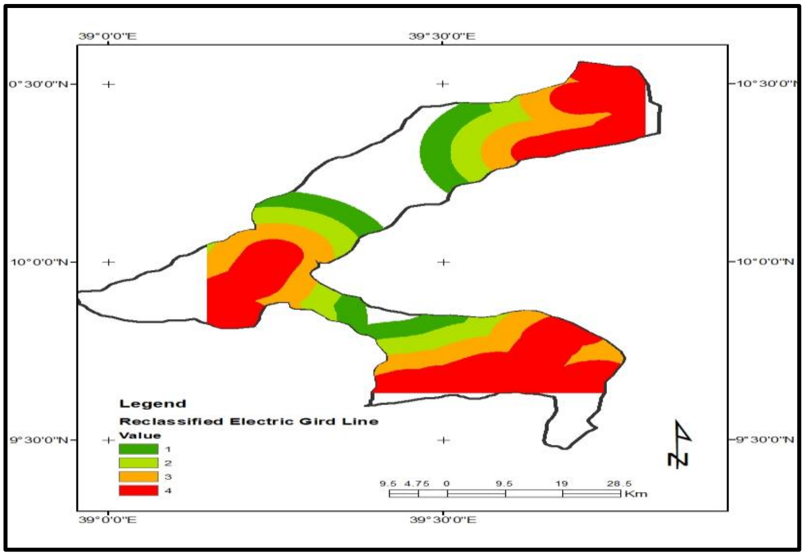


Figure 24: Suitability classification according to distance to power gridlines

4.5.5 Slope Reclassified

The last but not the list the suitability parameter is slope, which is reclassified suitable and unsuitable ranges based on different works of literature. All slopes above 40 degrees classified strictly unsuitable for the new construction site. It has a significant impact on wind variation and speed and it makes it too difficult to initiate the foundation of new wind power plant constriction.

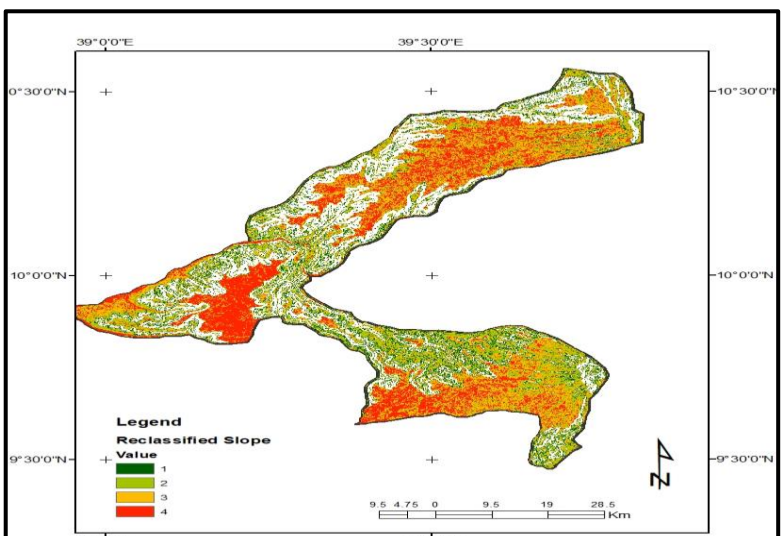


Figure 25: Suitability classification according to topographic slop

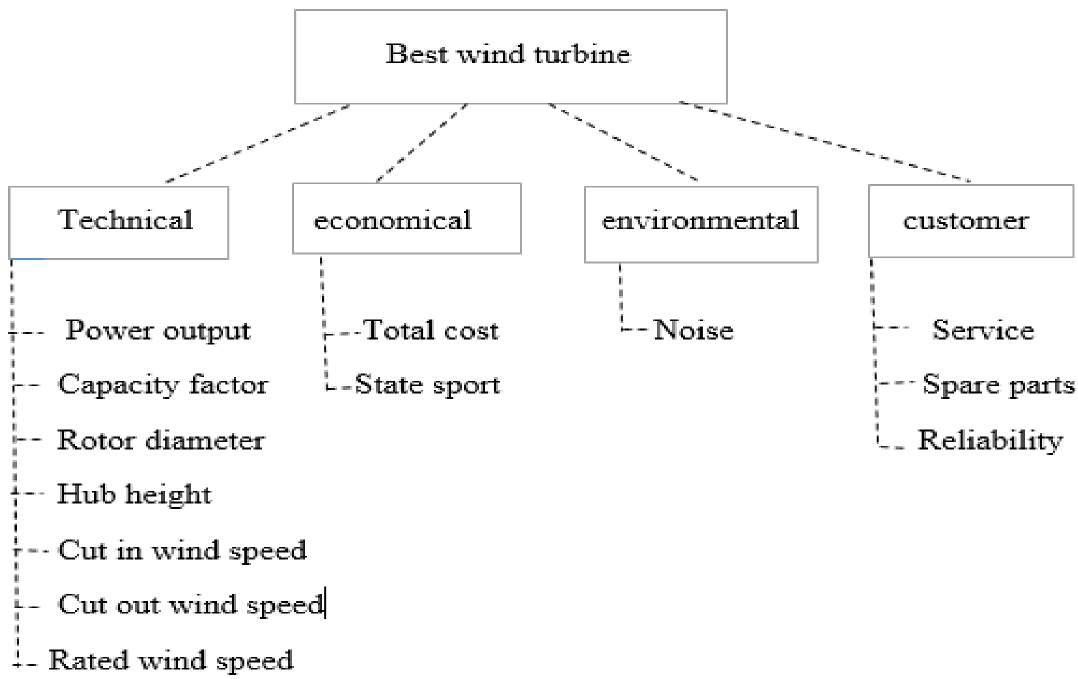
CHAPTER FIVE

SELECTION AND PERFORMANCE EVALUATION OF WIND TURBINE

5.1 Selection of Wind Turbine from International Standards

Effective and current wind farm enlargement depends on various important factors take into account such as, the selection of a potential windy site for the wind farm development, selection of efficient wind turbines that would result in maximum power generation and wind farm layout design [61]. Since the focus of this portion is on wind turbine selection by substantial attention has been given in the latest years to the use of computational intelligence (CI) methods for studying for these problems with a more systematic and competent way can either be treated as single-criteria or multi-criteria [61]. Hence, Site-specific turbine selection approach while considering maximum capacity factor, annual electrical power output of the wind turbine as well as the normalized performance of a wind turbine installed in a given site can be examined by the amount of mean power output over a period of time and the conversion efficiency of wind turbine with optimum energy cost [29]. Therefore, more criteria are needed to appropriately consider the effect of difference in rated energy output of different turbines, these criteria include hub height, wind speed, mean net energy output, rotor diameter, cut-in wind speed, and rated wind-speed were considered which was modeled as function of expected annual energy output[62].

This paper presents a multi-criteria decision-making method based on select relatively well turbines among many alternatives. Selected wind turbines evaluated through effective properties on diverse wind turbine brands with a rated output of 2 MW and 1.5 MW with respect to site wind class and the specialists in wind energy stations referred to express their professional opinion. While extents for some criteria are willingly existing, some others like client satisfaction can only be predictable with respect to other variables [63]. The subsequent priorities of technical, economic, environmental, and customer-related factors shown in the following chart.



After determining the priorities of each criterion with respect to the overall goal of selecting the best wind turbine and priorities. Wind turbines with low cut-in and rated wind speeds are required for higher wind energy productions and are more at low windy sites. Hence, it has its own suitable hub height range, suitable wind speed range, and most importantly, mean net energy output depend on available wind resources. Annual average wind speed for three study sites are 7.38m/s,9.17m/s and 8.03 m/s in Debrebrehan, Enewari and Mehalmeda respectively at 70-meter height as the purpose of commercial wind energy generation. Allowing to the Department of National Renewable Energy Laboratory defines the wind turbine class at a site based on average wind speed and power density to offer guidance to potential developers as to where wind projects might be feasible. Therefore, it has tried to follow the IEC standard for selecting the proposed wind farm appropriate wind turbine types [63].

There for the first site Debrebrehan which has a relatively low annual mean wind speed. With regard to this considerable site wind speed value relatively better and low-performance compromise. IECII wind turbines type was selecting with rated power is 1.5 MW. At the same time the remaining two sites, which are Enewari and Mehalmeda have medium annual mean wind speed as well as the same wind class are obtained. After all the detail understanding of site wind characteristics should be selected frequently used wind turbine of 2 MW rated power from a different manufacturer with make little bit compromise select one wind turbine on both wind sites. This wind turbine capacity selection criterion based on available wind speed class checking by standards from table 3.5. Besides the selected wind turbine, keep additional some important consideration as if fixed rotor speed based on the trained of our country grid interaction complexity challenges. In addition, any other parameter listed above were the environmental and customer side should be considered by checking the company background, market information and hosting company expansion rate and training.

Generally, some other positive contribution of wind turbine selection additional to technical criteria must be considered like diplomatic relation and market trained of wind turbine manufacture country and project site country of Ethiopia have a well-known relationship and also manufacturing commitment and company background as well as commissioning trained history information taken to account.

Based on those parameters relatively suitable type of wind turbines as follows.

Table 11: model name of the selected wind turbine from technical specification

Code	1.5 MW wind turbine	2 MW wind turbine
WT1	Goldwind G87/1500	Enercon E82:2E2-2000Kw
WT2	General electric GE-1.5sI	Games: G87
WT3	Anderson E-76	Vestas: V80-2.00
WT4	Suzlon S.82-1500	Vestas: V90-2.00
WT5	Acciona AW-82/1500	Repower: MM92
WT6	Vestas V82-1.5	Sunny: SE8220III

From those 12-candidate wind turbine compare again by using specific parameter and selected more suitable turbine for power generation per specific site. Annual energy production (AEP) model calculates the total energy generated by a specific wind turbine in specific wind sites per year, at its performance region one from V_{in} to V_r and region two from V_r to V_{out} of the power curve.

$$E_{AEP=} \int_{V_{in}}^{V_r} Pm \left(\frac{K}{C}\right)\left(\frac{V}{C}\right)^{K-1} \text{e}-\left(\frac{V}{C}\right)^{K} \text{DV} + \int_{V}^{V_{OUT}} \left(Pm \left(\frac{K}{C}\right)\left(\frac{V}{C}\right)^{K-1} \text{e}-\left(\frac{V}{C}\right)^{K}\right) \text{DV} \quad \ldots\ldots\ldots\ldots\ldots (5.1)$$

$$Pm = 0.5 * cp * A * V^3$$

V_{in} = Cut-in wind speed, m/s

V_{out}=Cut-out wind speed, m/s

V_r = Rated wind speed, m/s

5.2 Capacity facto

Capacity factor defined as the ratio of the actual energy produced by the system to the energy that could have produced by it by applied Equ.3.30

$$C_F = \frac{P_{Mwh}}{(8760\ hour)/year*ratedpower} \ldots\ldots (5.2)$$

By using this calculation value and selected wind, turbine technical specification value could be evaluated the best one was selected among the other.

Table 12:1.5 MW wind turbine priority criteria on Debrebrehan site

parameter	Wind turbine					
	WT 1	WT	WT 3	WT 4	WT 5	WT 6
Annual output kwh	4225000	3521100	3314200	4221100	4314200	4225000
Capacity factor (%)	32.15	26.8	25.2	32.1	32.83	32.15
Rotor diameter	87	79	76	82	82	82
Hub height	85	80	86	78.5	76.9	94
Cut-in wind speed	3	4	4	4	3	3
Cutout wind speed	22	25	25	22	20	25
Rated wind speed	9.9	12	12.5	12	10.5	13

Table 13:2 MW wind turbine priority criteria on Enewari site

parameter	Wind turbine					
	WT 1	WT	WT 3	WT 4	WT 5	WT 6
Annual output kwh	7285054	5961180	5314800	4521400	4714810	7285210
Capacity factor (%)	41.6.	34	30.33	25.8	26.9	41.6
Rotor diameter	82	82	80	90	92	82
Hub height	90	78	80	80	100	70
Cut-in wind speed	2	3.5	4	3.5	3	3.5
Cutout wind speed	34	25	25	25	25	25
Rated wind speed	12	13.5	15	14	11	12

Table 14:2 MW wind turbine priority criteria on the Mehalmeda site.

parameter	Wind turbine					
	WT 1	WT	WT 3	WT 4	WT 5	WT 6
Annual output kwh	6243205	4961530	4814700	4021208	4314213	6243215
Capacity factor (%)	35.5	28.3	27.4	22.9	24.6	35.6
Rotor diameter	82	82	80	90	92	82
Hub height	90	78	80	80	100	70
Cut-in wind speed	2	3.5	4	3.5	3	2
Cutout wind speed	34	25	25	25	25	34
Rated wind speed	12	13.5	15	14	11	12

5.3 Making the decision

Based on the calculations above, the relative priorities corresponding to the attractiveness of each wind turbine about all factors of technical, economic, environmental and customer satisfaction are presented in Table above. The obtained results indicate that the model WT5 is the alternative that contributes the most to the goal of choosing the best wind turbine that satisfies all the criteria selected in Debrebrehan site and WT6 is relatively better wind turbine for specific location of Enewari and Mehalmeda.
The first selection wind turbine is WT5 only in the first site at 70 meter is Acciona AW-82/1500, which made by Acciona Company located in Spanish considered as one of the global technological leaders in the wind industry, operating in 42 different countries in the world. It operates also in the wind turbine's process, maintenance services and production centers and the main wind market activity strongly takes place in Spain and USA. In addition to that main centers of maintenance, consultant and following offices were opining in numerous country specially in south Africa and India have multi-disciplinary office [64].

According to multi criteria dissension method, the second choice turbine is WT6 in the table code and in the manufacturer code, sunny: se8220III 2MW at 70meters, which made by Sunny company, located in china operating for more than 60 years. It has a great contribution for electrification value chain from power generation by efficient application. Sunny operates in 300 major production and sales offices throughout the world wide over [64].

5.4 Performance analysis of selected wind turbine rotor

The sub portion of this chapter, focused on significantly analyzed for aerodynamics challenges of site-specific selection of wind turbine rotor, which are determined the effect of non-typical environment on the forecast efficiency and operation of the turbine. These often deliberate to be its most essential components from both performance and inclusive cost outlook. Hence, significantly should be understood in the way of theoretical, mathematical and analytical concerns [65]. Depending on the size and shape of the blades and the airfoil characteristics of the wind turbine defines the aerodynamic performance. Which, directly related to power coefficient of a wind turbine. The optimal distributions of the chord length and the pitch angle in each section of turbine blade having the method of blade element momentum theory [65]. When the ideal design of wind turbine blade initially can take the ratio of Cd/Cl is equal to zero, not considering tip-hub loss and drag effect, i.e. F is equal to 1 with the partial derivative of the main part being zero, the optimum twist angle is obtained [66]. By using BEM, the chord and twist angle can calculate based on the following equation.

$$\varphi_{,i} = \frac{2}{3}\tan^{-1}\left(\frac{1}{\lambda_{r,i}}\right) \text{ .... } (5.3)$$

Assume, the drag coefficient Cd is zero, the tip and hub lose coefficient one, tangential induction is zero, lift coefficient Cl = $2\pi\alpha$ and finally $\alpha = \varphi - \beta$, when β =pitch angle from blade geometry information

$$ci = \frac{8\pi ri}{BCl} sin^2\left(1 - cos\varphi_{,i}\right) \text{ .... } (5.4)$$

Blade element momentum theory (BEM) refers to the determination of a wind turbine blade performance by combining the equations of general momentum theory and blade element theory independently [65]. This method is the accepted practice through multiple iterations aerodynamic parameters are calculated. The wind turbine performance analysis by BEM, the prediction of induction factor, axial induction factor, angel of relative wind, predntl correction factor F and power coefficient each blade element separately [65]. The relative angle of wind,φ to plane of blade rotation, determined by the following equation

$$tan\varphi = \frac{U_1(1-a)}{\Omega r(1+a')} = \frac{(1-a)}{(1+a')\lambda_r} \text{ .... } (5.5)$$

Hence, $\lambda r = \frac{\Omega r}{U} = \frac{\lambda X r}{U}$ ……………………………………………………………….. (5.6)

λ is the tip speed ratio often occurring in the aerodynamic equations for the rotor and λr , also the local tip speed ratio is the ratio of the rotor speed at some intermediate radius r ,to the site wind speed value u.

Since the pressure on the suction side of a blade is lower than that on the pressure side, air tends to leak around the tip from the lower to upper surface, reducing the lift and hence power Production near tip. The most acceptable and common tip loss model is developed by Prandtl by equation of correction factor F [67]. The final equation of the Prandtl tip loss factor and hub loss factor can calculated as follows. F =f (B, R, φ)

$$F_{tip} = \frac{2}{\pi} cos^{-1}[\exp(-\frac{B}{2}\frac{(\mathrm{R-r})}{\mathrm{r}\sin\boldsymbol{\varphi}})] \quad \text{……………………………………………………..(5.7)}$$

$$F_{hub} = \frac{2}{\pi} cos^{-1}[\exp(-\frac{B}{2}\frac{(\mathrm{r-R_{hub}})}{\mathrm{r}\sin\boldsymbol{\varphi}})] \quad \text{……………………………………………….(5.8)}$$

The combination of tip loss and hub loss factor is giving by

$F = F_{tip}.F_{hub}$

Determine the thrust coefficient using the following.

$$C_T = \frac{\sigma(1-\mathrm{a})^2\,(Cl\,cos\varphi + Cd\,sin\,\varphi)}{sin^2\varphi} \quad \text{…………………………………………………(5.9)}$$

By Appling, common method of Iteration technique to find the axial and tangential induction factors require initial guesses for their value with corresponding adjacent blade section. Start the iterative solution procedure for the number of iteration. For the first iteration Calculate the angle of the relative wind and the tip loss factor by equation next

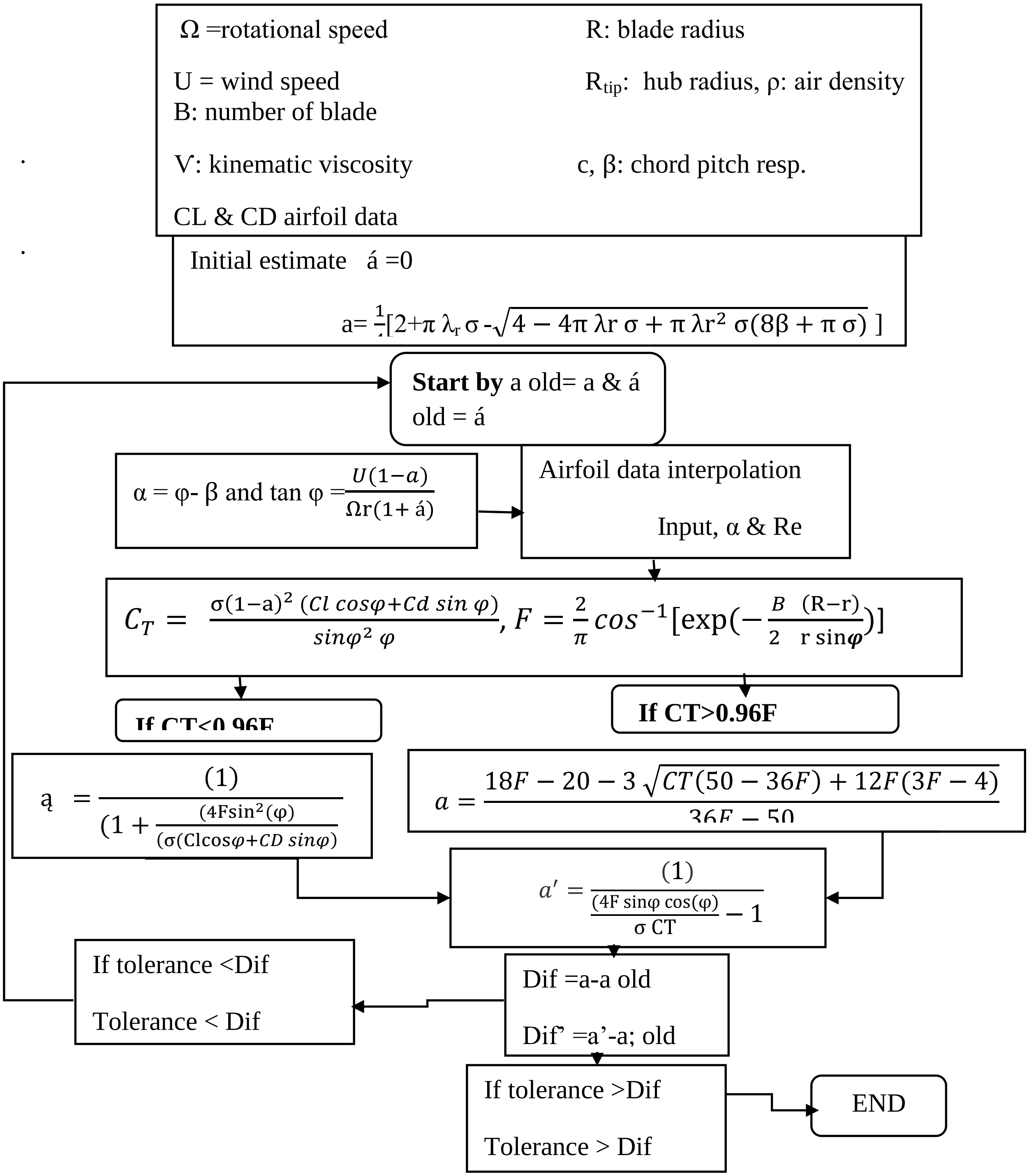
Now, if $C_T < 0.96F$ the element is highly loaded so update axial and tangential induction factor for the next iteration.

$$ą = \frac{(1)}{(1+\frac{(4\mathrm{F}\sin^2(\varphi)}{(\sigma(\mathrm{Cl}\cos\varphi + CD\,sin\varphi)}}, \quad \text{If } C_T < 0.96F \quad \text{…………………………………….(5.10)}$$

$$a = \frac{18F - 20 - 3\sqrt{CT(50-36F) + 12F(3F-4)}}{36F - 50} \quad \text{, If } C_T > 0.96F \quad \text{…………………………….(5.11)}$$

The axial induction factor can be calculating by eq. 5.10 or 5.11

Since, more appropriate solution method of this approach is iterative solutions, which most easily extended for flow condition and large axial induction factor. New induction factor calculate specifically by the following requirements.



Once a has been obtained from each section, the overall rotor power coefficient and thrust coefficient can be calculated by using the expression for the elemental power from the following final formula.

$$C_{pmax} = \frac{8}{\lambda N}\sum_{n=1}^{N} Fi\,sin^{2}\boldsymbol{\varphi i}\,((\cos\boldsymbol{\varphi i} - \lambda_{r}i\,\sin\boldsymbol{\varphi})(\boldsymbol{sin\varphi i} + \lambda_{ri}\boldsymbol{cos\varphi i}))[1 - (Cd/Cl)\cot\boldsymbol{\varphi i}]\lambda_{r}^{2}$$

5.5 Airfoil selection and analysis of the desired rotor blade

Based on the above wind turbine selection method to offer two relatively better and low performance compromise horizontal axis wind turbines type were selected with better considerable site wind characteristics those wind turbines are a modern wind machine, the preferred configuration is to place the rotor consisting of the rotor blade and the hub upwind of the nacelle and tower. Since the power contained in moving air stream is proportional to the square of the rotor diameter and to the cube of the wind speed the rotor blade should be check carefully designed in order to optimal extract this power and convert it into torque that derive the electrical generator [54].

This HAWT rotor consists of three blades; it divided into discrete number of sections along its span. In this portion should be focused on selection of suitable airfoils depends on the aerodynamic behavior and operating conditions. According to manufacturer technical specification, NACA63xxx airfoil family as per blade size and wind characteristics to be recommended options. Hence, the choice relatively better airfoil along the blade can determine the performance of the rotor under a variety of flow conditions [54]. According to different literatures and scholar’s investigation result to be, make confidentially having two airfoils type chosen.

Case I: here selecting the most common and recommend by selecting wind turbine company type of aero foil, National Advisory Committee for Aeronautics NACA$63_4$421 as the basic group for exploration because the power curve is enhanced specifically low and medium wind speed ranges, but progressively drops under operation at higher wind speeds [67]. However, the airfoil has high pitching moment, poor stall characteristics; it has been shown that these airfoils have noticeable performance degradation from roughness effects resulting from leading-edge contamination [68].

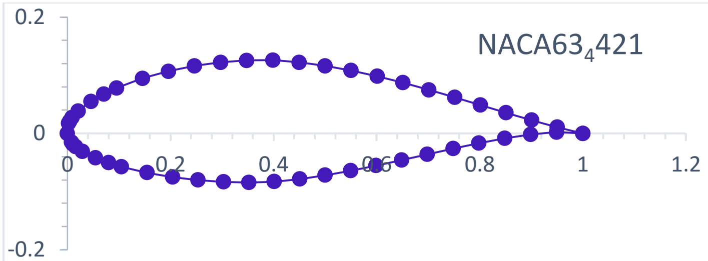


Figure 26:NACA634421 airfoil type 2D model

Case II: However, NREL S- series airfoils, national renewable Energy laboratory (NREL), which was developed by USA as s-series type of aero foil families are being successfully used for commercial wind turbine application [67]. These types of airfoils provide significant increases total energy production by 15% because of less sensitivity to roughness effects, better lift-to-drag ratios[69]. The appropriate blade rotor diameter and types for each airfoil family along with the corresponding airfoils consisting each family from blade root to tip suitable one. Then from these airfoil family s818 was relatively good with regard to blade length and site aerodynamic profile.

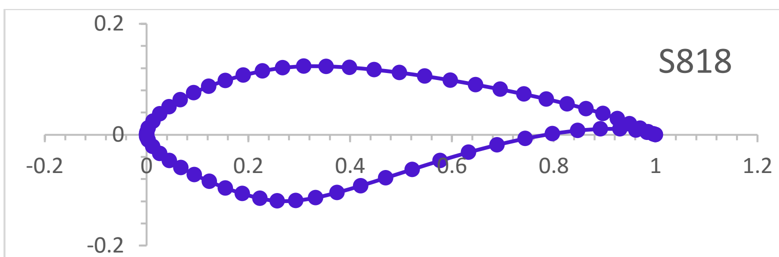


Figure 27:S818 airfoil type 2D model

Based on horizontal axis wind turbine application better airfoil type from both cases can be decided after some basic aerodynamics analysis have done. From aerodynamics force point of view, the net force acting on airfoil classification into two significant components such as lift force and drag force besides one moment that act upon an airfoil. Lift is the force used to overcome the gravity and defined to be perpendicular to the direction of the incoming airflow. The drag force is due to both viscous friction forces at the surface of the airfoil and unequal pressure on the airfoil surfaces facing toward and away from the oncoming flow for an airfoil [70]. Illustrated as follows.

Lift = $l = \quad cl\frac{1}{2}\rho U^2 c$ ………………………………………………… (5.12)

Drag = $d = \quad cd\frac{1}{2}\rho U^2$c……………………………………………………(5.13)

Moment = $m = \quad cm\frac{1}{2}\rho U^2$cr…………………………………………………….(5.14)

In this equation, Cl is airfoil lift coefficient, Cd is airfoil drag coefficient, Cm is airfoil moment coefficient, and c is the chord length.

Most of the incoming air over the airfoil is not the same by different factors, which are velocity, ambient temperature, atmospheric pressure and air viscosity. In case of those factors, force and moment over an airfoil are different. Consequently, most of these effects represented by non-dimensional number of Ronaldo's number which the ratio of inertia force is over viscose force.

$Re = \frac{\rho UL}{\mu}, \frac{\text{inertia force}}{\text{viscose force}}$ …………………………………………………………………….(5.15)

In this formulation, U and L are velocity, reference length, ρ is fluid density, and μ is dynamic viscosity. Reynolds number represents character of the flow and it has direct effects on the force coefficients

Site-specific air density should be calculated depends on site temperature and pressure (thus altitude) if the site pressure known, the hourly air density values with respect to air temperature can be calculate from the following equation.

$\rho = \frac{P}{RT} EXP^{\frac{-gz}{RT}}$ Kg/m ……………………………………………………………(5.16)

However, the site-specific Temperature value known air density can be calculating as follows.

$\rho = \frac{353.05}{T} EXP^{\frac{-0.034z}{T}}$ ……………………………………………………………..(5.17)

P = standard sea level atmospheric pressure (101,325 Pa)

g= gravitational constant (9.8 m/s^2); and

z = site elevation above sea level (m).

T= site ambient temperature

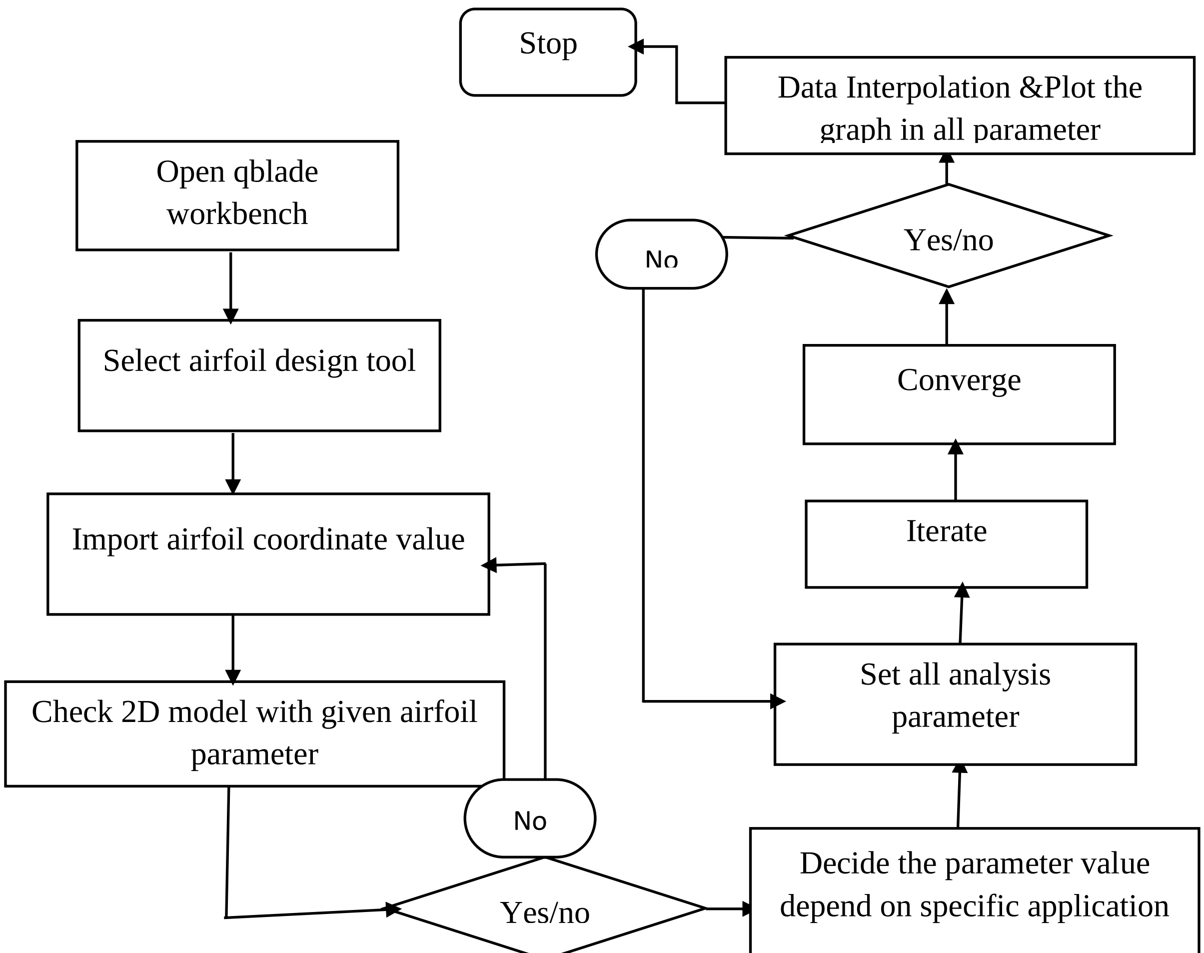
Substituting in the numerical values for Po, R, and g, we get

The other dimensionless coefficients that are important to know is the pressure distribution around an airfoil surface for the purpose of determining the aerodynamic forces is the pressure coefficient which is expressed as [mil].

$$CP = \frac{static\ pressure}{dynamic\ pressure}, \frac{p-p\infty}{p\infty} \quad \text{……………………………………………………………..(5.18)}$$

Where; p the static pressure on the airfoil surface and $p\infty$ is the free stream pressure

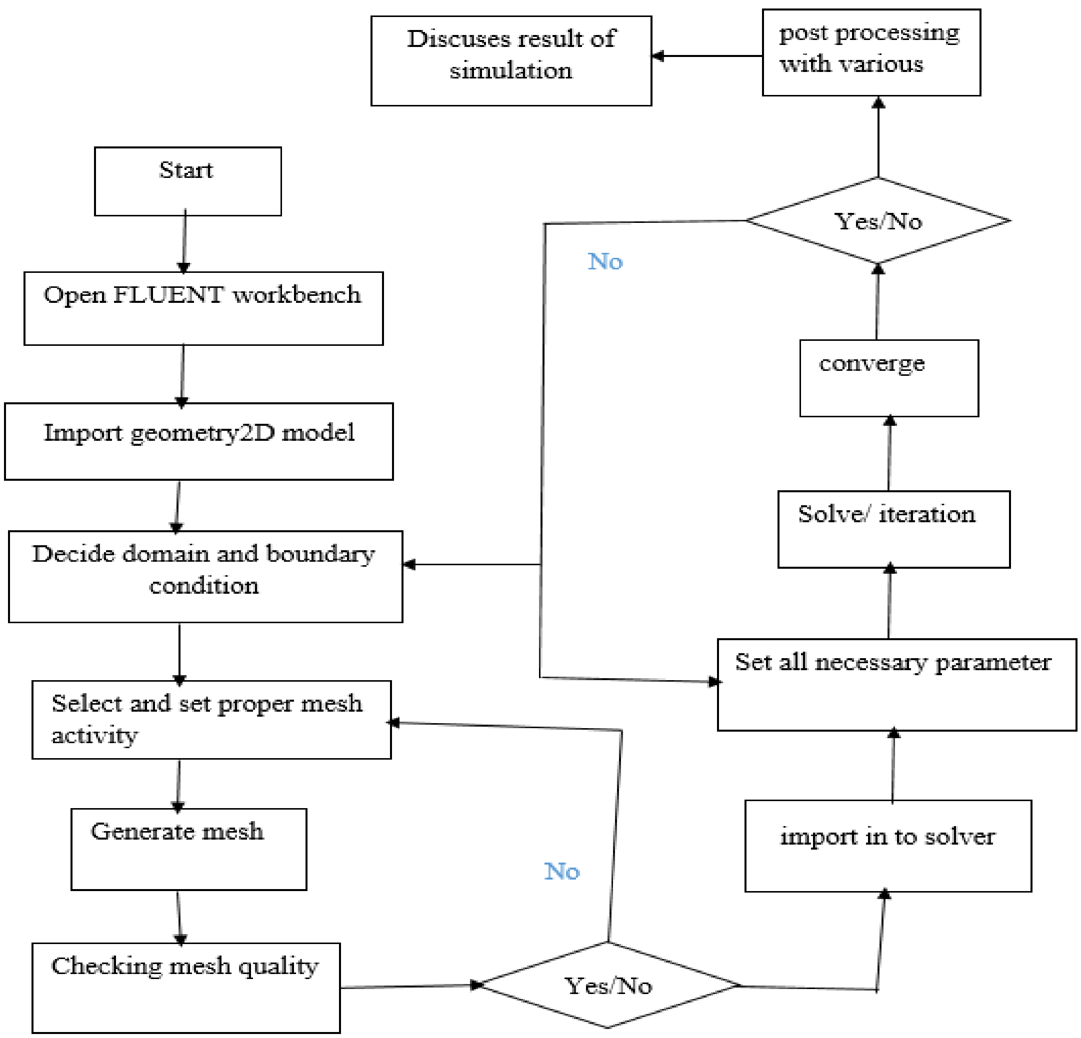
Different lift and drag coefficient value leads to different power output result. It stated that lift and drag ratio should maximize to improve the capability of given wind turbine generate electricity. As the result, optimum lift to drag ratio with angle of attack can make it. To compare and contrast which one is relatively good airfoil from case I and case II airfoil family after to computing the result of life and drag coefficient verses AOA with the desire value of Ronald's number by Qblade foil analysis on the following steps and parameters.



Having the lift and drag coefficients output to the display window, the values are interpolating and plot with the corresponding angles of attack using MS excel.

5.5 Aerodynamic analysis of wind turbine blade airfoil by CFD

The present study utilized computational fluid dynamics (CFD) simulations to analyze the flow field around the analysis of the 2D airfoil model of S818 have done using ANSYS FLUENT 15.0, standard commercial software. The analysis used a computational finite volume method to analyze the 2D airfoil. ANSYS CFD meshing tool, used to generate 2D mesh in the computational domain. By using CFD to reproduce airfoil characteristics, depend on different practice way of literature and recent guidance to illustrate by the following road map.



5.6 Fluent Analysis Parameters

For this specific study of airfoil performance, analysis approach justified by the software stated above, this is open source CFD software fluent. The solver of this software is used to determine the simulation result is accepted or not with in the setting boundary conditions. After specifying the physical models and boundary conditions, the calculation starts from arbitrary initial conditions and converges to the correct solution after performing a number of iterations. For different angle of attacks and different velocity, components are set as velocity inlets, lift and drag coefficients are monitoring. All the parameters for used to this aerodynamic simulation tools as follows.

Table 15: CFD parameter of two-dimensional simulation

Parameter	value
Airfoil profile	s818
Fluid material	Air
Flow type	incompressible flow
Temperature	297k
Kinematic viscosity	1.789x10^-5
Density	1.225kg/m3
Reynolds number	4*10^6
Fluent version	Fluent 15.0
Simulation type	steady simulation
Turbulence model	sst kw module
Formulation	Implicit
Pressure	101325pa
Velocity	30m/s
Boundary Condition	velocity inlet, pressure outlet, stationary wall with no slip condition
Interpolation method	pressure(standard), modified turbulent viscosity (second order up wind ,momentum ((second order up wind)
Initialization	inlet value
Force monitor	lift and drag coefficient
Reference value	inlet value
CFD algorithm	SIMPLEC

The simulation, Therefore, run with an inlet velocity of 30 m/s over a range of different angles of attack. The x and y components of the velocity are controlled by modifying the angle of attack appropriately. $V_x = V\cos\alpha$, $Vy = V\sin\alpha$

CHAPTER SIX

RESULT AND DISCUSSION

In this chapter, a Discussion about the analysis result of wind speed data, wind energy potential, suitable wind farm location and the findings of selected wind turbine performance at three selected sites in Ethiopia has investigated in the earlier sections. As the previous portion have been including mean wind speed value, Weibull parameter and wind direction presented by polar diagram to estimate the dominant wind direction, the selected sites suitability map developed by implementing geography information system (GIS) software as an impute of geodatabase information and also, mean power density were determined in each consecutive sites. Farther more, the generated simulation results of wind turbine blade airfoil lift and drag coefficient by Qblade and effects of wind stream velocity and pressure difference below and above airfoil with the optimum angle of attack were concerned. The detail discussion and results of the investigation will be offered in the following sections.

6.1 Result of wind speed characterization

Based on wind speed analysis result in chapter four, to determine the wind speed behavior on the sites under different classifications. Starting from hourly up to monthly average wind speed value converts systematically. At the same time, at 10 m data converts to other desire height by using extrapolating techniques. To well understanding and point visibility, the result of average monthly wind speed value has taken in all study areas and deferent height. Illustrates in table 17.

.

Table 16: monthly average wind speed value in all respective sites

Station	Hub Height	Monthly average wind speed											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Debre brehan	10m	3.91	4.43	4.3	3.91	3.92	3.7	3.1	2.84	3.05	3.61	3.6	4.48
	30m	5.44	6.16	6	5.44	5.45	5.1	4.2	3.95	4.25	5.03	5.0	6.23
	50m	6.87	7.79	7.6	6.88	6.88	6.4	5.4	4.98	5.36	6.35	6.4	7.87
	70m	7.73	8.76	8.5	7.74	7.74	7.2	6.0	5.61	6.04	7.14	7.1	8.85
Enewari.	10m	5.84	5.94	6.11	5.96	3.97	3.28	4.0	4.69	5.57	5.46	5.07	5.12
	30m	8.12	8.26	8.5	8.29	5.51	4.6	5.6	6.52	7.75	7.59	7.1	7.11
	50m	9.47	9.6	9.9	9.7	6.43	5.3	6.6	7.6	9.0	8.9	8.2	8.29
	70m	10.5	10.7	11	10.7	7.11	5.9	7.3	8.41	9.99	9.79	9.1	9.17
Mehal meda	10m	4.26	4.28	4.4	4.97	4.68	4.0	3.6	4.23	5.13	5.18	4.8	4.17
	30m	5.93	5.96	6.2	6.92	6.51	5.6	5.0	5.89	7.13	7.20	6.6	5.79
	50m	6.91	6.94	7.2	8.06	7.59	6.5	5.8	6.86	8.31	8.39	7.7	6.75
	70m	7.64	7.68	7.9	8.92	8.39	7.2	6.5	7.59	9.19	9.28	8.5	7.47

For Debrebrehan, the monthly mean wind speeds that vary between 3.1 and 4.48 m/s at 10m at the same time 6m and 8.85 m/s at 70m height this maximum wind speed available in December and minimum wind speeds also on July respectively. Similarly, on the Enewari site the monthly mean wind speed variations find out in meteorology data that maximum and minimum wind speeds occurred on March 6.11m/s and July3.3 m/s at 10m and at 70m 5.9m/s and 11 m/s respectively. At the last study area of Mehalmeda, the maximum wind speed 5.18 and 9.28 at m/s occurred in October and minimum wind speed fluctuates between 3.6 and 6.5 occurred in July at 10 m and 70 m respectively.

Considering the fact that rotors of the actual wind turbines are placing at height of more than 10 m. in order to choose the suitable height of the wind turbines, it is necessary to know the variations of wind speed with altitude. Extrapolating wind speed data collected at anemometric height to the required height is the first step to use these data in calculating and assessing wind energy within the designated location in the site. Thereby, the data collected at the measured 10-

meter height then extrapolated to 30m, 50m and 70-meter height for monthly average wind speed. Those wind speed variations are shown in the following figure with respect to 10-meter wind speed variation

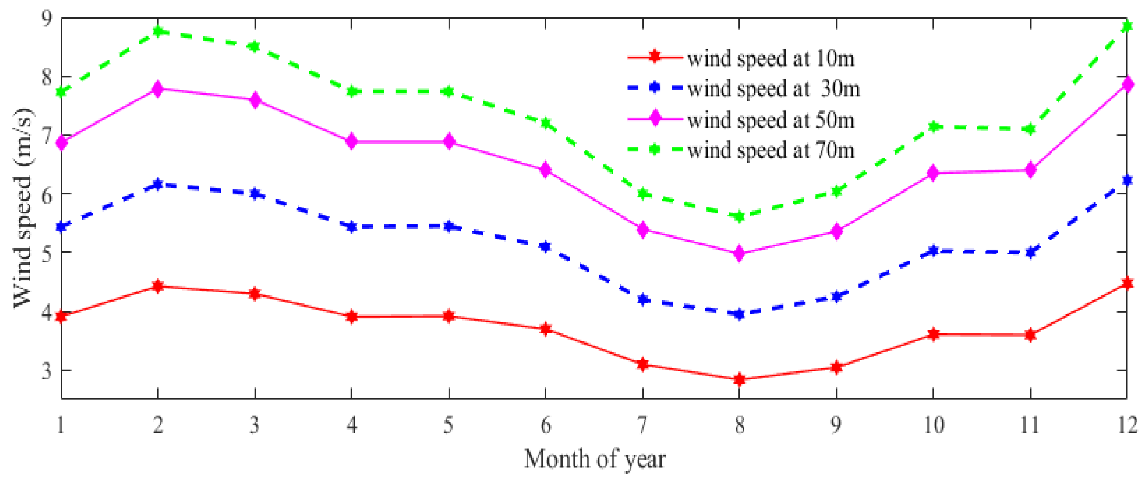
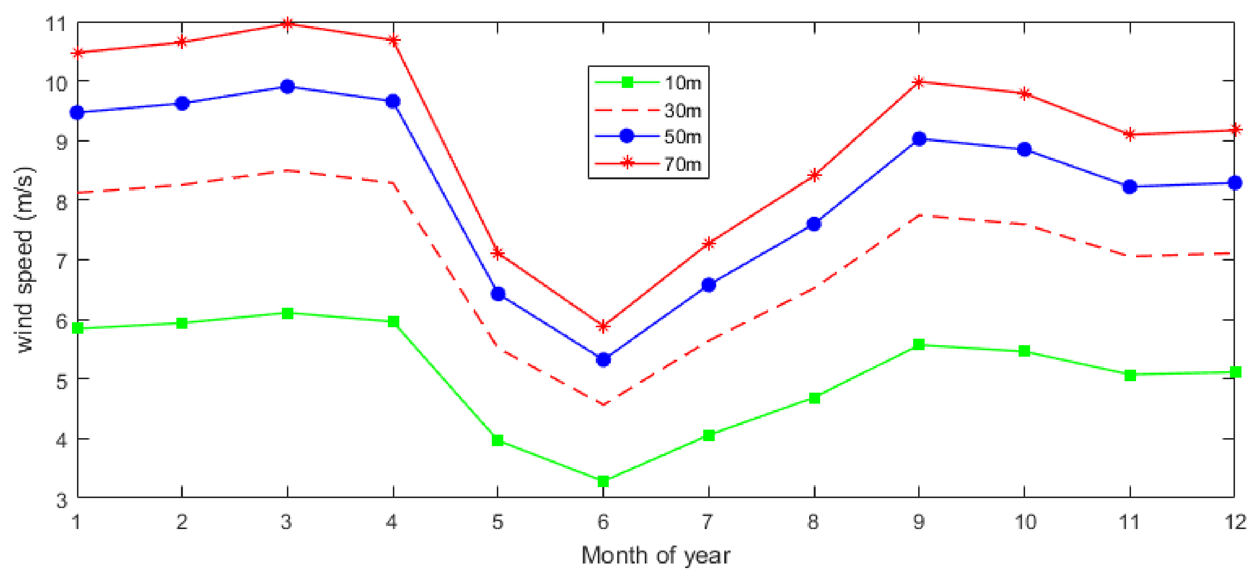


Figure 28: Monthly average wind speed variation at different height in Debrebrehan



: Figure 29:Monthly average wind speed variation at different height in Enewari

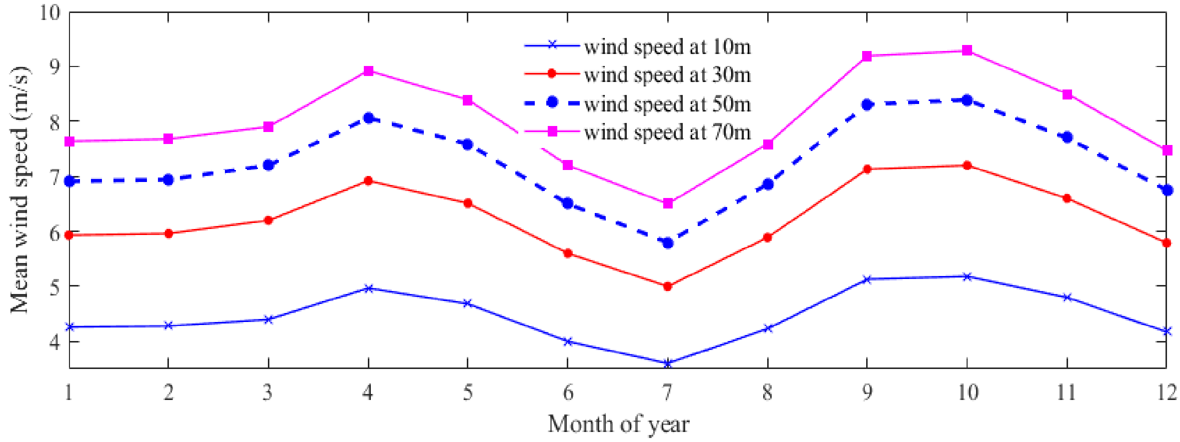


Figure 30: Monthly average wind speed variation at different height in Mehalmeda

The result of Fig30 to 32 illustrates wind speed value with different height, which is indicating to the available wind speed at desire hub height. Therefore, the extracted amount of wind power depends on wind speed value at a similar height.

Subsequently, the first site of this article which is Debrebrehan has the wind speed was found to be above 3.75 m/s 50%, 81% and 100% at 10m, 50m, and 70m. Enewari also greater than 4m/s 73%, 99% and 100% at 10m, 50m and 70 respectively. The last site for this study was, Mehalmeda as the same thing to above 4m/s 61.5%, 91% and 100% as per 10m, 50 and 70 heights respectively. According to this result, all study area achieve at minimum above 50% of measured data have greater than cut-in wind speed of specific wind turbine at 10m height.

According to the above relationship, the wind speed is increasing at the same time extracted power is also increasing by three times. However, there is a limitation to ultimately increase tower height and wind turbine blade length for a recent manufacturer scale. Some of these facts are the level of infrastructure, economic status and trained of the wind power plant. Due to this challenge, to decide the study of the wind resource at 70-meter height. The wind speed analysis results at 70m in all study areas as follows.

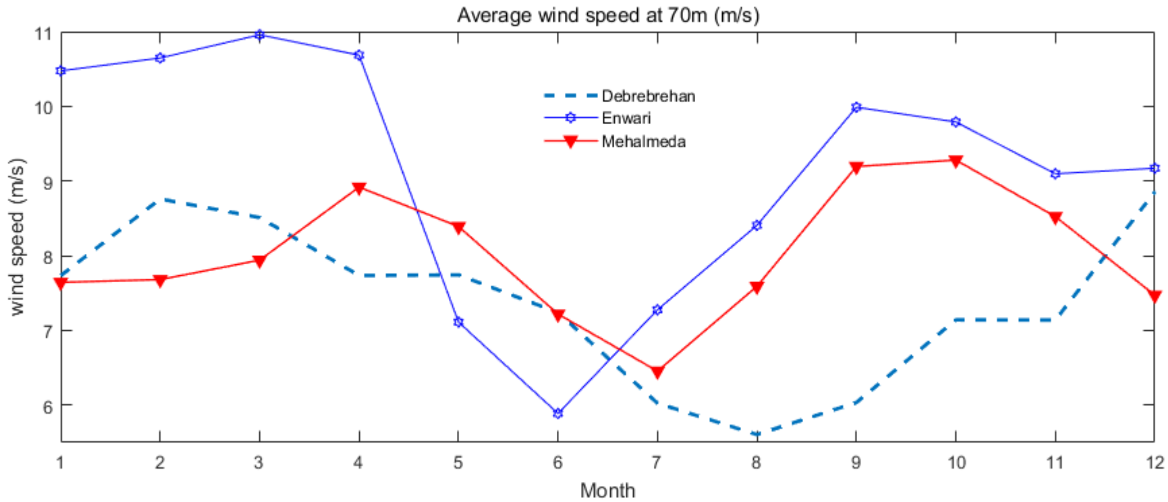


Figure 31: monthly average wind speed at 70-meter height at three respective sites

As the result shown in fig: 34 the wind speed as well as wind power are season dependent. In all study areas, in summer season wind speed value gradually decreases. Specifically, Enewari wind site has got relatively maximum wind speed. Value in all season except summer. Therefore, these study areas have well complementary for the hydropower plant.

6.1.2 Wind direction

One of the key factors in wind farm installation is the wind direction. To attain the optimum design of a wind farm, the prevailing wind direction must be assessing. The prevailing direction of windfall shows in chapter four in fig12 the dominant wind speed is from the West (West (W) and from the north (north (N) to the northeast (NE) which is 80 % of all the time in Debrebrehan wind site. Other wind direction result shows from the (north direction, north (N) to north-northwest (NNW) and northeast (NE) which is more than 75 of all the time in Enewari site. in the west (West North West (WNW) to the northwest (NW) and south-to-south west direction. Which is more than 82.5 of all the time in mehalmeda wind site? These results are important when planning multi-wind turbine installation or in erecting single wind machines having windbreaks or obstacles upwind in the predominant sectors.

6.1.3 Weibull probability distribution function

The Weibull probability distribution, which is the most common, tools to the characterization of wind speed variation. This Weibull distribution depends on all the parameters, like the annual average wind speed, wind speed standard deviation and the Weibull parameter mean, shape factor and scale parameter. Those parameter result list on the table below for the corresponding sites

sites	parameter	2013	2014	2015	2016	2017	**Ava (2013-17)**
Debrebrehan	Vm	3.84	3.55	4	4.01	3.93	**3.87**
	δ	1.25	1.05	1.23	1.27	1.02	**1.27**
	K(-)	3.38	3.75	3.6	3.49	4.37	**3.6**
	C(-)	4.28	3.94	4.45	4.47	4.32	**5.31**
Enewari	Vm	4.61	5.28	4.97	5.17	5.55	**5.12**
	δ	1.36	1.47	1.86	1.4	1.89	**1.53**
	K(-)	3.75	4.02	2.91	4.12	3.22	**3.36**
	C(-)	5.01	5.83	5.36	5.7	6.2	**6.1**
Mehalmeda	Vm	4.76	4.8	4.86	4.6	4.09	**4.62**
	δ	1.38	1.25	1.21	1.45	1.51	**1.35**
	K(-)	3.84	4.31	4.37	3.5	2.95	**3.85**
	C(-)	4.16	7.04	5.34	5.12	4.59	**5.45**

The Weibull distribution of wind speed at 10 m height illustrates on fig

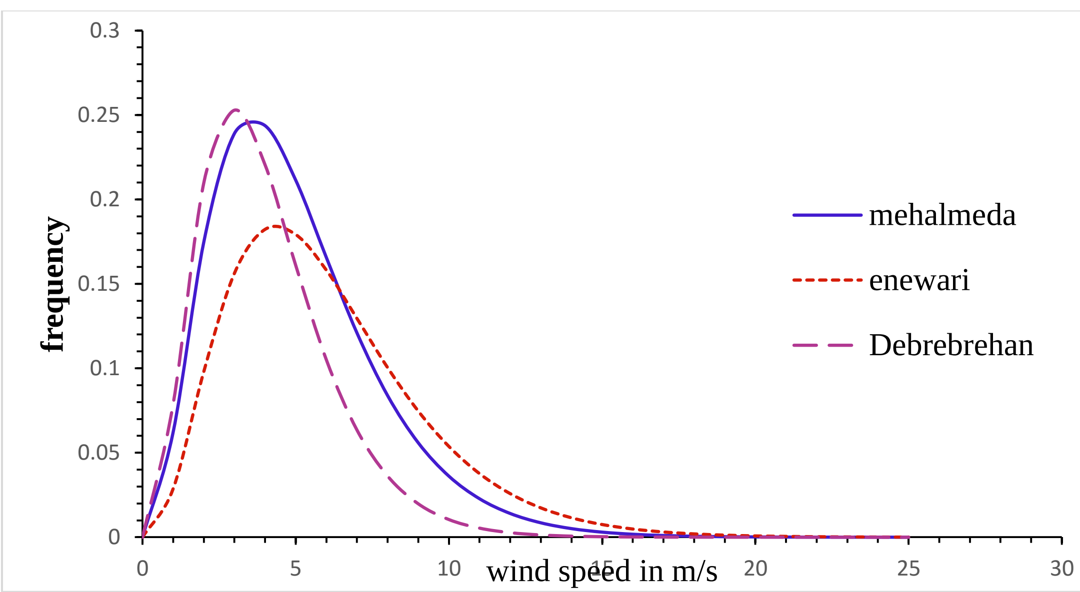


Figure 32: Weibull probability density function for three locations

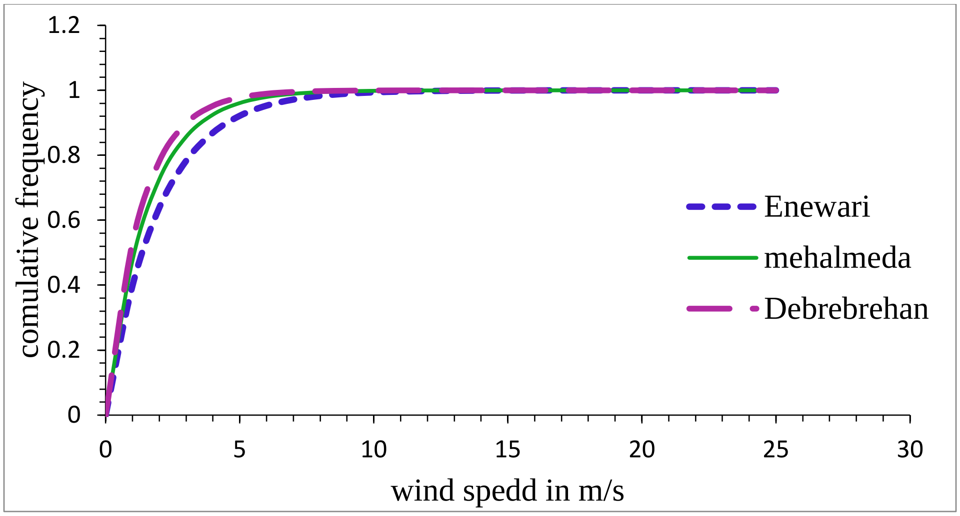


Figure 33: Weibull cumulative frequency distribution in three locations

he result of mean Weibull probability density and cumulative distributions on three locations described by fig 33 and 34 above to estimate the minimum and maximum Weibull parameter of shape and scale value in all sites from table 18. As a result of the five-year average frequent occurrence of wind speed in Derebrehan wind site 3m/s, Enewari 5m/s and Mehalmeda 4 m/s. at the same time probability density value in percent 25%,18.5%, and 24 % respectively. According to cumulative result in all sites, 90 % wind speed is below 10m/s at 10m height. It concludes that even highly frequent wind speed value is above and equal cut-in wind speed. Therefore, in all study areas, the wind plant can be operational with regard to the site-specific wind turbine.

6.3 Wind power density and energy

The annual power and energy density of the locations under both Weibull and Raleigh methods; however, the Weibull method was a relatively recommended technique to give an accurate result. According to this, the value of power density and energy density of the yearly average value shown in table 8, which are dominantly maximum, and minimum values as follows. The maximum and minimum mean power densitie**s** of Debrebrehan 283.04 W/m^2 on 2014 and 252.09 W/m^2 in 2015 respectively, in Enewari site the maximum and minimum wind power density find out 495.33 W/m^2 on 2017 and 343.9 W/m^2 on 2013 and the remaining site for this study is Mehalmeda. It has maximum and minimum power density 357.9 W/m^2 occurred in 2015 and 276.2W/m^2 in 2017. As shown in Fig.35.

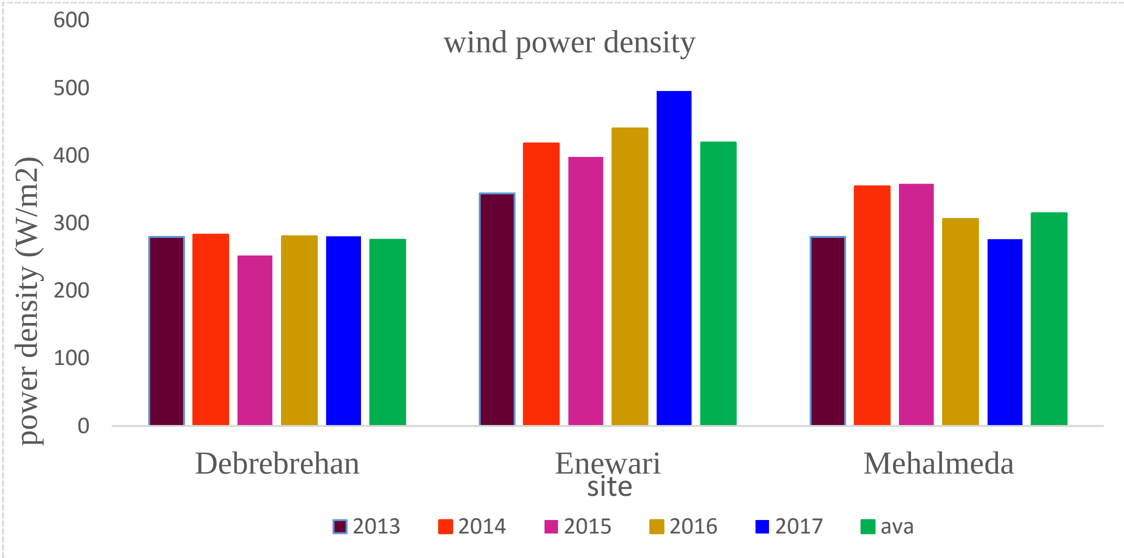


Figure 34: wind power density in all study area

In addition, to wind speed classification defined in table 3. There is another classification that can used to evaluate the wind resource based on power density, which is express below [48].

P/A < 100W/m^2, fair

100w/m^2 < P/A <200W/m^2, fairly good

200W/m^2 < P/A < 500W/m^2, good

P/A>500W/m^2, very good

According to the above classification, with the mean power density of higher than 300 W/m^2, in Enewari and Mehalmeda sites. When the evaluation of the site power density with the maximum and minimum value performs under the classification of good standards. Hence, in the Debrebrehan site, the mean power density varies between 252 to 285 w/m^2 under the fair standards. Then could draw the conclusion here the relatively promising wind energy potential site is Enewari, because of the minimum power density of this study area greater than the maximum power density of Debrebrehan. The second good potential site is Mehalmeda with regard to potential standards. The last rank from three respective sites based on wind power density is Debrebrehan, the value of power density under the classification of fair only. However, based on only wind potential analysis result cannot decide the site is withered suitable or not. Should be determining which site is more recommending rather than wind potential for wind turbine implementation?

The analysis results of three locations within good suitability score that indicates substantial potential for more wind farm placement region development map coincide with the area that has good suitability range located at shown in the fig: 38

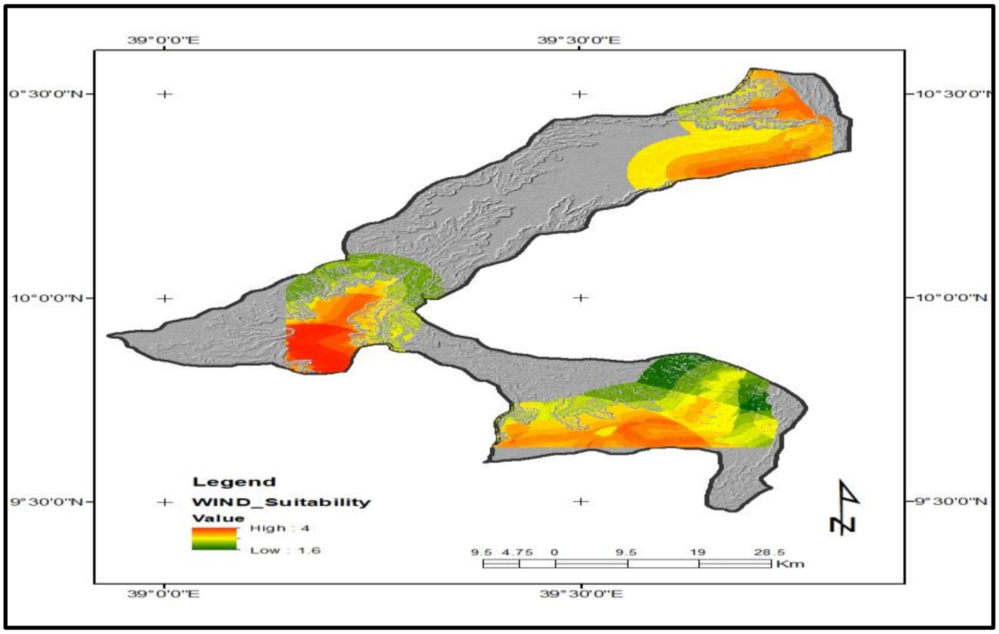


Figure 35: Aggregated suitability map, based on four criteria

The map shows a pattern of higher influence of wind speed and land-use factors the isolated gray color patterns that represent features that have not been the suitable for new wind farm project and also in the remaining color of the map indicate the suitable location for different ranges like highly to the low suitable area. After analysis of a suitable location should be selecting the type of site matching wind turbine based on annual energy production, capacity factor and site wind characteristics mean that turbulence intensity and mean wind speed value also considered.

Table 17: basic parameter of wind turbine type selection.

site	mean ws	σu	TI (%)	selected turbine	AEP(kwh)	CF
Debrebrehan	7.38	1.25	16.9	Acciona AW-82/1500	4314200	32.83
Enewari	9.12	1.6	14.5	suny: SE8220III	7285210	41.6
Mehalmeda	8.03	1.45	16.05	suny: SE8220III	6243215	35.6

From table 19 wind turbine selection parameter, wind speed and turbulence intensity class help to determine the number of wind turbines with different size and performance. In addition to this, to keep any other set of parameters from technical specifications, like relatively small cut-in wind speed, rated wind speed hub height, less noisy from table 13 to 14. Furtherly, some of the parameters are got form calculation results, such as annual energy production, and capacity factor.

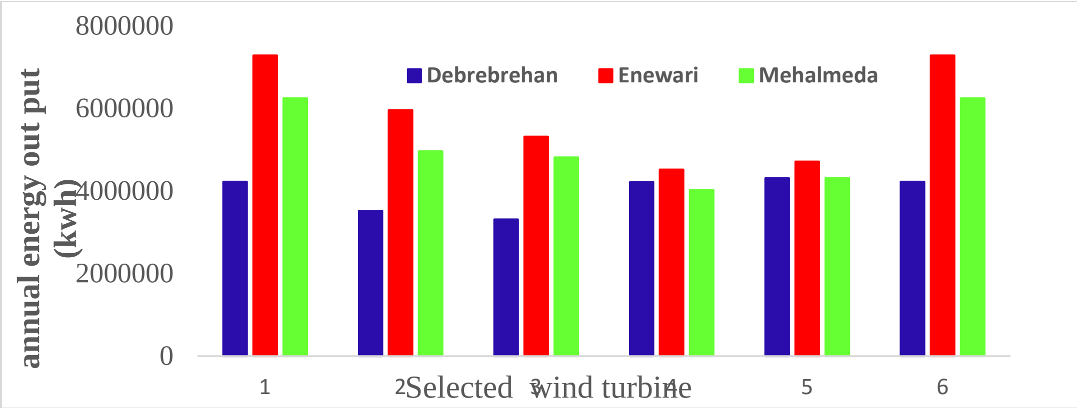
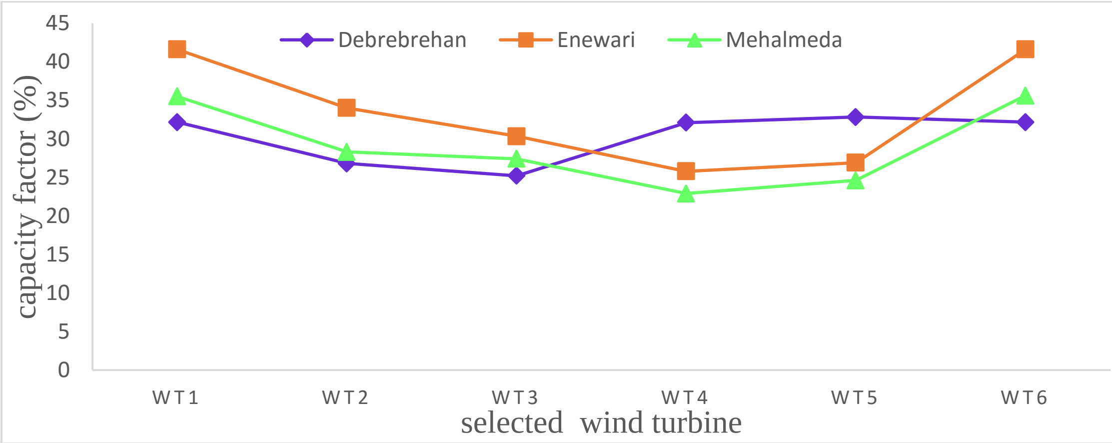


Figure 36: Annual wind energy production with candidate wind turbine

Other comparison have make by the result of capacity factor, good indication of highly performed wind turbine type have relatively greater capacity factor with corresponding site to wind turbine.



Generally, wind turbine selection based on one or two-parameter only considered it is controversial.so that all the parameters should be considered and analysis it. The cumulative effect gives less capacity to compromise wind turbines. According to this manner, Enewari wind site has relatively WT6 and the other site and corresponding value observed from table 19.

6.4 Performance evaluation of selected wind turbine

After the selection of relatively site matching wind turbine, have to be checking the performance of those turbines by using tip speed ratio, axial and tangential induction factors to applies iteration solution method to get optimum value and calculate optimum relative wind angle then after some arrangement to analysis the maximum power coefficient value. Finally, to understand the relationship for site wind and wind turbine mean the maximum achievable efficiency of wind turbine with specific locations of the available wind resource. Then generate the Cp Vs λ curve and the analysis result of blade shape. In figure 38 illustrates the relation of power coefficient to tip speed radio.

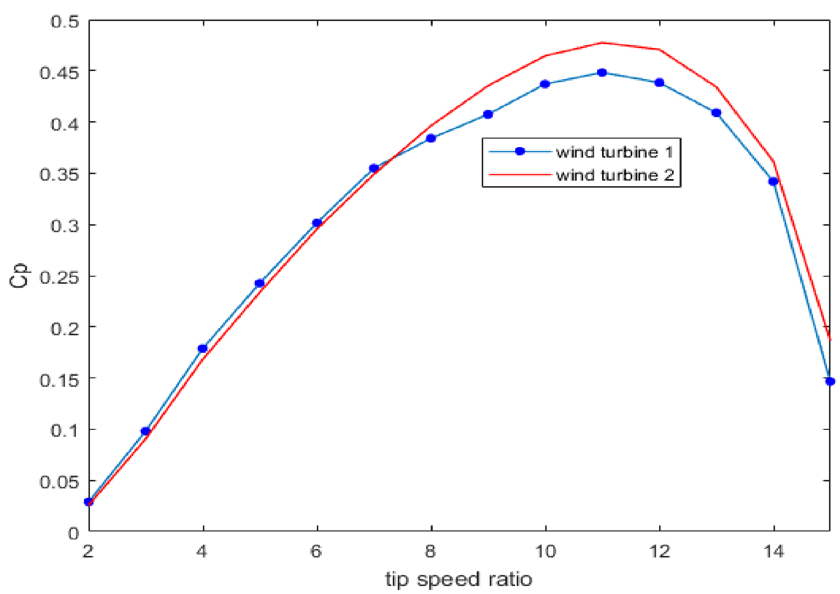


Figure 37: Power coefficient versus tip speed ratio

The power coefficient by the selected wind turbine one, which is Acciona AW-82/1500, 1.5 MW can achieve 44.86% for the maximum one and **suny: SE8220III, 2** MW achieve 47.3% of power coefficient

6.4 Blade Cord and Twist Angle Distribution

Wind turbine blade performance maintain by arranging the optimum distribution of cord length and twist angle for each blade element with respect to the radial position for illustrating figure 6. According to both selected wind turbine blade cord and twist angle destruction similarly lies on the root and tip position, as well as the twist angle is large near the root and small near the tip depending on local speed. Mean that, near the blade root local speed is a low while, near the blade tip also high local speed. The optimum distribution of twist angle helps to maintain the optimum angle of attack through the blade length; similarly, the lift coefficient will be increased in all section of blade element. At the same time, the cord is maximum at the root and minimum at the tip of the blade with regard to the capability of stress, since the occurrence of stress is maximum at the root and minimum at the tip.

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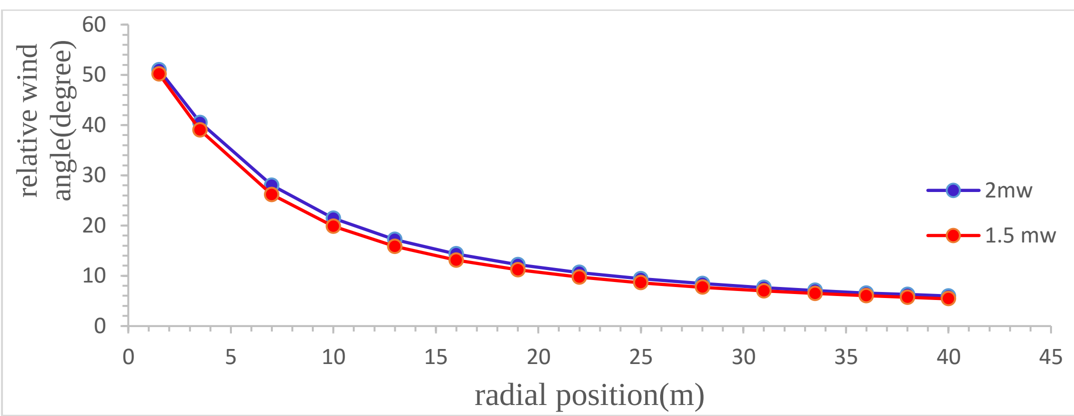
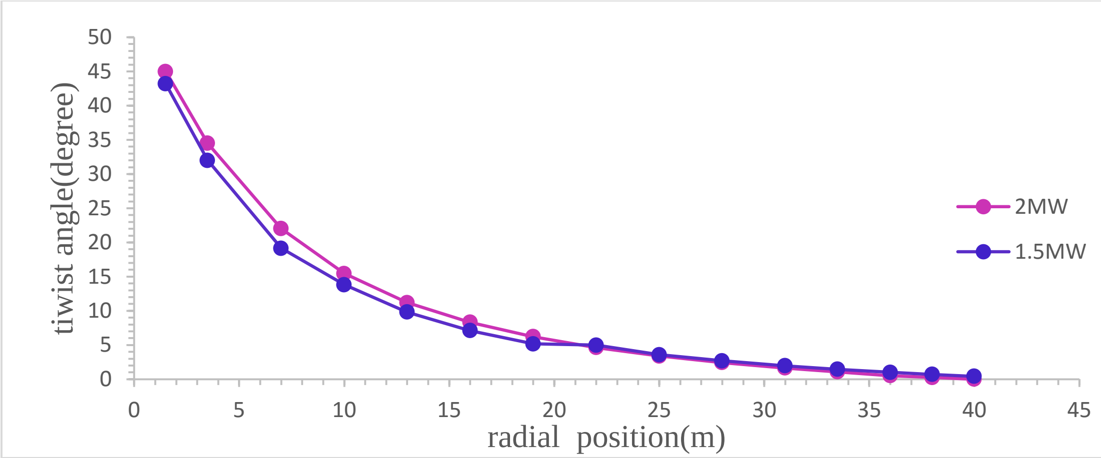
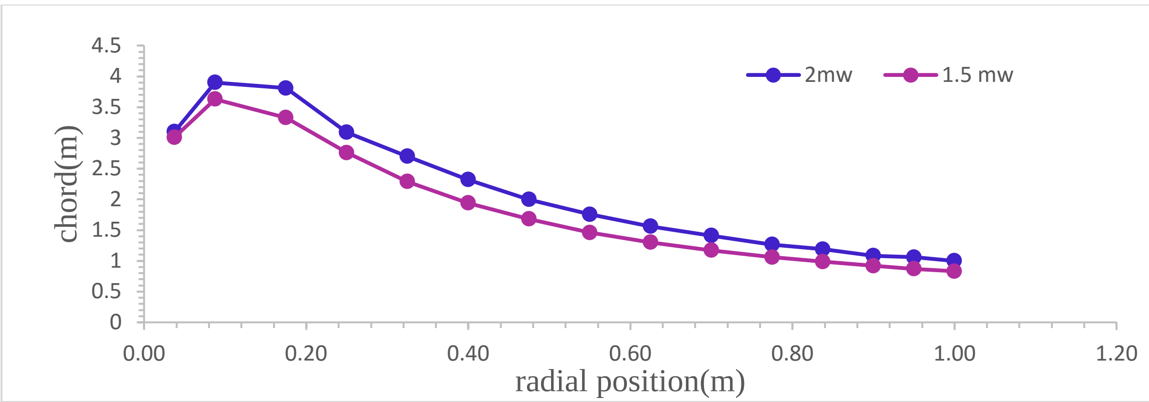






When coming to the aerodynamic challenges on the wind turbine blade forming airfoil, we have to make an analysis of lift and drag coefficient and the ratio of lift to drag coefficient on both selected airfoil. Then to decide which one is relatively compatible airfoil type.

According to a graphical analysis by Qblade, a software product can be Obtain and examine the analytical curves. for the aerodynamic properties of the airfoil at each section, this analysis was done by taken both airfoil type and keeping the parameter to be maximum the ratio of lift coefficient to drag coefficient and maximum lift and minimum drag are made by S818 and NACA$\mathbf{63_4 421}$ respectively.

Table 18: ratio of lift coefficient to drag coefficient

S818				NACA 63_4421		
AOA	CL	CD	CL/CD	CL	CD	CL/CD
-5	-0.332	0.0079	-41.53	-0.2907	0.0075	-38.6569
0	0.324	0.0074	43.7	0.5009	0.0055	80.3

5	1.2439	0.0093	100	1.2046	0.015	72.89
10	1.4	0.017	84.5	1.4799	0.04892	30.25
15	1.67	0.043	38.69	1.5529	0.10645	14.58
20	1.6	0.11	14.4	1.3908	0.2449	5.68

In figure 642 -45 have four plots it indicates the lift and drag coefficient variation with the corresponding value of AOA. The linear variation of lift coefficients is strongly depending on the range of angle of attack. However, the drag coefficient is a function of the lift coefficient.

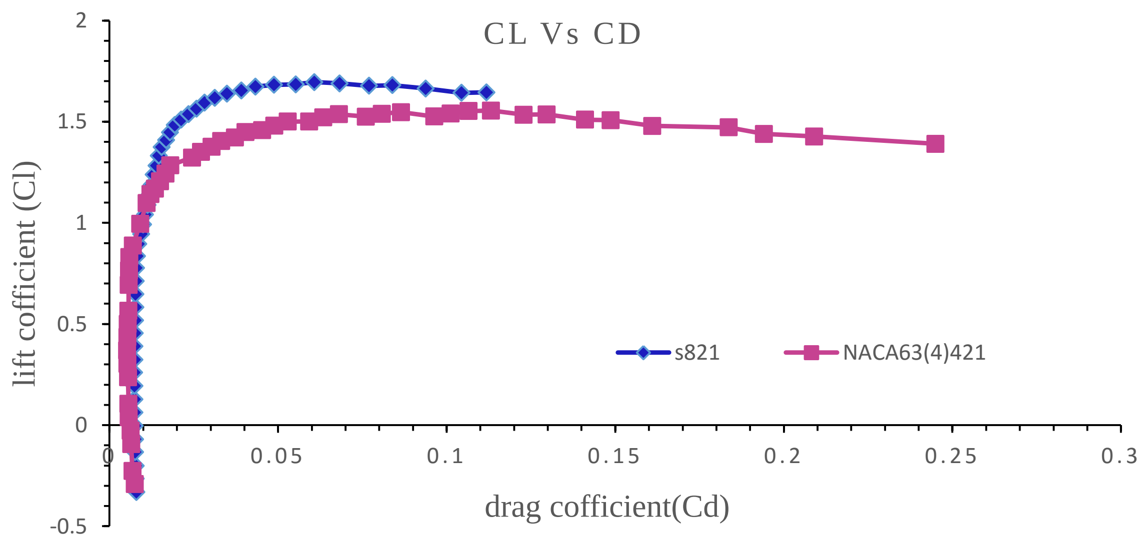


Figure 38: analysis result of lift coefficient versus drag coefficient

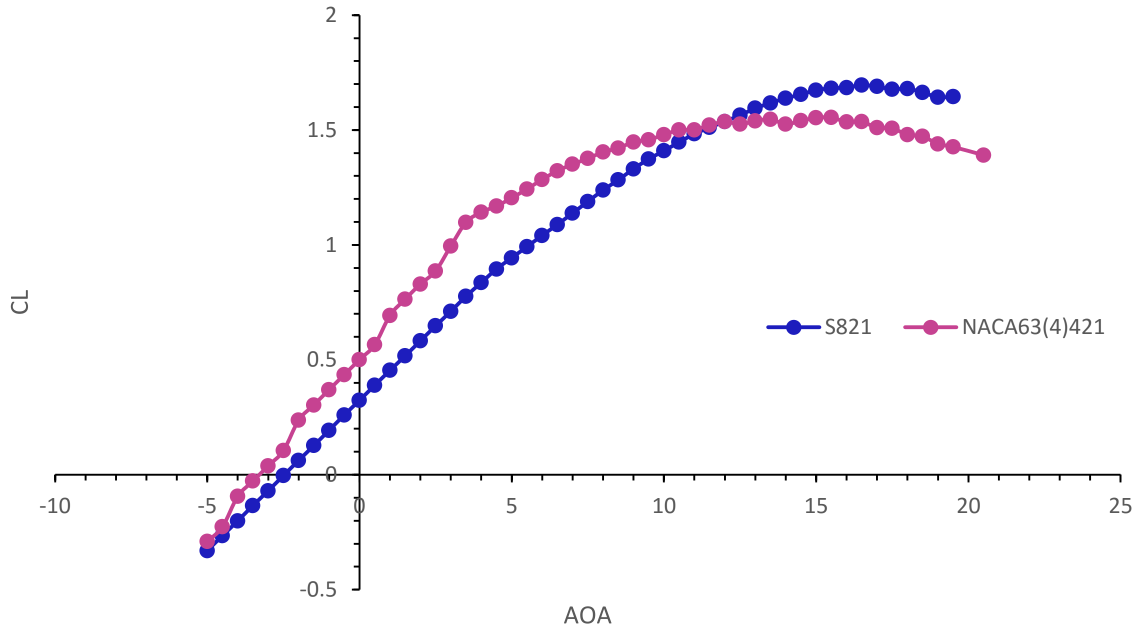


Figure 39:the variation of lift coefficient with angle of attack

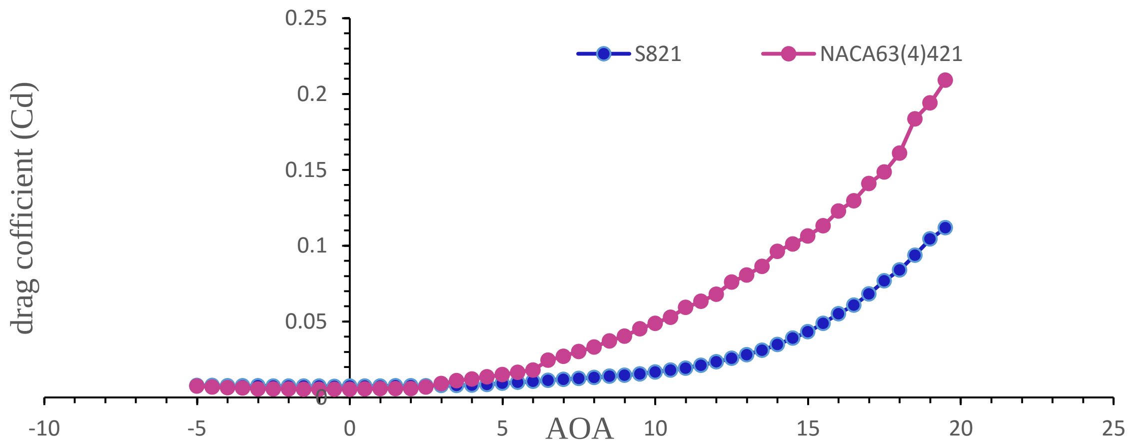


Figure 40: the variation of drag coefficient with angle of attack

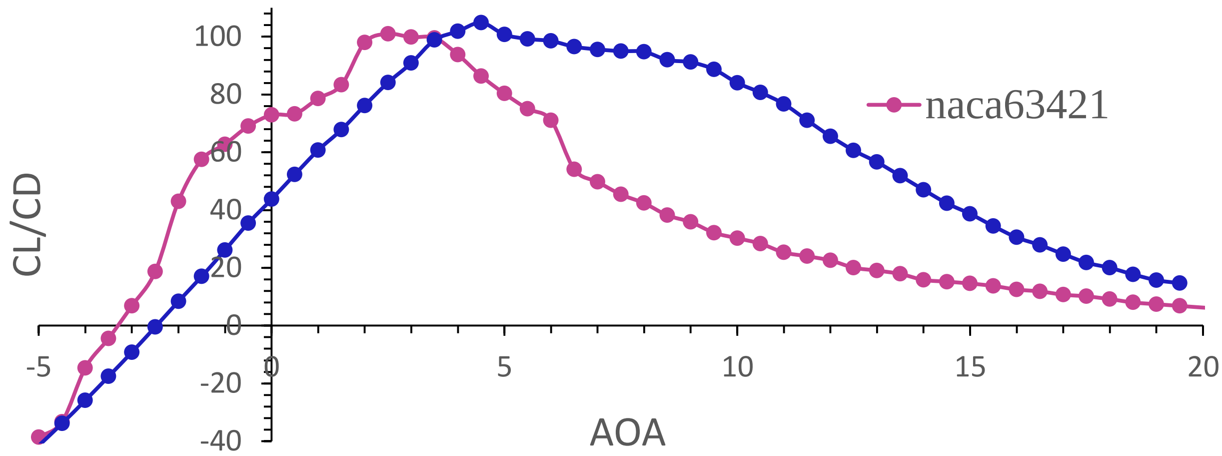


Figure 41: the variation of lift to drag coefficient ratio with angle of attack

The aim of this analysis was to determine the maximum lift coefficient and minimum drag coefficient to keep the ratio of maximum lift to drag coefficient as well as the pressure coefficient at a different angle of attack. However, the lift decrease and drag increase that can be observed from analysis curve indicates that reducing the performance of wind turbine conversion system and leading of power output losses.

According to this analysis result both airfoil, lift coefficient value significantly increases up to an angle of attack 15° but to decreasing the angle of attack greater than 15◦ this angle its a critical angle of attack. Additional parameters like Ronaldo's number was to keep constant $4x10^6$ and Mack number 0.28. Under these parameters in case I, airfoil family NACA 63_4421 drag 0.068 and the ratio of lift and drag was 22.56. During in case II, airfoil family S818 analysis result has seen, lift coefficient 1.67 drag, coefficient also 0.043 and the ratio of lift to drag 38.69. However, the ratio of lift to drag coefficient attains at a maximum value at an angle of attack 5 for S818 and between 0 and 5 for NACA 63_4421. The corresponding value of lift and drag coefficients are illustrated in a table: 20 and figure: 39.

5.6 Effects of lift to drag coefficient variation for optimum performance

In this, portion shows the analysis result of the three-blade wind turbine can achieve maximum power coefficient under the different ratio of lift and drag coefficients at the same tip speed ratio.

By using this formula, $Cp_{max}= \frac{16}{27}\lambda\left[\lambda+\frac{1.32+(\frac{\lambda-8}{20})^2}{B^{2/3}}\right]^{-1}-\frac{0.57(\lambda)^2}{\frac{cl}{cd}(\lambda+0.5B)}$

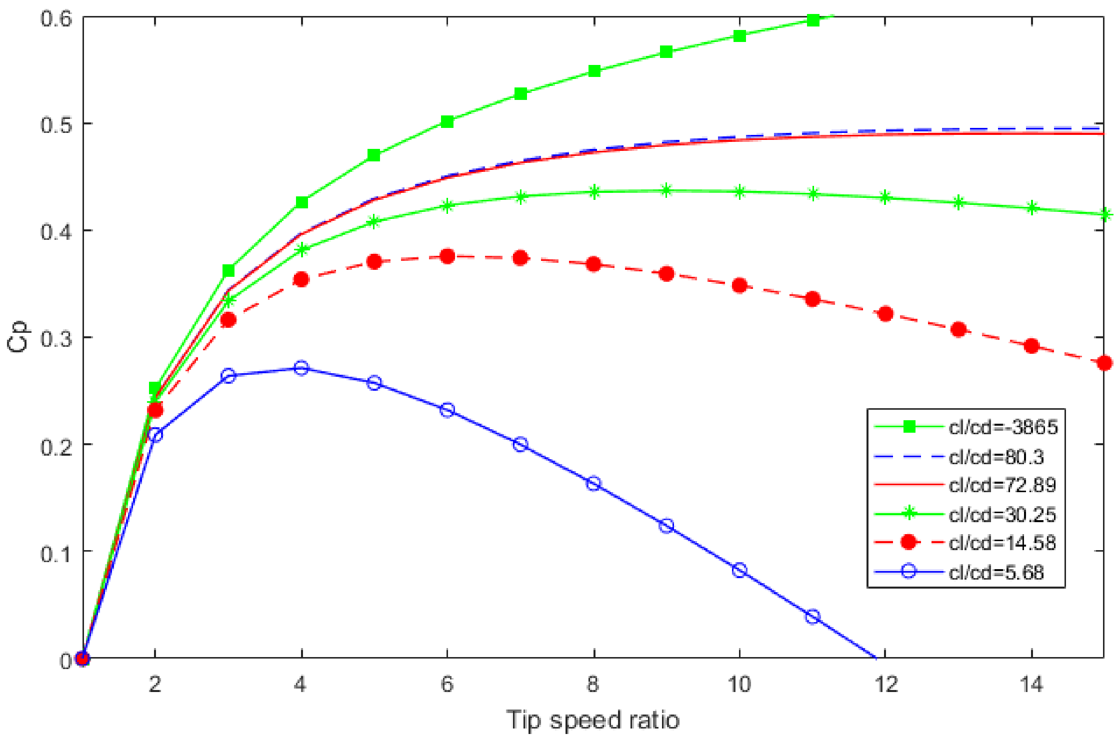


Figure 42: maximum achievable power coefficient by different Cl/Cd value on NACA$63_4$421

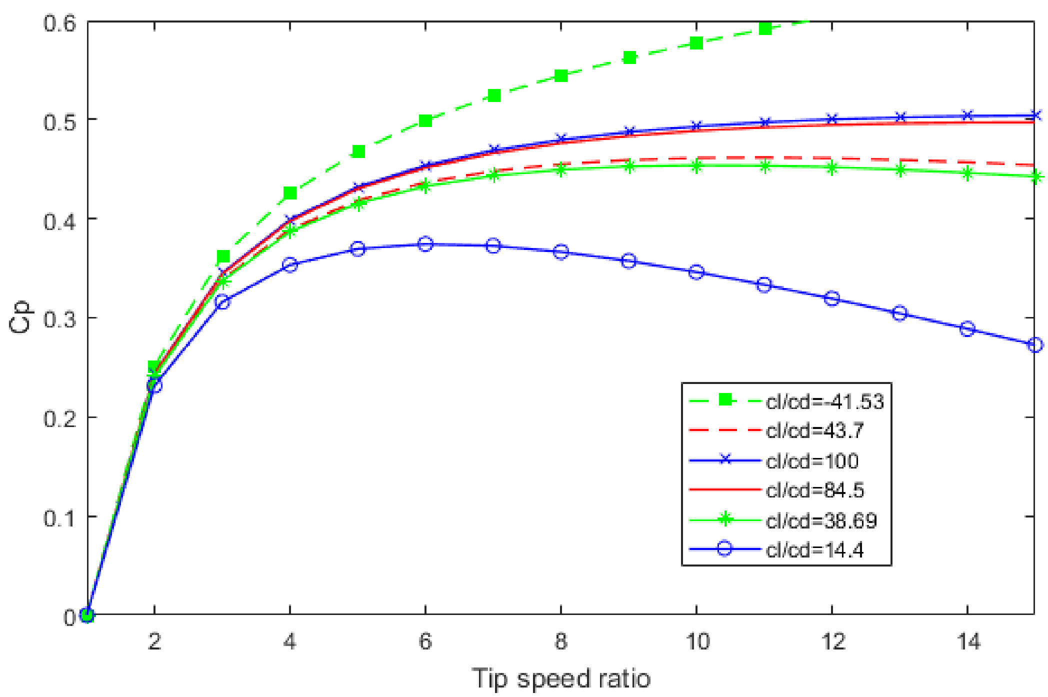


Figure 43: Maximum achievable power coefficient by different cl/cd value on S818

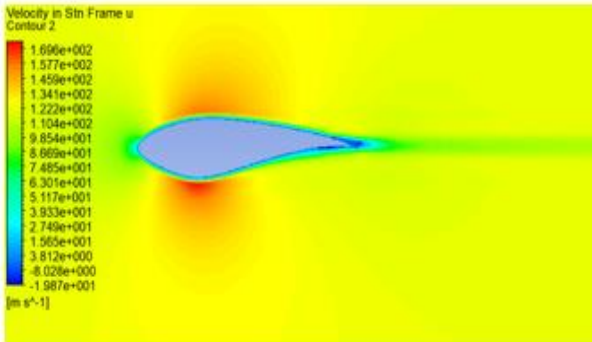
On the figure, 43 and 44 illustrate the power coefficient versus tip speed ratio with the turbine blade forming airfoil, typically NACA$63_4$421 and S818 respectively.in both cases, Cl/Cd value is negative the cp value an acceptable because above the Betz limit. In another way, the Cl/Cd attain maximum value Cp value also achieves the maximum one.to compare and contrast each individual airfoil value S818 can achieve the maximum power coefficient in each lift and drag ratio.

Therefore based on those airfoil analysis result and different literature recommendation should be concluded relatively good performing type of airfoil was s818. Based on this analysis result S818 is relatively better airfoil.

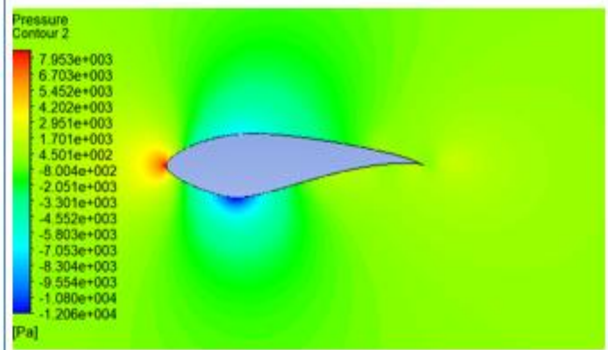
6.5 Result and discussion of CFD simulation

.in this portion also discusses the flow field around selected airfoil by using CFD simulation. The main objective of this analysis checking again and select an optimum angle of attack with the optimum ratio lift to drag coefficient. From the above simulation result, chosen s818 airfoil type. Therefor to generate a 2D model and analyzed at the various angel of attack.

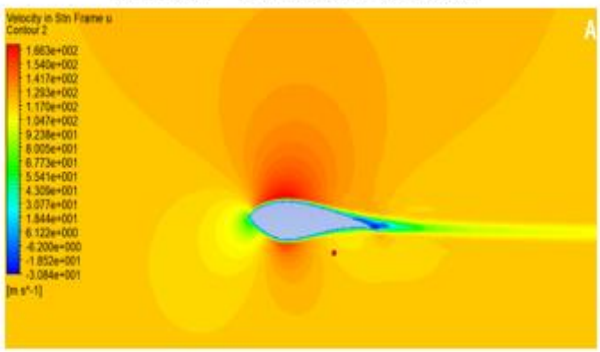
An AOA = 0 , velocity contour



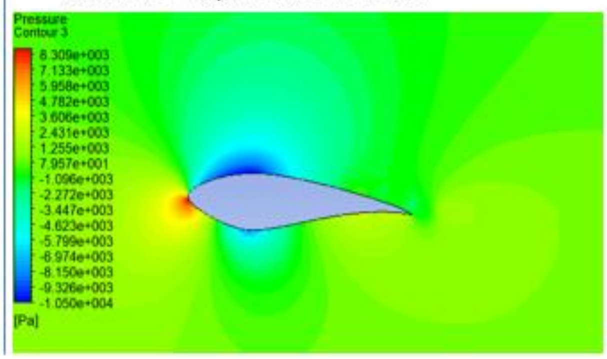
An AOA= 0, pressure contour



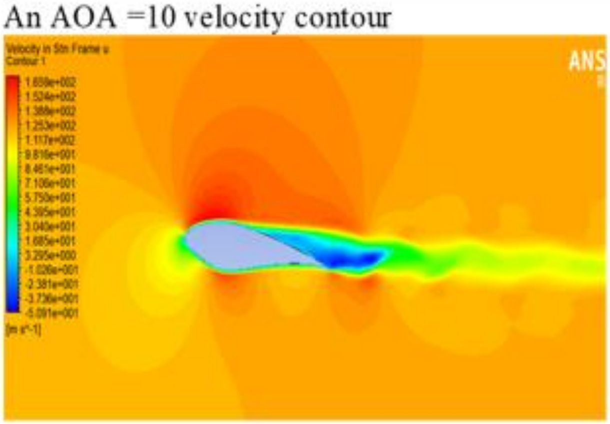
An AOA = 5 , velocity contour



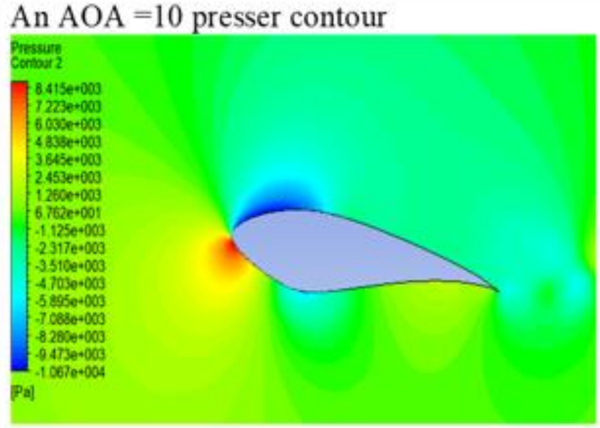
An AOA= 5, pressure contour



An AOA =10 velocity contour



An AOA =10 presser contour



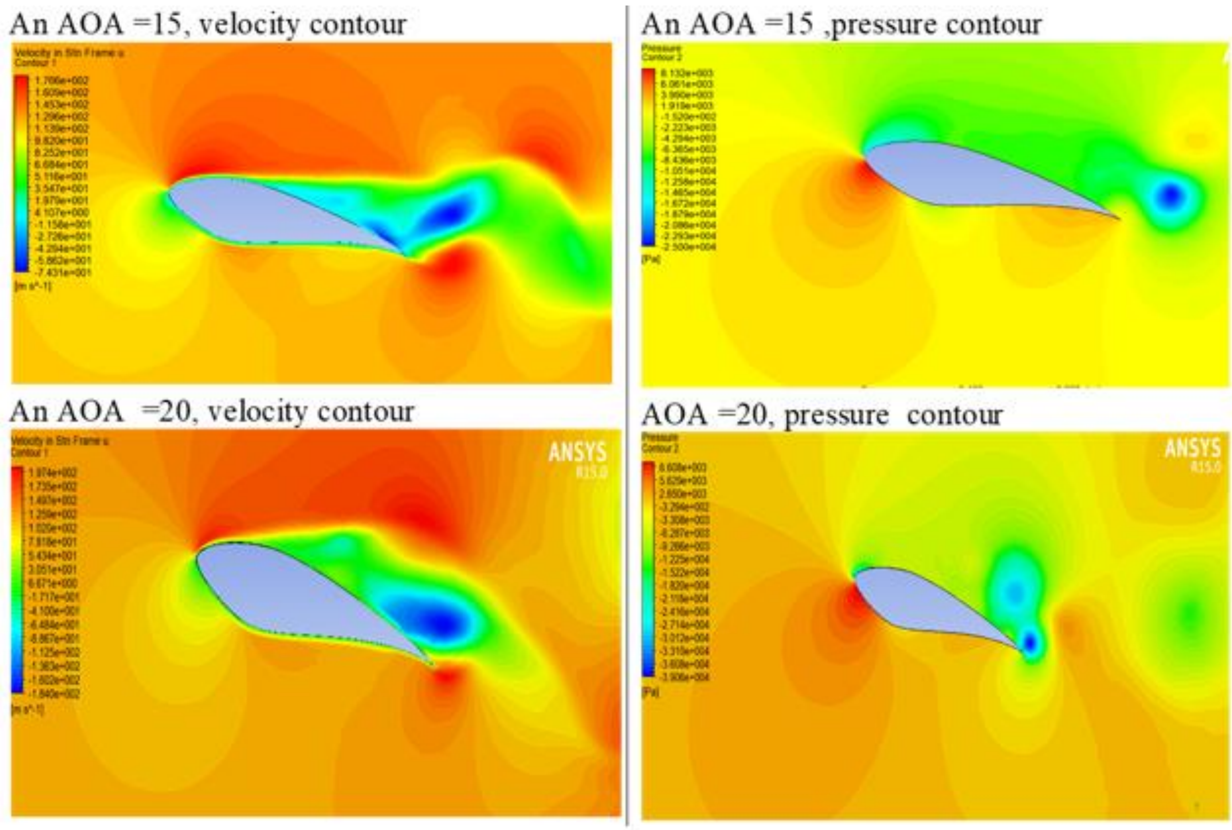


Figure 44: CFD simulation by different angle of attack

From fig.48 shows the velocity and pressure distribution on the top and bottom side of airfoil with regard to different angle of attack when the angle of attack is increase from 0 to 20 degree. The result of this increment, it forms the lager regions of separation called stalling will occur and leads to the turbulence effect. An airfoil set an AOA adjust to 0 degree it makes relatively symmetry and equal velocity and pressure distribution on both side of airfoil at the same time an AOA sets 5 to 20 degree, it understood that velocity and pressure distribution are progressively increasing at the top and bottom side respectively. In addition, the stagnation point shifts on bottom side of an airfoil

CHAPTER SEVEN

CONCLUSION AND RECOMMENDATION

7.1 CONCLUSION

This study conducted an investigation of wind energy potential assessment with the site matching wind turbines from three consecutive sites. Such as, Debrebrehan, Enewari, and Mehalmeda by using five-years wind data to analyze mean wind speed variation, dominant wind direction with 10- meter height, and average wind energy density. In addition, several criteria are considered in order to obtain relatively suitable areas for wind farm installation by implement ArcGIS software, based on-site wind speed classification, selection of wind turbine class from IEC and performance prediction by using engineering analysis software MATLAB and ANSYS have.

From the analysis result, the average wind speed value for extrapolated at 70m high is found to be 7.38, 9.12 and 8.03 m/s respectively. The prevailing wind direction lies on the first site W, N and NE, for the second site N, NNW, and NE and for the third site WNW and NW with estimated to be the maximum percentage wind coming from those directions. The average wind power densities are estimated to be 275.11, 420 and 315 W/m^2 for the respective sites. Therefore, based on wind power density classification standards, it should be concluded that the Enewari wind site is categorizing under very good wind energy resource potentials. and is relatively attractive to construct large wind farms as well as to benefit from complimentary seasonal variation with hydropower energy sources so, as to contribute to diversified energy mix for Ethiopia.

In addition, for wind energy potential investigation it is important to know the cause of site suitability likewise, physical and socio-economic factors need to be selected as criteria by using cost-effective spatial decision spurt tools, like GIS. The Enewari site has a relatively more suitable area demanding priority. According to the site and site potential result, the two-wind turbine has selected from manufacturer technical specifications such as suny: SE8220III for

Enewari and Mehalmeda with 2MW capacity and Acciona AW-82/1500, 1.5 MW capacity for Debrebrehan site using different parameters taken into account.

Based on airfoil selection criteria, such as lift and drag coefficients the ratio of lift to drag coefficient analysis, S818 type of airfoil has been found to have maximum results at an angle of attack 5^o can achieves the maximum power coefficient 0.47 and 0.448 for both respective selected wind turbines.

7.2 Future work

Giving respect to the renewable energy assessment research activity, the following future work is suggested. The total economic feasibility of wind power potential assessment should be assess based on investment costs, transmission costs, O& M costs and all relevant accessory costs. It is highly suggested that the wind farm design should be carried out in each sites along with energy generation capacity estimations for each of the sites.

7.3 Recommendation

Rapidly growing of Ethiopian population, drastically increasing rate of industrialization, evolving higher living standards and usage of energy intensive appliance and so on are the cause of raising to electricity demand. Consequently, the Ethiopia annual energy demand increase to 17000 TWh on 2020 it is not feasible depend on fossil fuel and the only renewable energy source of hydropower. However, Ethiopia has a huge potential of other renewable energy resources, which can be, contribute to suitable energy mix for hydropower in commercial scale like wind power plant, by implementing wind energy generation plant on promising wind potential site and similar wind energy potential assessment can be conducted for other site in the country. Thus, the author of this work recommends that the government, non-governmental organizations and the private sector should make combined efforts to overcome these challenges by using more flexible approaches to improve the current poor status of energy generation capacity in Ethiopia.

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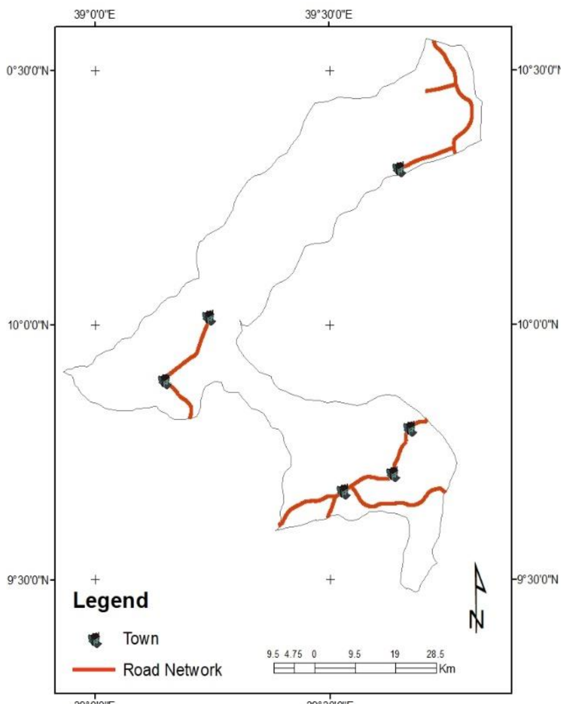
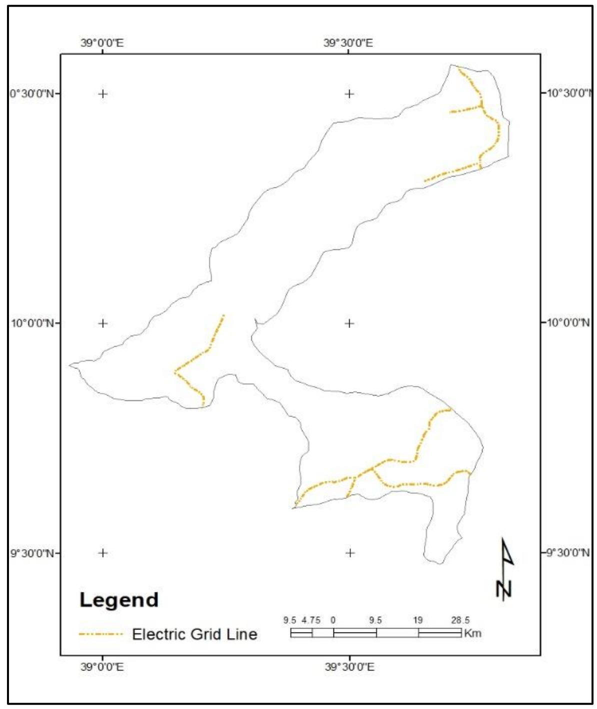
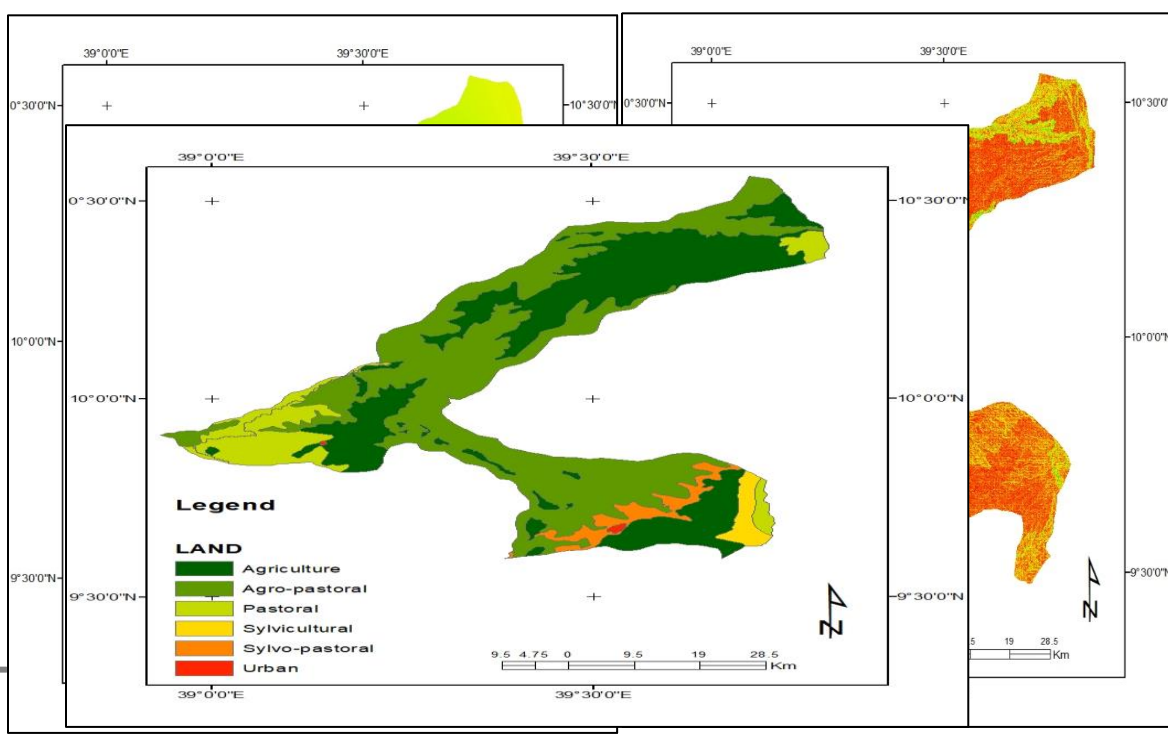
Appendix A

Site suitability map by using input data before reclassification







Appendix: B Ideal wind turbine geometry by using blade element method

segment number	segment) radius(r	radius ratio(r/R)	tip speed ratio	inflow angle(ϕ)	cord length (m)	twist angle	solidity
1	1.5	0.04	0.24	51	3.1	45	0.99
2	3.5	0.09	0.56	40.5	3.9	34.5	0.53
3	7	0.18	1.11	28.01	3.81	22.01	0.26
4	10	0.25	1.59	21.44	3.09	15.44	0.15
5	13	0.33	2.07	17.19	2.7	11.19	0.10
6	16	0.40	2.54	14.33	2.32	8.33	0.07
7	19	0.48	3.02	12.21	1.999	6.21	0.05
8	22	0.55	3.50	10.63	1.756	4.63	0.04
9	25	0.63	3.98	9.4	1.56	3.4	0.03
10	28	0.70	4.45	8.44	1.41	2.44	0.02
11	31	0.78	4.93	7.64	1.265	1.64	0.02
12	33.5	0.84	5.33	7.08	1.19	1.08	0.02
13	36	0.90	5.72	6.52	1.083	0.52	0.01
14	38	0.95	6.04	6.27	1.06	0.27	0.01
15	40	1.00	6.60	5.96	1	0	0.01

segment number	segment) radius(r	radius ratio(r/R)	tip speed ratio	inflow angle(ϕ)	cord length (m)	twist angle	solidity
1	1.5	0.0375	0.2625	50.19	3.01	43.19	0.96
2	3.5	0.0875	0.6125	39	3.63	32	0.50
3	7	0.175	1.225	26.15	3.33	19.15	0.23
4	10	0.25	1.75	19.83	2.76	13.82	0.13
5	13	0.325	2.275	15.819	2.29	9.82	0.08
6	16	0.4	2.8	13.1	1.94	7.15	0.06
7	19	0.475	3.325	11.16	1.68	5.19	0.04
8	22	0.55	3.85	9.7	1.46	4.97	0.03
9	25	0.625	4.375	8.58	1.3	3.58	0.02

10	28	0.7	4.9	7.69	1.17	2.69	0.02
11	31	0.775	5.425	6.96	1.06	1.96	0.02
12	33.5	0.8375	5.8625	6.45	0.986	1.54	0.01
13	36	0.9	6.3	6.01	0.92	1.02	0.01
14	38	0.95	6.65	5.7	0.87	0.7	0.01
15	40	1	7	5.42	0.83	0.42	0.01

Appendix: C Wind turbine manufacturer specification

Sany wind turbine Acciona AW-82/1500

general data	manufacturer	suny china	Rotor	rated capacity (MW)	1.5
	model	SE8220III		wind class	IEC IIIB
	wind class	IIA		rotor diameter (m)	82
	power control	pitch		swept area (m2)	5289
	offshore model no	no		rotor speed	14.4
	power density	0.027m^2/kw		hub height (m)	80
operation	rated power	2MW	operating data		
	temperature condition	-40 to 40 ^{0}C		rated wind speed	10.5
	cut in wind speed	3.5 m/s		average wind speed	7.5
	cut out wind speed	25 m/s		cut in wind speed	3
	rated wind speed	12 m/s		cut out wind speed	20
	diameter	82.5 m		survival wind speed	52.5
	swept area	5346 m2		component data	
	rotor speed	18rpm	**blades**		
tower	rotational direction	clockwise		material	GFRP
	height	70 m		blade length	40m
blade	number of blade	3		aerodynamic brake	full feathering
	length	40.3		tower	
Generator	type	Double-fed asynchronous		material	s355J2G3
	rated power	2060kw		tower height (m)	76.9
	voltage	690v		nacelle	

	rotated frequency	50Hz		height of nacelle and hub	4
	rotation speed	600rpm	**mass**		
				blade(t/blade)	5.78
				rotor (t)	32.34
				nacelle(t)	52.5
				tower(t)	135

Appendix: D Selected airfoil data coordinate value

NREL's S818 AIRFOIL		NACA 63(4)421 AIRFOIL	
1	0	1	0
0.99628	0.001172	0.95037	0.01022
0.985749	0.005042	0.90078	0.02144
0.969733	0.011567	0.85111	0.03364
0.949331	0.019933	0.80135	0.04643
0.925013	0.029036	0.75145	0.05947
0.896604	0.037958	0.70143	0.07232
0.86363	0.046635	0.65126	0.08455
0.826424	0.055387	0.60096	0.09582
0.785533	0.064216	0.55054	0.1058
0.741535	0.073043	0.5	0.11412
0.695038	0.081746	0.44937	0.12044
0.646674	0.090172	0.39567	0.12439
0.597088	0.098138	0.34793	0.12558
0.546926	0.105437	0.29719	0.12352
0.496826	0.111844	0.24649	0.11837
0.447405	0.117113	0.19585	0.10993
0.399254	0.120979	0.14535	0.09774
0.352929	0.12315	0.09506	0.08097
0.308961	0.123253	0.07007	0.0701
0.267649	0.120477	0.04527	0.05675
0.228032	0.114783	0.02086	0.03925
0.190293	0.107047	0.00902	0.02717
0.154881	0.097687	0.00452	0.02054
0.122185	0.08703	0.00237	0.01661

0.092615	0.075381	0	0
0.066516	0.063028	0.00763	-0.01461
0.044275	0.050276	0.01048	-0.01774
0.026233	0.037351	0.01598	-0.02289
0.012606	0.024534	0.02914	-0.03181
0.003757	0.012217	0.05473	-0.04411
0.000672	0.004557	0.07993	-0.05314
0.000133	0.001836	0.10494	-0.06029
0.000037	0.000887	0.15465	-0.07082
0.000025	-0.00074	0.20415	-0.07809
0.000499	-0.00328	0.25351	-0.08257
0.001427	-0.00595	0.30281	-0.08464
0.003293	-0.00973	0.35207	-0.08438
0.012369	-0.02146	0.40133	-0.08155
0.026385	-0.03381	0.45063	-0.07664
0.044928	-0.0464	0.5	-0.07
0.06775	-0.05908	0.54946	-0.062
0.09426	-0.07191	0.59904	-0.05298
0.123523	-0.08438	0.64874	-0.04335
0.155152	-0.09599	0.69857	-0.03344
0.1885	-0.10623	0.74855	-0.02367
0.222881	-0.11477	0.79865	-0.01459
0.257026	-0.11943	0.84889	-0.00672
0.293098	-0.11888	0.89922	-0.00076
0.331998	-0.1136	0.94963	0.00242
0.374522	-0.10428	1	0
0.420642	-0.09207		
0.470046	-0.07785		
0.52228	-0.06249		
0.576716	-0.04689		
0.63254	-0.03192		
0.688741	-0.01841		
0.74414	-0.00705		
0.797417	0.001664		
0.847171	0.007428		
0.891988	0.010222		

0.93052	0.010291
0.961558	0.008111
0.983734	0.004337
0.99614	0.001111
1	0