ASSESSING THE POTENTIAL OF WIND ENERGY FOR ELECTRICAL POWER GENERATION IN DODOMA REGION, TANZANIA

BY

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DECLARATION

This research project report is my original work and has not been presented for a degree in any other University**.**

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DEDICATION

This research project work and all efforts that put forward into developing is dedicated to my parents, relatives and friends whose wise counsel, love, guidance and prayers kept me moving on. May the Almighty God bless you all abundantly.

ABSTRACT

Tanzania depends heavily on hydropower for her electricity demand and experiences power shortage during the dry seasons. This research project investigates the wind power potential of Dodoma, a Central station of Tanzania which can be used to supplement the shortfall in hydro-electricity generation. The potential for wind-generated electricity was examined using three hourly wind data collected from Dodoma Meteorological station located at Dodoma Airport for the period between 2007 and 2012.

Three hourly wind speed data measured at 10 m height was collected was used to determine the mean monthly wind speed, annual wind speed and the wind speed distribution. The wind data was extrapolated to 50 meters height by using Power Law. The wind resource at 50 meter yielded an annual mean wind speed of 5.5 m/s and mean wind power density of 280.5 $W/m^{2.}$ Wind energy that can be harvested from this annual average wind speed is 23343.21 kWh per year. The average annual power output of the area is 366 kW, which brings the area into the moderate class-4 category of power potential making the area to be suitable for moderate wind farms. The windy season, which is from March to November, coincides with the dry season.

It is recommended that by generating electricity from wind, the already limited hydrological resources in the country could be used for irrigation schemes instead of channeling them for developing new hydropower plant

Key words: Wind speed frequency; wind power density; wind power generation; Power potential; Wind energy; Wind speed

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LIST OF ACRONYMS

COSTECH	Tanzania Commission for Science and Technology
CTI	Confederation of Tanzania Industries
GDP	Gross Domestic Product
HAWT	Horizontal Axis Wind Turbine
KW	Kilowatts
MW	Megawatts
NGO	Non Governmental Organization
TANESCO	Tanzania Electricity Supply Company Limited
TMA	Tanzania Meteorological Agency
URT	United Republic of Tanzania
WEPA	Wind Energy Potential Assessment
WRAP	Wind Resource Analysis Program
WRAP	Wind resource analysis program

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Power generation is increasingly becoming a challenge for many developing countries as well as under-developing. As the economies of these countries grow, often times it is found that investment into power supply is not directly linked to the growth of the economies. As a result, in most cases, these economies end up suffering tremendous power outages or shortages due to inadequate supply of electric power to support the growing economies.

The trend of most Governments in these emerging economies usually seem to be more of reactive in nature as opposed to anticipatory or pre-emptive in dealing with power generation as well as other infrastructural areas. This phenomenon has become a norm in these economies and the effects have tremendous negative impact to the productivity of the economic sectors and hinder development progress. It is also true that the size of the economies of our countries like Tanzania are very small, such that making adequate investment to redress the power shortage is often a intimidating commitment that they may not be able to sustain.

Although our economies are small but we still need to invest in energy like electricity using renewable energy resources. As affirmed by Grogg (2005), renewable energy technology and products have great global market demands, especially wind and solar power. In the developing countries with considerable quantity of population, there are many people living in remote villages or isolated islands who are not able to access electricity. Providing electricity service is on the top list of most developing countries. These technologies are having been proved mutual in rural electrification. It is a highly appreciated way transferring such technologies and localization of production to low the production cost, and it also will benefit both enterprise itself and beneficiary population, especially in poverty alleviation

Wind energy is the fastest growing renewable energy source today. A continued interest in wind energy development worldwide has produced steady improvements in technology and performance of wind power plants. New wind power projects have proven that wind energy not only is cost competitive but also offers additional benefits to the economy and the environment (Ramachandra *et al*., 1997).

A steady supply of reasonably strong wind is necessary requirement for utilizing the power in the wind. Development of wind energy depends upon a clear understanding of wind resources. Site location, turbine performance and physical effects of turbulence and energy extraction represent a few of the issues that must be addressed by anyone interested in developing wind energy. As such any plan to develop wind energy must begin by understanding the wind resource. Where is the best potential wind sites located? How much energy could be extracted from the wind at those sites? (Grogg, 2005)

1.2 Problem statement

TANESCO's generation system consists mainly of Hydro and Thermal based electrical generation. Hydro contributes the largest share of TANESCO's power generation. Hydro contributed 73% of total power generated from October 2009 up to September 2010. Gas and Thermal contributed the remaining amount. During the year 2010 the total units generated to the grid and isolated plants were 4,938,748,209 kWh. The hydro-plants operated by TANESCO are all interconnected with the national grid system and their installed capacity for each station is as follows: Kidatu 204 MW; Kihansi 180 MW; Mtera 80 MW; Pangani 68 MW; Hale 21 MW; and Nyumba ya Mungu 8 MW totaling to 561 MW (www.tanesco.co.tz –April 2013). During severe droughts and prolonged dry seasons most hydrological sources are depleted. At such situations Tanzania faces electric power shortage whereby rationing of electricity becoming necessary.

The capacity produced by all the power generation plants i.e. 561 megawatts is little as compared to 833 megawatts required by the demand and Tanzania's economy size. According to engineering evaluation, the combined capacity of the listed power plants is supposed to be 1,005 Mwh (Gas, Hydro and Thermo) which is more than the expected supply of 857 Mwh (Tesha, 2012). This amount is still at least slightly more than 833 Mwh peaks which is the substantial demand of electric energy in Tanzania. It is not surprising to see acute power crisis in Tanzania due to the facts that all the power plants are not operating at full capacity or at least efficiency levels. With regard to this observation, a robust solution must be sort out for the nation to come out of her energy problem which it is experiencing now.

Manufacturing is one of the key sectors of the Tanzanian economy. Statistics indicate that contribution of the country's manufacturing industry to GDP in 2008 was 9.4%, and over the period of eight years (2002 – 2009), average growth rate of the manufacturing sector in the country was 8.4%. In 2008 the country's GDP growth rate was 7.4%, which was lower than the rate of growth of the manufacturing sector (URT1, 2009). In this accord the manufacturing sector has a great potential for the transformation of the country's economy for the achievement of sustainable economic growth through the sector's contribution to the national income, employment, improvement in the balance of payments and overall economic development. In view of this, the manufacturing sector should be one of the priority sectors of the economy. According to the CTI (2011) report, Tanzania's economy has been growing steadily at 6% annually, which is lower than for the last 2 year. The report highlights that electrical energy shortage is one of the causes of this decrease in addition to others. It further state that investment into this sector might have been neglected by the Government, causing frequent power cuts and power rationing.

1.3 Justification of the study

The electric energy crisis in Tanzania obliges the country to seek out for alternative energy sources in order to stabilize the energy status and reduce the overdependence on hydrological cycle and the fossil fuel sources. Wind is renewable energy resources which seem to be plentiful in the country but their magnitudes have not yet been measured and analyzed to an encouraging stage. The study by Kainkwa (2008) showed that Tanzania has been with reasonably high wind power but this potential has not been used for many years. Evaluating wind power potential for a site is indispensable before making any decision for the installation of wind energy infrastructures and planning for relating projects. This research project will present a branch of a composite analysis whose objective is to investigate the potential of wind energy resource in Dodoma Region

Clearly Tanzania needs to increase investment in the energy sector to ensure that economic growth is sustained with energy capacity. Investment into this sector needs to be based on strategic review of the energy capacity currently produced by TANESCO and meaningful project proposals for expansion and looking for alternative energy sources, with investment geared towards enhancement of the weak areas. Having analyzed fully the need, production capacity, storage capacity and distribution ability, the analysis would be the guide for the Government in reaching the energy solution for Tanzania. The research on wind potential in different regions for producing electricity is of paramount importance since can reduce the current problem as it stands.

According to Tesha (2012), there was hope from the recent commitment by the United States Government to assist Tanzania Government to produce the level of 3,000 Mwh in three years starting from 2012. This news was welcomed by many Tanzanian who are experiencing the recent power problem as a step in the right direction. However this has not been implemented due to some reasons which are beyond their ability. While hoping that the project will be successful, still the Government must do more by implementing alternative electrical energy sources to redress the current power problem so as to reduce its effects to productivity of businesses and costs of production. The wind power is theoretically to be the alternatives among others to be invested to some areas like in the area of this study where the average wind speed and frequencies can be enough to produce electric power. Promising wind conditions are indicated for South-East Tanzania, along with several hot-spots in the central Tanzania has been shown by Kainkwa and Uiso (1989). Within these areas it is likely to find sites suitable for large scale wind power. Dodoma is among the region in central Tanzania and the now the Capital City of the country where investments are geared. These make assessing the wind resource potentiality at this location significant.

In attempting to search for a suitable site where wind energy is significantly high and worth harnessing this particular type of study is also necessary. The data and analysis to be produced will be essential for assessing the quality of the site (whether there is enough wind for a turbine to be cost effective) and the turbine type needed. The site can be available for wind power production but according the behavior the wind may not be able to generate electrical energy. With this study will help in “finding the right combination of size, shape, materials, and location that will produce the most electricity for the least cost (Matthew, 2006).

With the recent concerns about the environment and the need for cleaner, renewable energy resources have brought about several innovative exploitations of the earth’s energy supplies which is environmental friendly to some extent. Fossil fuel sources currently provide a larger share of world electricity generation than any other energy resource and are expected to remain in that position for some years (http://www.eia.doe.gov/cneaf/electricity/epa/epat1p1.html - April 2013). The demerits of fossils are that they have high price growth rates apart from being non-replenishable and also are destructive to the environment. These demerits of fossil fuels have compelled many electricity developers to opt for renewable energy resources that are inexhaustible and have less adverse impact to the environment. The use of wind as the source of energy is one of the least expensive of the alternative/renewable energy sources and is becoming more affordable as the technology improves and infrastructure develops while conserving our natural environment (Manwell *et al*., 2002). Knowing the available wind power will be helping in addressing the problem of the conservation of the environment as we reduce the use of fossils fuel in production of electric power.

1.4 Objectives

The main objective of this research project is to assess the wind power potential in Dodoma Region located in Central Tanzania, to assist in planning for the increase in electrical power generation. To achieve this main objective, the following specific objectives were undertaken:

(i) Investigate the temporal characteristics of wind over Dodoma.

(ii) Determine the potential power that can be generated from the winds at Dodoma

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Study area

Located at 6°10′23″S 35°44′31″E, in the centre of the country, the town is 486 kilometres west of the former capital at Dar Es Salaam and 441 kilometers south of Arusha, the headquarters of the East African Community. It covers the area of 2,669 square kilometres of which 625 square kilometres are urbanized (URT, 2011).

Figure 1: Map of Tanzania showing the location of Dodoma Region

2.2 Climatology

Dodoma features a semi-arid climate as unique climate compared to most regions in Tanzania. The region has relatively warm temperatures throughout the year. While average highs are somewhat consistent throughout the year, average lows dip to 13 °C in July. Dodoma has an average rainfall of 570 mm per year, the bulk of which occurs during its wet season (unimodal) between November and April. The remainder of the year comprises the region's dry season (Mary and Majule, 2009).

2.3 The Wind as a Source of Energy

Wind is called a renewable energy source because the wind will blow as long as the sun shines. It has been harnessed for thousands of years. The wind's kinetic energy can be converted into other forms of energy, either electrical energy or mechanical energy. One of the oldest uses of wind energy is transportation, people use it to sail ships, and farmers also have been using wind energy to pump water and grind grain. But more recently, it has been widely used for special purposes such as generating electricity using wind turbines (Forsyth, 1997).

The employment of efficient wind turbines, which convert the mechanical energy of the wind into usable electrical energy, requires extensive use of physics. Wind turbines convert the kinetic energy in moving air into rotational energy, which in turn is converted to electricity. The turbines usually have blades mounted in horizontal axis or in a vertical axis. For a horizontal axis wind turbine (HAWT), the plane of the rotor (i.e. the blades and the hub) turns so that the wind is perpendicular to it and can flow around the blades to make them rotate around the hub. The horizontal shaft of the rotor also turns and runs a generator to which it is connected through a gearing system. The generator creates electricity from the mechanical energy and sends the resulting current down the tower to the electrical grid, which supplies electricity to the consumers (Carless, 1993).

The importance of accurate wind speed data becomes clear when one understands how the speed affects the power. Consider a disk of area A with an air mass dm flowing through that area. In a time dt the mass will move a distance U dt, creating a cylinder of volume $A\ U$ dt, which has a mass d$m = A\ \rho\ U$ dt, where ρ is the density of air. The power contained in the moving mass is the time rate of change in kinetic energy, given by

$$P = d(KE) / dt = d(\tfrac{1}{2} mU^2)/dt$$

$$= \tfrac{1}{2}U^2\ dm / dt,\ \textit{but } dm=\rho dxdydz,\ A=dydz,\ \textit{and } Adx=U,\ \textit{Where } A \textit{ and } \rho \textit{ are constants.}$$

$$= \tfrac{1}{2}A\rho\ U^3$$

Therefore, the power is proportional to the wind speed cubed (Boyle, 1996).

According to Oludhe (2008), the wind characteristics necessary for wind energy assessment studies are the wind speed strength, its direction and more critical its reliability. Wind speeds are known to vary significantly in both space and time and therefore wind resource assessment requires a careful and detailed space-time evaluation of the wind speed characteristics. Depending on the region, wind resources can vary from year to year, (seasonally), from day to day, (diurnally), and even from minute to minute (Turbulence). Long-term averages of wind speed and direction are most important for estimating power output at a given site. Seasonal and diurnal variations are important when considering peak demand and power supply.

2.4 Wind Electricity Generation Technology in Tanzania

According to Nzali et al., (1997) a few attempts have been made to install wind turbines for electricity generation in Tanzania which mainly has been for charging batteries located in Tabora region which is one of the region in central Tanzania. The other projects were installed in Manyoni district in Singida and at the Lindi, rural district. Due to the instability of wind regime the wind projects failed. In Karatu by then in Arusha region , a Spanish NGO has installed a wind turbine of 400W for electricity generation for battery charging, power lighting and powering of computers while at the Mang`ola a wind turbine of 1500W has been installed for charging a battery, lighting and for communication purposes.

Nzali (2000) quoted the Climatological Statistics for East Africa, Part III of Tanzania given by the East Africa Meteorological Department September 1975 that, for the 17 wind regions of Tanzania, the annual average wind speeds vary from 2.1 m/s in Morogoro to 6.3 m/s in Tanga regions. From the data which showed that the mean wind speed are Tanga, (6.3 m/s), Mtwara (5.7m/s), Dar es Salaam (5.4 m/s), Mbeya (5.4 m/s), Mwanza (4.9 m/s) Lindi (4.6 m/s), Ruvuma (4.5 m/s) Mara (4.3 m/s) windmills for electricity generation could be installed. This study showed that the wind energy technologies recorded in the study areas found to be used mainly for water pumping. It concludes that wind technology particularly for water pumping has a very good potential in this country since it has proved to be reliable and environmentally friendly.

However, there was no any fully fledged working wind energy technology for electricity generation. Wind energy technology for electricity generation demands higher wind speeds starting from 5 m/s, while for water pumping technology requires minimum wind speeds of 2 m/s. But for low energy power appliances it is possible to get a wind generator operating at 3 m/s for electricity generation (Kainkwa, 1999).

According to Kainkwa and Uiso (1989), some preliminary measurements show that Tanzania has a reasonably high wind power but this potential has not been used for many years because the type of available wind data is not sufficient to convince the government to invest in wind-generated electricity. This is because before one can decide to harvest the wind energy resource, that is very variable with time and space, systematic investigation of its characteristics needs to be done. The energy content at the site calculated for the period under study gives some light on the available wind energy at the site which is fairly high.

CHAPTER THREE

3.0 METHODS AND DATA ANALYSIS

3.1 Wind Data

According to literature, when there are no remarkable changes in terrain, wind speed can be applied as far as 25 km (Matthew, 2006). Detailed and reliable information about how strongly and from which direction the wind blows, and when, is vital for any prospective wind power potential assessment. Initial assessment of the wind resource available in Dodoma Region involved the study of the wind speed and direction data taken from Tanzania Meteorological Agency. The data originate from Dodoma Synoptic Station and wind speeds are given in knots at the standard recording height of 10 m above ground level. The wind speed is estimated from knots into m/s by using the relation 1knot = 0.514m/s. The average monthly wind speed for six years and the frequency distribution of the wind velocity were determined from the six year three hourly wind speed raw data collected from the station located at the airport between 2007 and 2012.

3.2 Extrapolation of wind speeds to higher heights

Wind speed tends to increase with height in most locations, a phenomenon known as wind shear. The degree of wind shear depends mainly on two factors, atmospheric mixing and the roughness of the terrain. Atmospheric mixing typically follows a daily cycle driven by solar heating. At the hub height of a wind turbine, this cycle often causes wind speeds to increase in the daytime and decrease at night. However, the range of variation between night and day typically diminishes as hub height increases. At a height of approximately 50 meters, it weakens or may even disappear in some cases (Chaudhry, 2008).

The atmospheric boundary layer extends to the first few 100 m above ground level, and therefore the friction offered by earth's surface affects wind speed. While smooth surfaces like water offer low resistance, irregular surfaces such as forests and buildings offer higher resistance. An expression that takes into account this effect on the wind speed is the power law represented as follows

$$U_Z = U_{10} X \left(\frac{Z}{10}\right)^{\alpha} \quad \text{---------------------------------} (1)$$

Where, U_z is the average wind speed at a given height Z, U_{10} is the average wind speed at 10m, Z is height at the wind speed is estimated and α is an empirically derived friction coefficient that varies dependent upon the stability of the atmosphere. For neutral stability conditions at open lands, α is approximately 1/7, or 0.143. This relationship were used extrapolate wind speed from 10m to 50m (Masters, 2005).

The power law is the easiest way to calculate the increase in wind speed with height. Another approach is using logarithmic extrapolation. This is a mathematically derived from a theoretical understanding of how the wind moves across the surface of the earth while the power law equation is derived empirically from actually measurements. This makes the power law to work better and more conservative than the logarithmic method (Ramachandra *et al*., 1997).

According to the calculations of wind resource analysis program (WRAP) report, in 39 different regions, out of 7082 different wind shear coefficients, 7.3% are distributed between 0 and 0.14 and 91.9% above 0.14, while 0.8% is calculated as negative, due to the measurements error (Ramachandra *et al*., 2005). So the use of 0.143 as friction coefficient could give a good estimate of wind speed at higher heights.

3.3 Wind Characteristics over Dodoma

As the wind power is proportional to the cubic wind speed, it is crucial to have detailed knowledge of the site-specific wind characteristics. Even small errors in estimation of wind speed can have large effects on the energy yield, but also lead to poor choices for turbine and site. An average wind speed is not sufficient. A site wind characteristics pertinent to wind turbines included were wind speed distribution: monthly, diurnal, annual patterns, Inter-annual wind speed variation, distribution of wind direction and mean wind speed. Wind speed frequency distribution was simply obtained by plotting the different wind speeds against their frequencies / relative frequencies. The diurnal and monthly wind profiles were also obtained by plotting the average wind speed at a certain time of a day and the month respectively

3.4 Wind Power Density (WPD) estimation

WPD can be defined as the power available from wind per unit area (perpendicular to the wind direction), averaged over a year at a particular site, and is expressed in watts per square meter. While investigating a wind power potential of an area, the average values of wind speed does not truly represent this potential because lot of information regarding frequency distribution of wind speed is suppressed in the process of averaging wind speed. In this regard, the power density of turbine is a good comparative indicator to show the average power output per m² of wind-swept area A, at a given site. This can be defined as:

Power Density, $\boldsymbol{P = \frac{1}{2} A\rho\, U^3}$ -------------------------------- (2)

Where ρ is the air density (*kg/m*^{3}) and *U* is the mean speed in (*m/s*). The area *A* depends upon the size of the rotor. Therefore, it is clear that power density chiefly depends on wind velocity and goes up as a cube of it (Burton *et al*., 2001).

3.5 Wind Power Class

While eq. 2 depicts the instantaneous power extracted from the wind, a good indicator of wind energy generation potential of a site is the annual average WPD, which accounts for variations of wind speed and thereby, power produced at any instant. The estimation of wind potential as resources was done by comparing the monthly average wind speed to the wind power class. To simplify the characterization of the wind power potential, it is common to assign areas to one of seven wind classes, each representing a range of wind power density at the special height above the ground. The standard International wind power classifications are shown in Table 1. This will enable to know the wind power density for different wind speeds using a comparative analysis of the Wind Speed Scale at 10m heights or when computed to 50m (Yaniktepe, 2010)

Table 1: Wind power class

Wind Power class	10m		50m	
	Speed (m/s)	Wind power density (W/m^2)	Speed (m/s)	Wind power density (W/m^2)
1	4.4	100	5.6	200
2	5.1	150	6.4	300
3	5.6	200	7.0	400
4	6.0	250	7.5	500
5	6.4	300	8.0	600
6	7.0	400	8.8	800
7	9.4	1000	11.9	2000

By and large, the areas being developed today using large wind turbine are ranked as class 5 and above. Class 4 areas are also being considered for further development as wind turbines are adopted to run more efficiently a lower wind speeds. Class1 and class2 areas are not being deemed suitable for large machines, although a smaller wind turbine may be economical in areas where the value of the energy produced is higher (available at http://www.awea.org/faq/basicwr.html "American Wind Energy Association").

3.6 Converting from Wind Speed to Power Output

The power output of wind turbines is dependent on a range of factors, however turbine size and wind speed are strongly related to electricity output. The rated capacity of a wind turbine represents the maximum power measured in watts, which each individual wind turbine can produce under suitable wind conditions. Power is generally presented as kilowatts (kW) or megawatts (MW). The energy produced by a wind turbine is equal to power output multiplied by time (Forsyth, 1997).

Wind turbines have specific wind speed range within which they operate, with wind power output dependent on the speed of the wind. Table 2 and Figure 2 show relationship between wind speed and power output for a 2000kW Gamesa G90 wind turbine. For this turbine, electricity is generated by the turbine when the wind reaches 3m/s (cut-in speed) and cut-out speed of 25m/s. Between 3m/s and around 14m/s the power output of wind turbine varies in response to changes in wind speed. Between 14m/s and 25m/s the power output of wind turbines has reached a maximum and is essentially constant, irrespective of wind speed changes (figure 2). Some of the properties of Gamesa G90-2.0 MW IIA model are as follows: Diameter= 90 m, Swept area A= 6,362 m^2, Rated power= 2.0 MW, Power factor = 0.95

According to Ramachandra *et al*., (1997) the Wind power is computed as follows,

Wind power =Average (Power Density) * Swept area

Wind energy = [[Wind Power * (Count of days * 24)]/1000] * Plant Load Factor

Table 2: Conversion of wind speed to power output for a 2000kW wind turbine

Wind speed at hub height 50m	Power output	Wind speed at 50m	Power output
1	0	15	2000
2	0	16	2000
3	21	17	2000
4	85	18	2000
5	197	19	2000
6	364	20	2000
7	595	21	2000
10	1649	22	1906
12	1971	23	1681
13	1991	24	1455
14	1998	25	1230

Available at www.awea.org/faq/basicwr.html

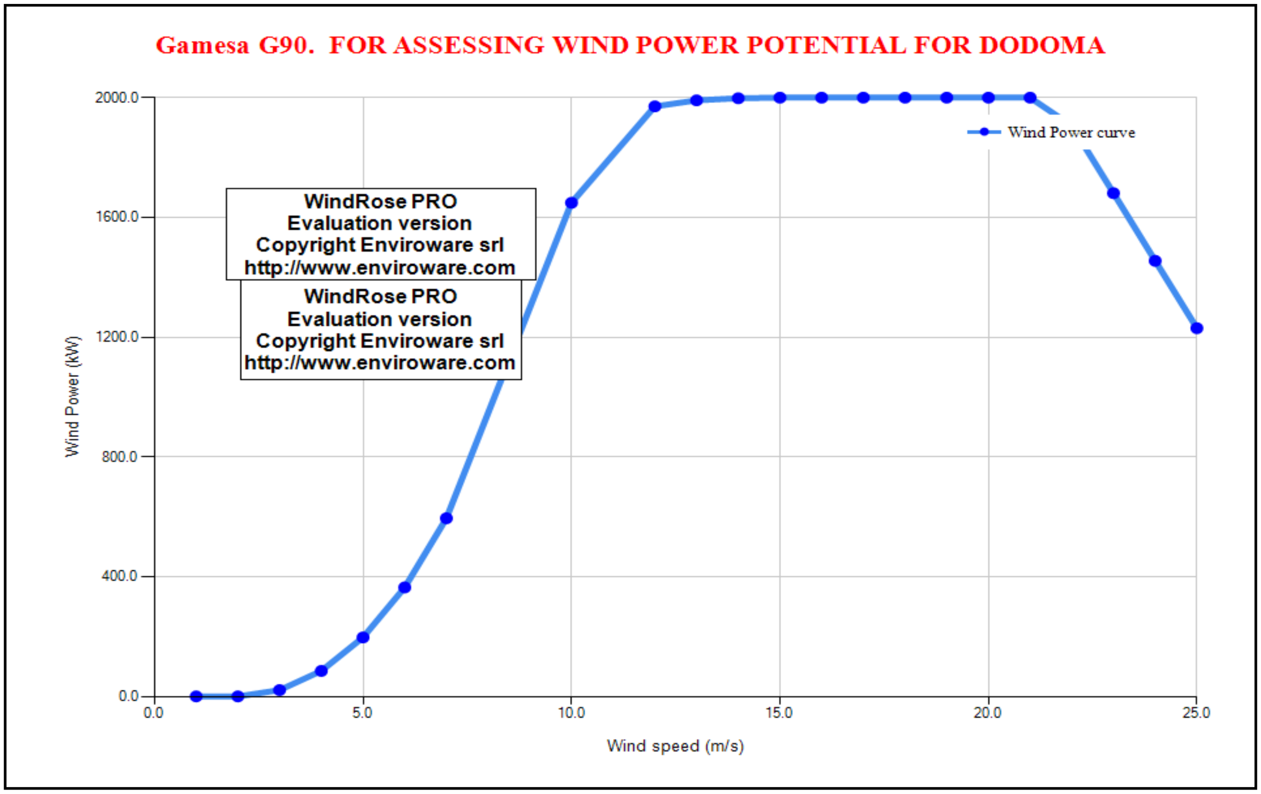

Figure 2: Graphical representations of the wind speed and potential wind power

This is a step involved in moving from a wind speed to a power output. First, the wind speed is adjusted to take it from the location at which it was measured to the location at which it is being 'used', so these two places must be identified. As has already been mentioned, all of the wind data essentially originated from airports and measurements were taken at a height of 10 m. The original wind speed data were to be corrected for two things; height above ground and ‘roughness’ of surface. Equation 1 shows how this correction is carried out. So the wind speed increases logarithmically with height, but the shape of the profile is dependent on the aerodynamic roughness length of the underlying surface. For the purpose of this study these figures are taken to be the average hub height of a flat surface wind turbine (50 m) since the data is from the station at the airport. Figure 2 shows that when the wind speed is below 3m/s and above 25 m/s no power is produced and that the amount of power increases non-linearly between 4m/s and 14 m/s, after which the power output remains at its maximum up to the 25 m/s cut off. The power production cuts off at an upper limit of 25 m/s in order to prevent damage to the turbine in gale force conditions (Jianq *et al*., 2008).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Temporal characteristics of wind over Dodoma

4.1.1 Monthly wind profile

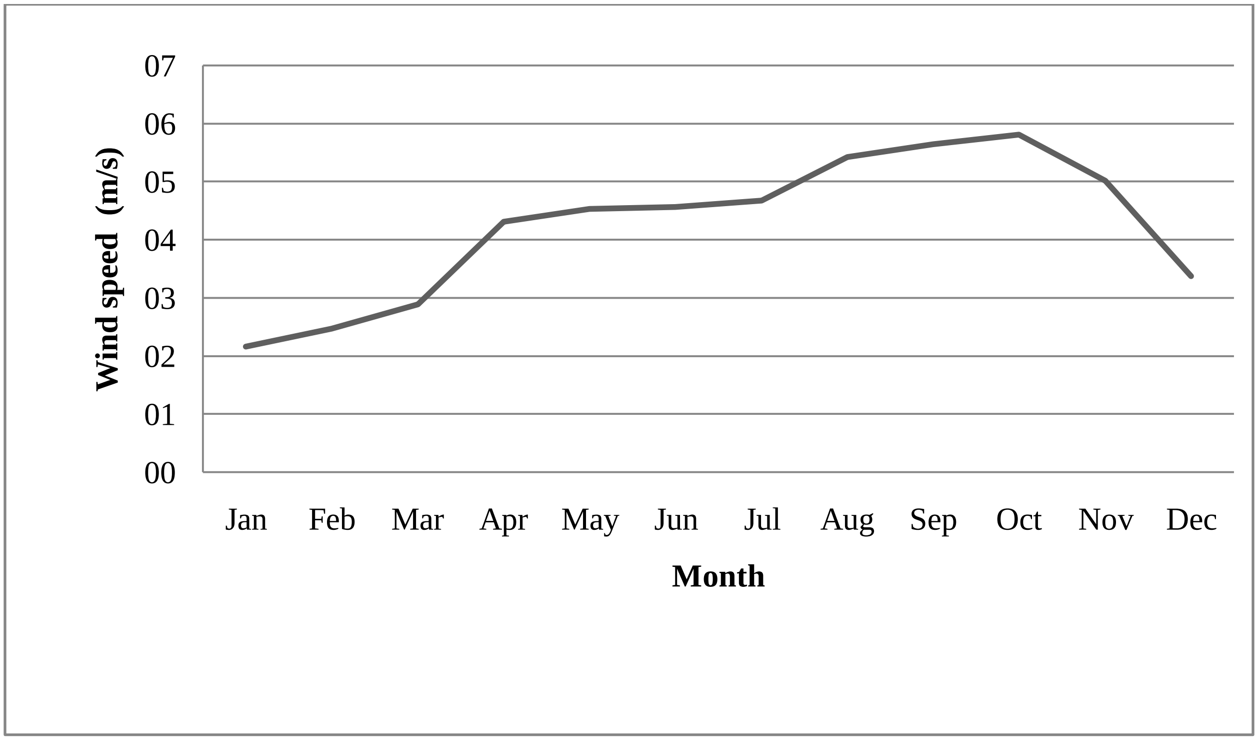

Figure 3.1: Monthly Average Wind Speed at 50m

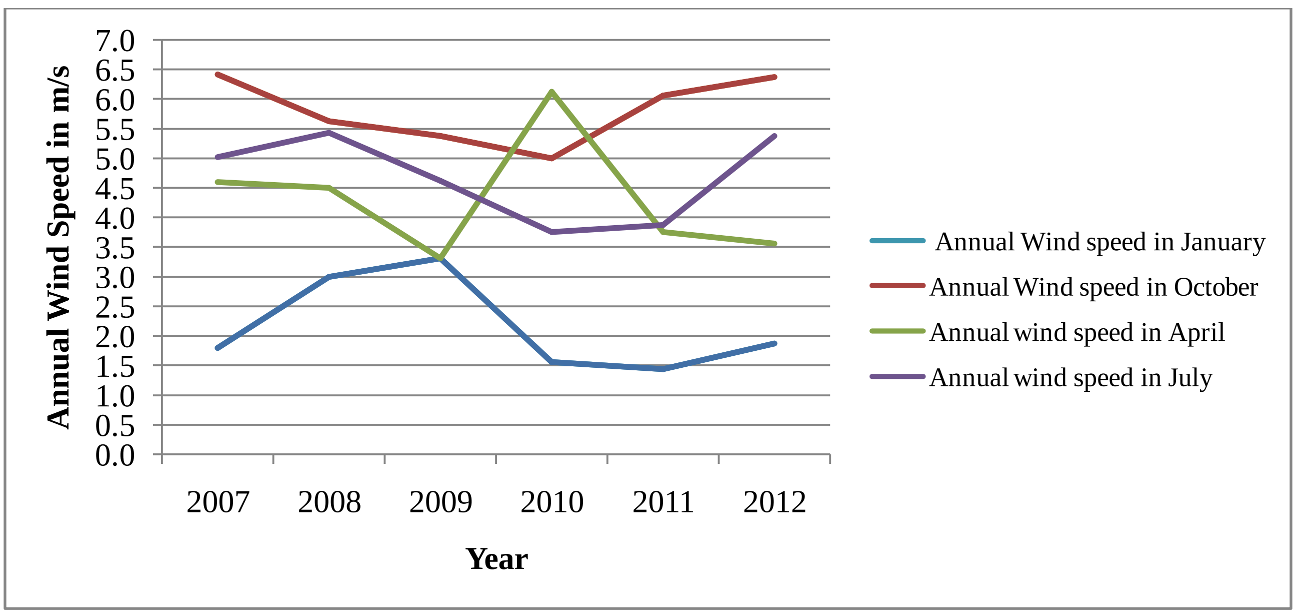

Figure 3.2: Annual average Wind speed for January, April, June and October at 50m

The monthly variation of wind speed at 50 m over Dodoma (figure 3.1) shows the general increasing average wind speeds from January reaching the maximum in September and October. It decreases thereafter to December. The months of April and May, when wind speeds start to be highest are months of transition between the wet and the dry season over the region, which seem to be characterized by strong winds.

The weak winds take over in the third week of November which is when the wet season starts properly in region. During this period the region is characterized by low pressure systems. The winds converge over the area causing calm to low wind speeds conditions. The region has unimodal rain season which starts in late November and end up in April. The average wind speeds remain low throughout the wet season. This explains the seasonal characteristics of the wind speeds as noted earlier. Thus power generation will peak during the months of May to November while lowered from December to end of March.

The comparison between the selected months, calmest month (January), the transition period (April), the middle of the dry period (July) and the windiest month (October) in figure 3.1, shows that for all years the average wind speed in January remained minimum than in any month of April, July or October of any year (figure 3.2). January of every year has wind speed between 1.5m/s and 3.5m/s which is not enough for power production.

The mean annual wind speed during this period (2007-2012) was 5.5 m/s (Figure 3.1). Mean monthly wind speed in Dodoma was above the annual average from about mid July to Mid November. From August to October the wind speed was above 5.5 m/s and also is fairly steady with little fluctuations. From June to December, the wind speed was above 5.0 m/s. According to Kainkwa (1999), wind speeds from 5.0 m/s has been proposed as feasible for energy extraction. The windy season happen together with the time when most parts of Tanzania are usually dry making the use of wind energy, in electricity generation important. This can help to lessen the shortage of electricity from hydropower plants that normally prevails during the dry season.

December to April was a calm period because wind speed was far below the annual average. This calm season coincided with the wet season in most parts of the country when there is usually sufficient water in the rivers and dams to run the hydroelectric power plants. Except for December to March, wind speed was greater than 4.0 m/s. The minimum value of monthly wind speed was slightly above 5.0 m/s as recorded in April to November. This minimum value is enough for turning wind turbine. Therefore if a wind turbine whose hub height is 50 m is installed at the site in the Region, it would produce electricity during this period.

The wind turbine with a cut-in wind speed of at most 4.0 m/s would thus generate electricity most time of the year for the site of such wind speed averages. According to Stevens and Smulders (2007), small-scale converters adapted for lower wind speeds are now available and even wind speeds around 3.0 m/s may be found of interest for remote decentralized grids. Under such conditions small turbines can be valuable and a higher cost of energy may only be acceptable as the alternative generally is fuel-dependent diesel generators.

4.1.2 Diurnal wind speed distribution

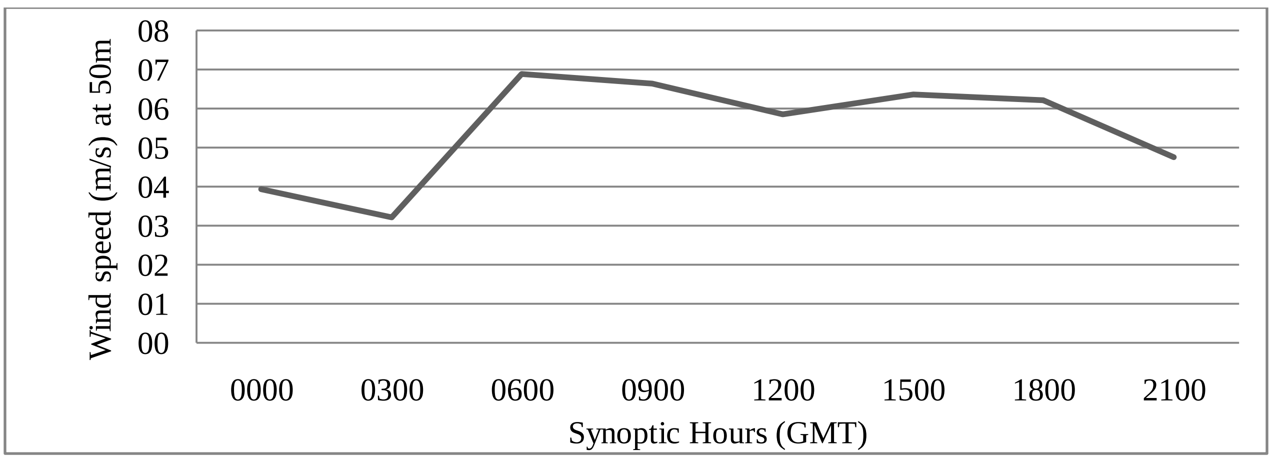

Figure 4.1: Annual Diurnal Wind speed distribution

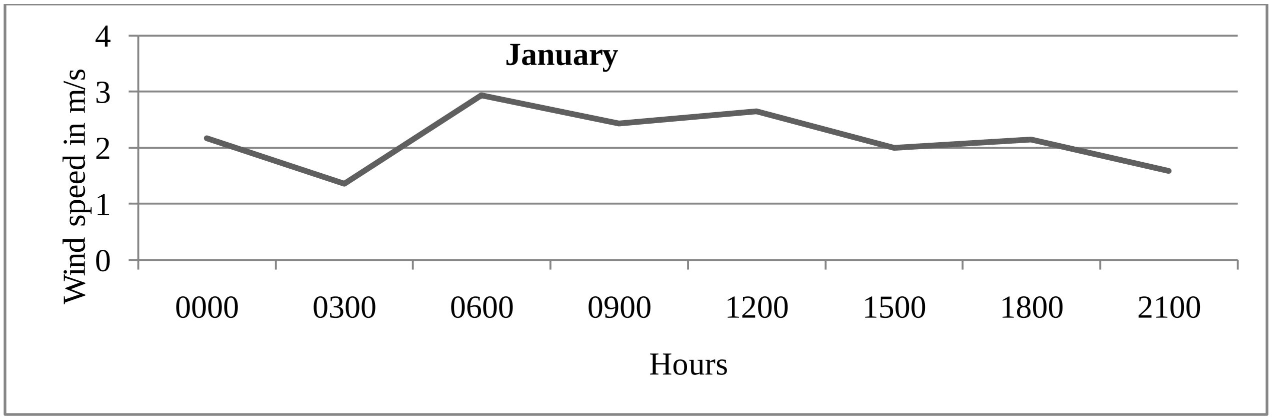

Figure 4.2: Diurnal wind speed distribution for January

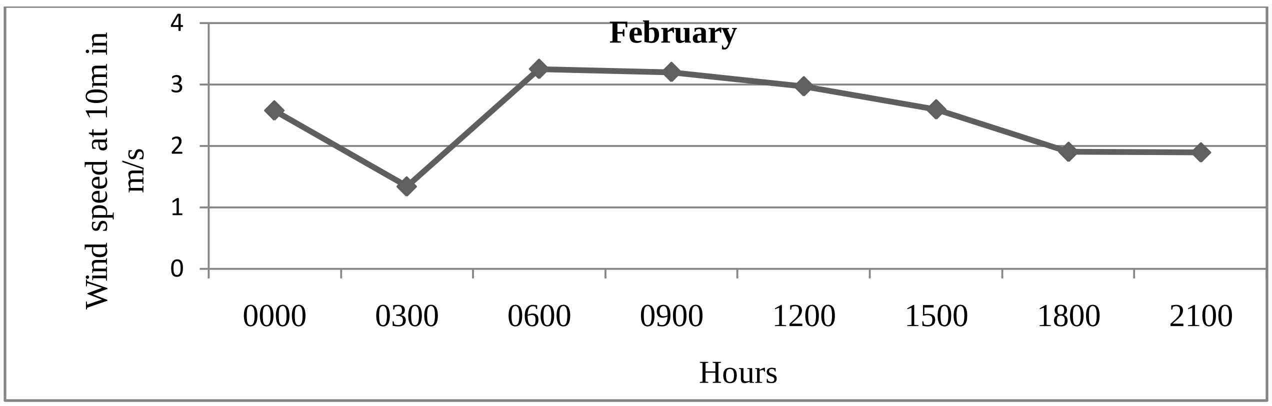

Figure 4.3: Diurnal wind speed distribution for February

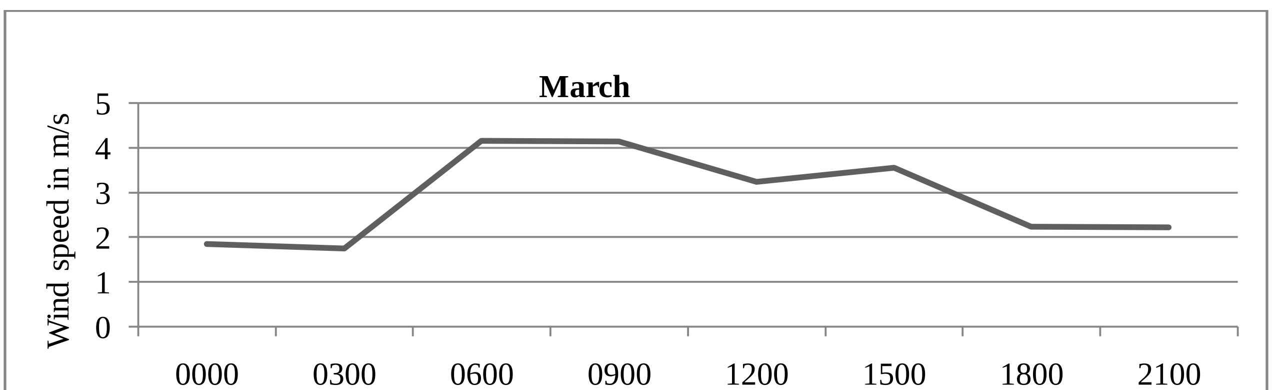

Figure 4.4: Diurnal wind speed distribution for March

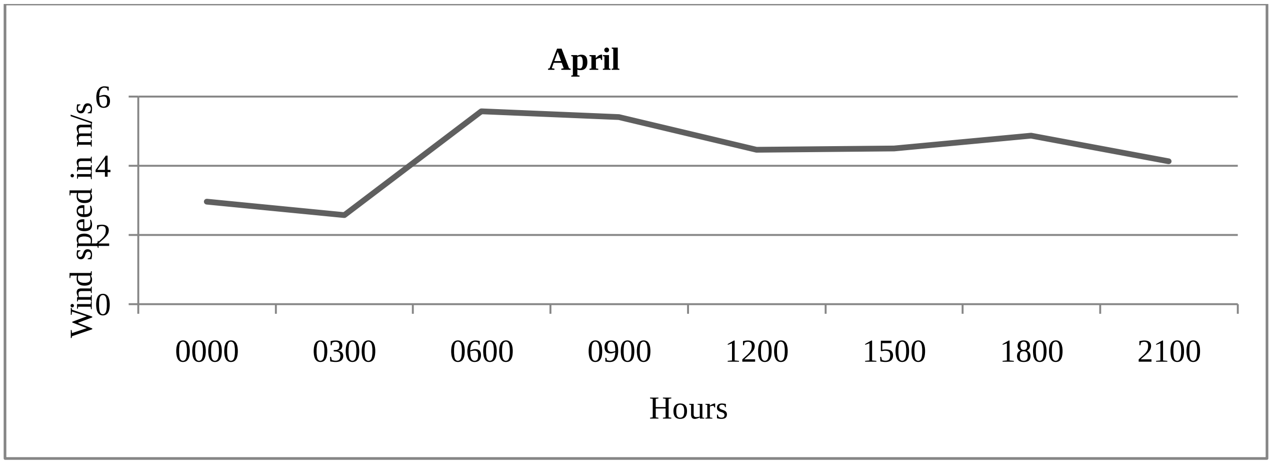

Figure 4.5: Diurnal wind speed distribution for April

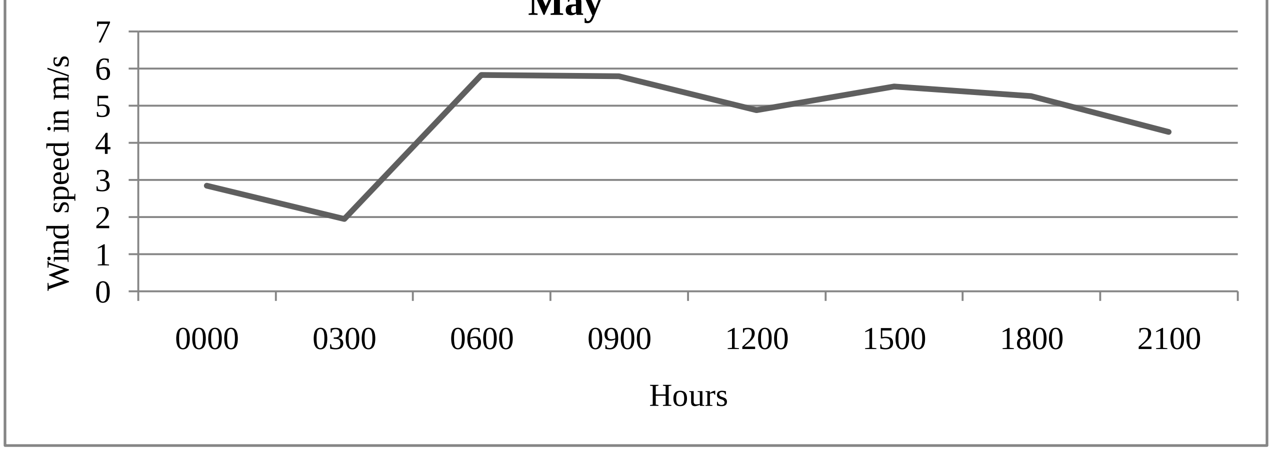

Figure 4.6: Diurnal wind speed distribution for May

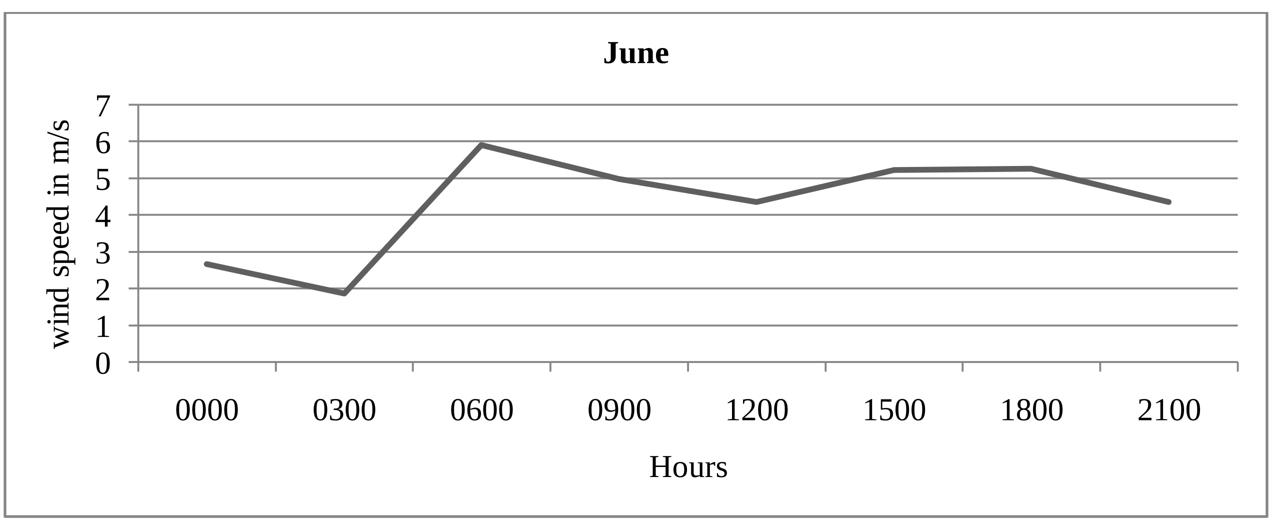

Figure 4.7: Diurnal wind speed distribution for June

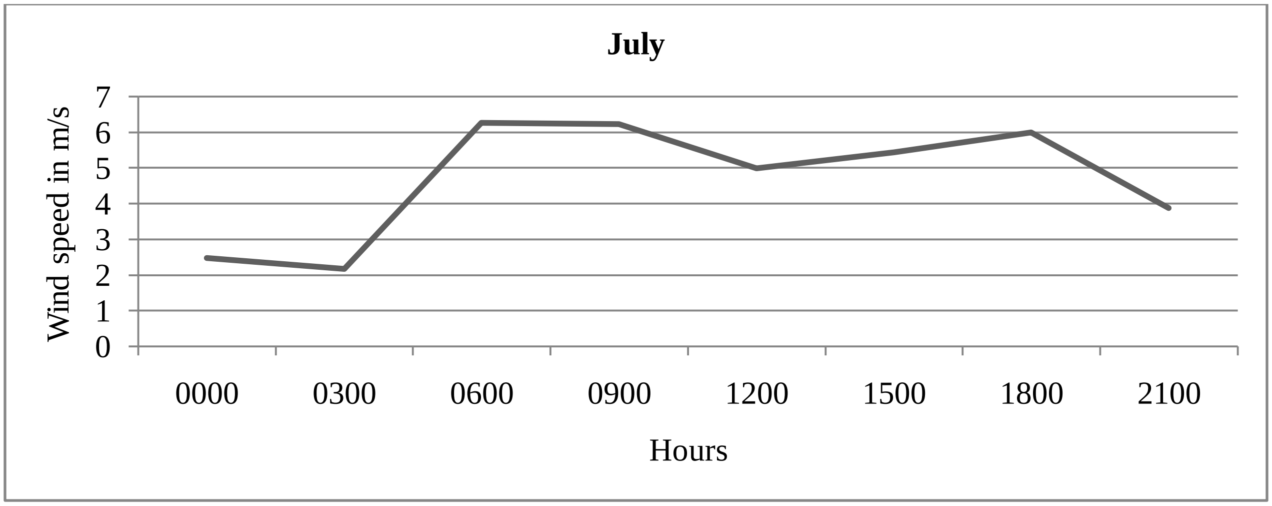

Figure 4.8: Diurnal wind speed distribution for July

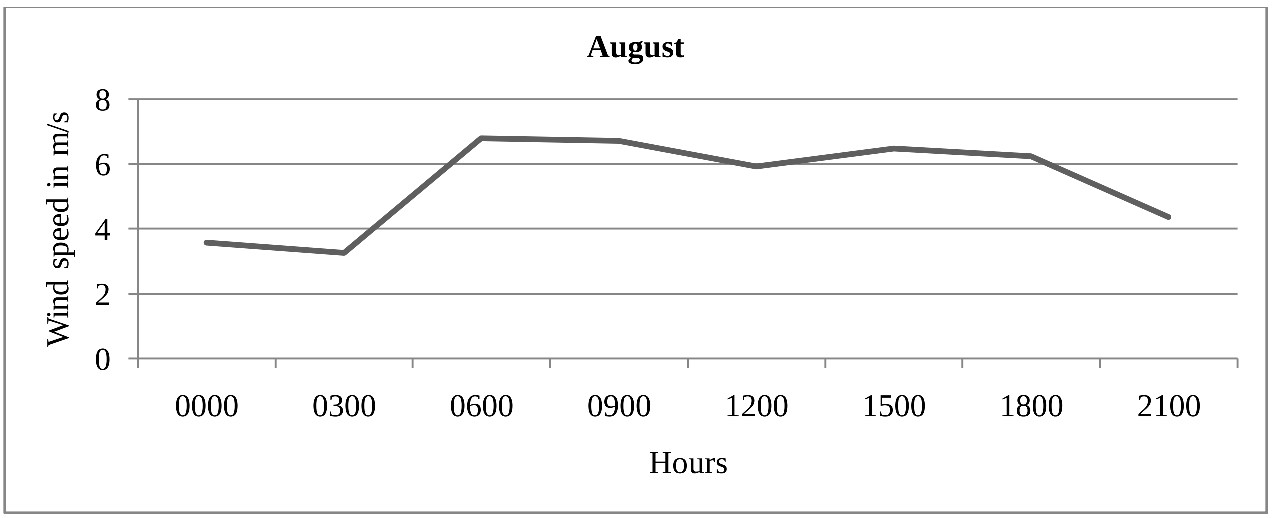

Figure 4.9: Diurnal wind speed distribution for August

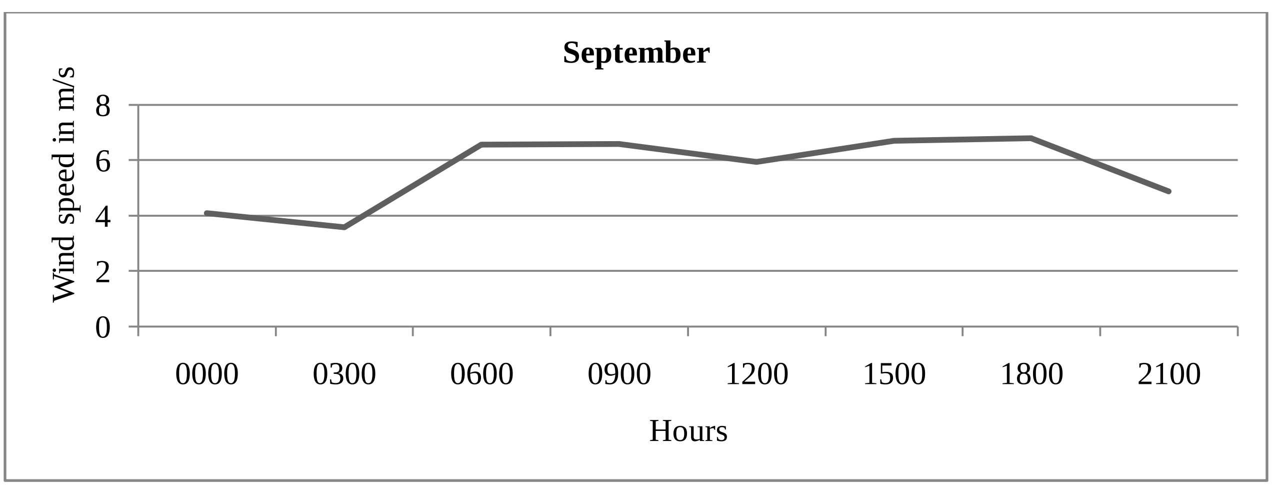

Figure 4.10: Diurnal wind speed distribution for September

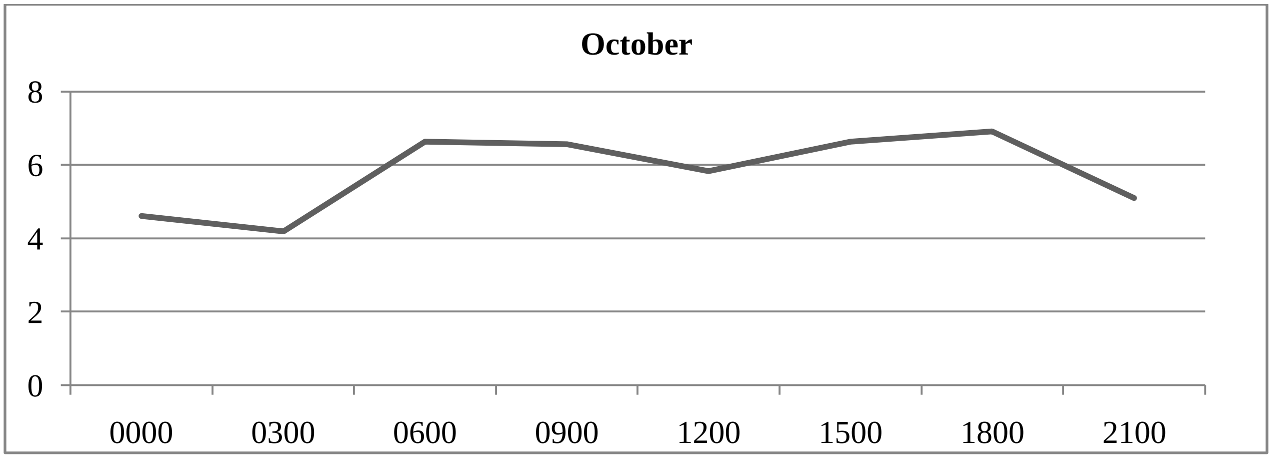

Figure 4.11: Diurnal wind speed distribution for October

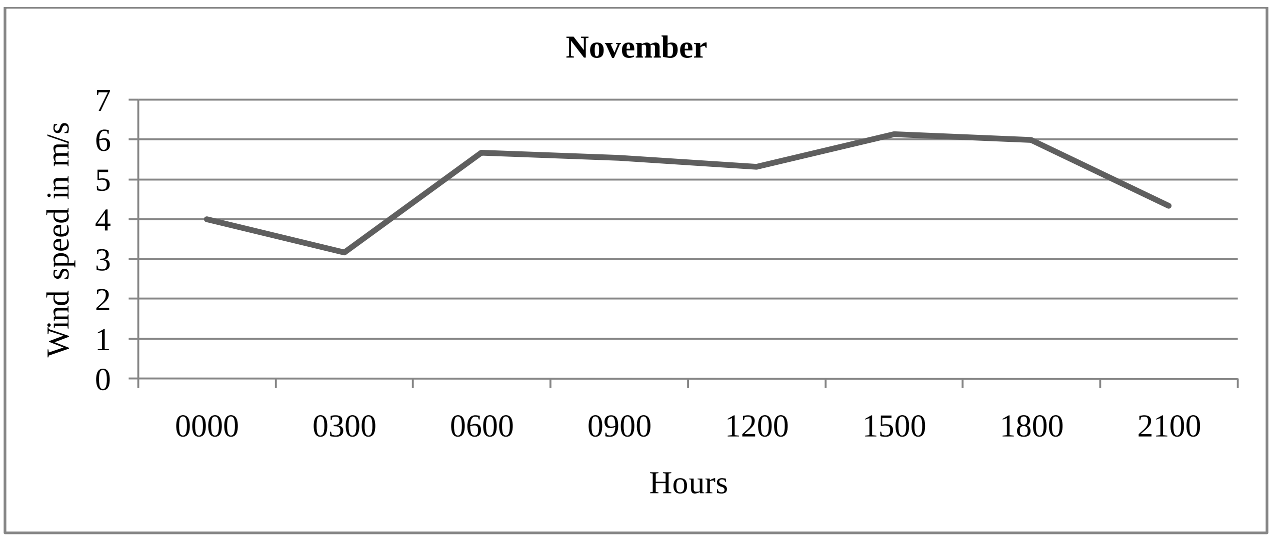

Figure 4.12: Diurnal wind speed distribution for November

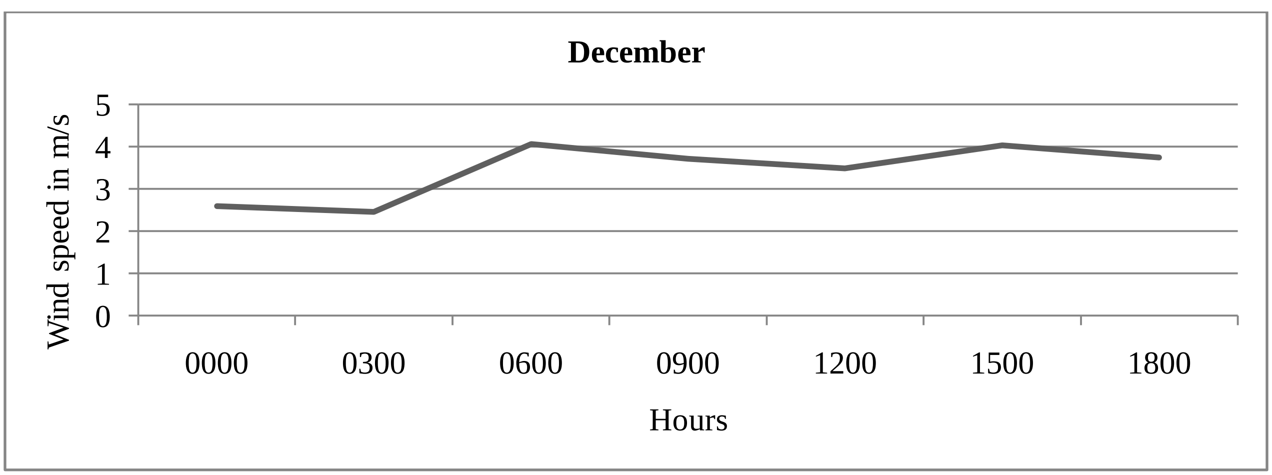

Figure 4.13: Diurnal wind speed distribution for December

Amounts of wind generally change systematically throughout the day (diurnal variations) as a result of the sun warming the Earth's surface. This effect can be seen in the data (Figures 4.1 - 4.13), although it is only constrained at eight times of the day (0000, 0300 0600, 0900, 1200, 1500 1800 & 2100). This can make difficult to ascertain at exactly what time of day it tends to be most windy for example. Out of the eight times of the day at which data were available, around 0600Z to 0900Z was consistently most windy.

Changes in the thermal energy input to the atmosphere due to earth's rotation result in a diurnal variation in wind speed. The diurnal variation of heat energy (temperature) and pressure will determine the magnitude of wind speed. Maximum wind speeds are usually realized in the afternoon when the earth's surface and atmosphere attain maximum temperature. Minimum winds occur in the morning hours just before sunrise when we have minimum temperature. High diurnal variations in winds are usually more pronounced in the local winds such as land and sea breeze and mountain and valley winds. The diurnal variation of wind speed depends on the vertical exchange of momentum.

In this region the thermal eddy (rising air) starts at around 0600Z. The air near the ground becomes warmer and rises. The air moving down from higher levels to take up the place of the rising air is from a layer of faster moving air, and hence higher momentum. This air brings with itself high momentum to the lower level and hence surface winds increasing.

Characteristic daily cycles for three hourly wind speeds shown above shows that the maximum wind power production is during 0600Z to 1800Z. However the results suggest that the daily wind power does have distinctive monthly patterns; some months are more prominent than others as portrayed in the monthly graphs in figures 4.2 – 4.13. Some months have maximum wind speed for many hours compared to other months. The months of May to October show this pattern. These average daily wind profiles show that for this particular Region wind power levels are generally higher during the day and early night hours than those during the late night and early morning. The monthly graphs (figure 4.2 – 4.13), show that the wind speed starts to increase around 0600Z in every month of a year and decreasing in the late night.

4.1.3 Inter-annual wind speed variation

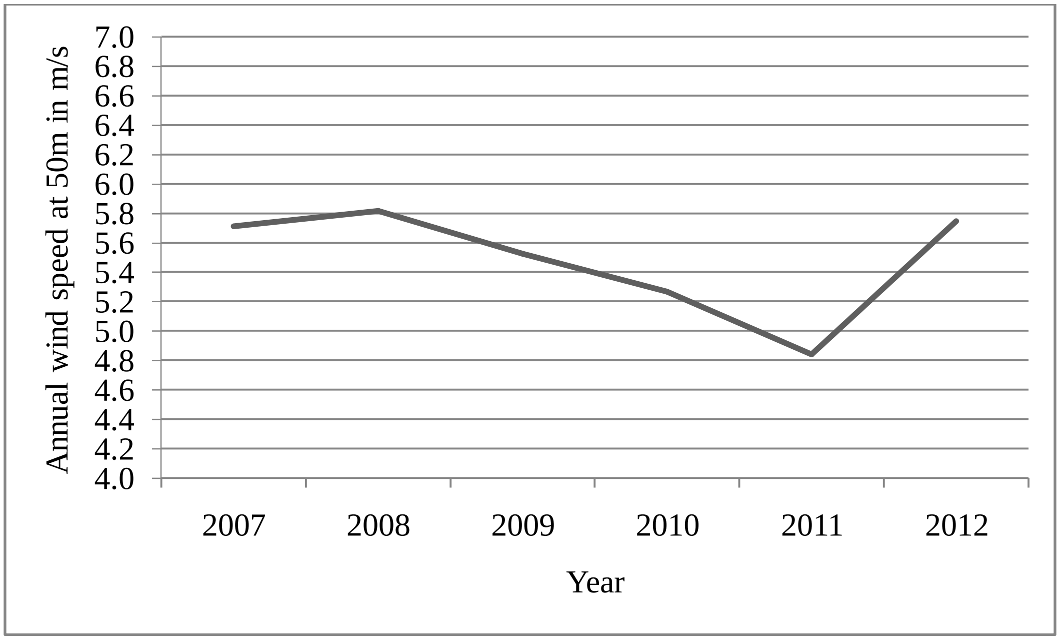

Figure 5: Annual Wind speed variation between 2007 and 2012

The average wind speeds for 2007, 2008, 2009, 2010, 2011 and 2012 were 6, 6, 6, 5, 5 and 6 m/s respectively. The variation among these figures is 0.26 which is very small when compared. However a time period of decades rather than years would need to be analyzed to properly asses the long period behavior of annual wind patterns. The average wind speed for every year of study is enough for generation of electricity.

4.1.4 Annual wind speed variation

The figures (6.1 -6.6) shows the monthly variation of wind speed at each year

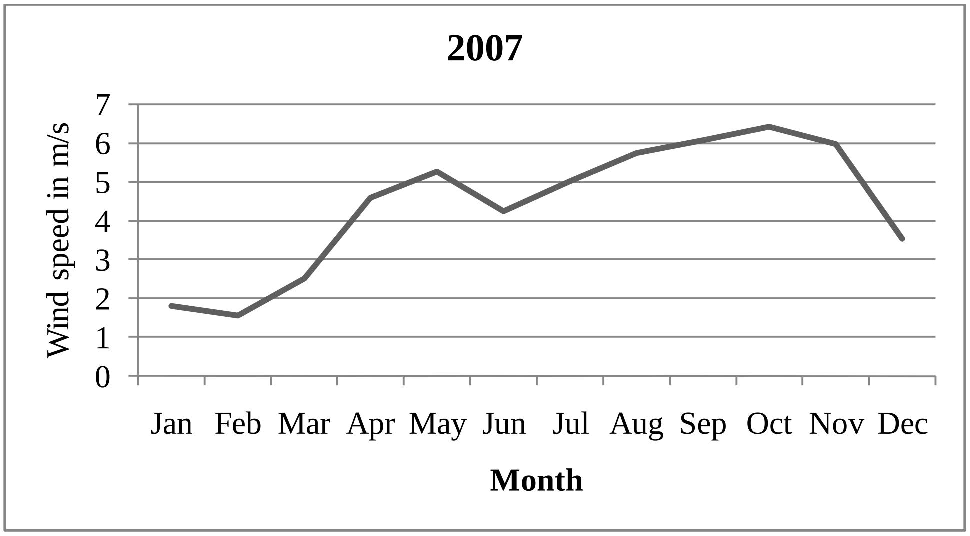

Figure 6.1: Monthly variation of wind speed for 2007

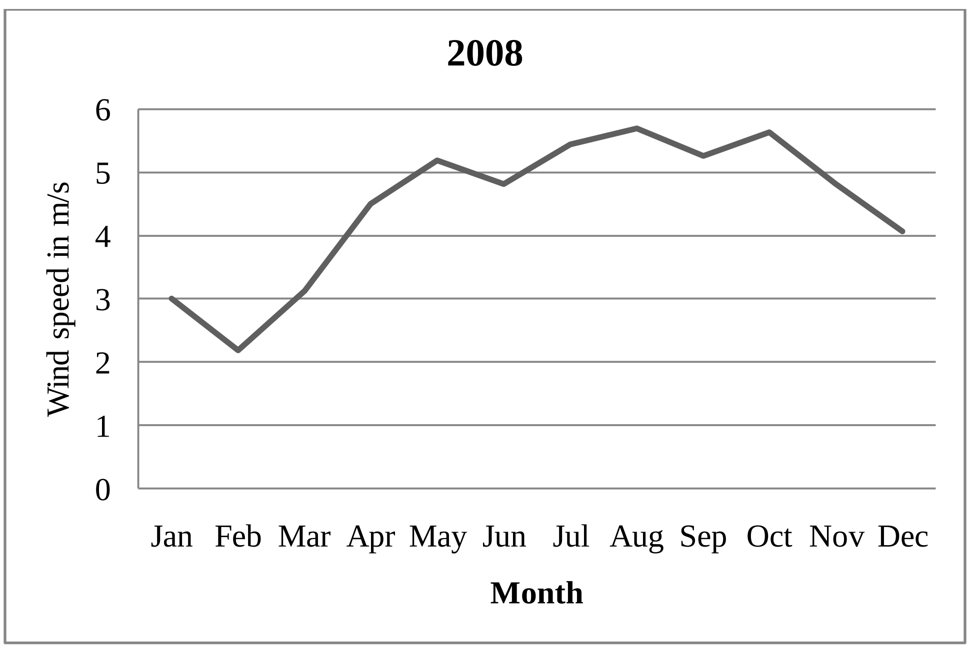

Figure 6.2: Monthly variation of wind speed for 2008

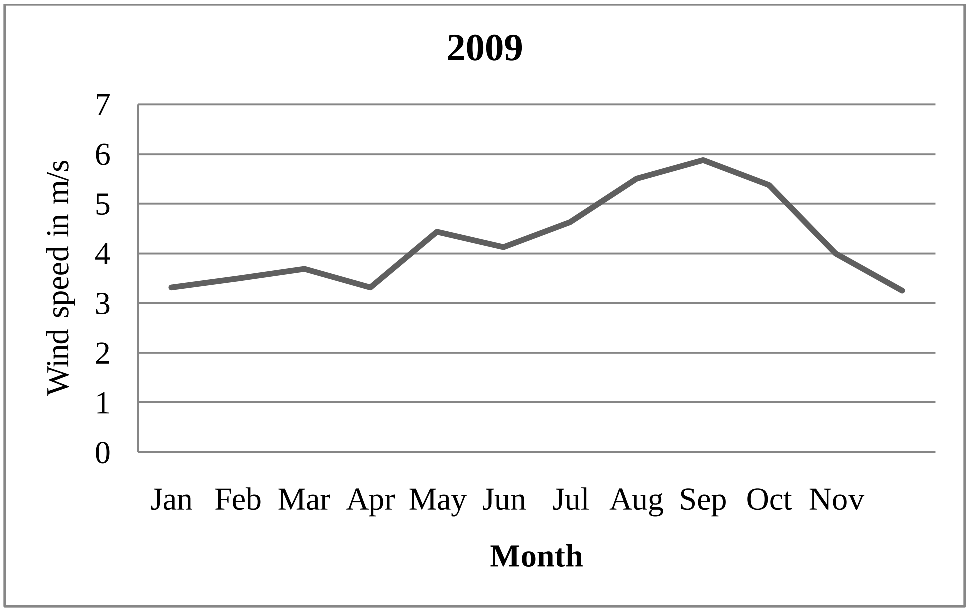

Figure 6.3: Monthly variation of wind speed for 2009

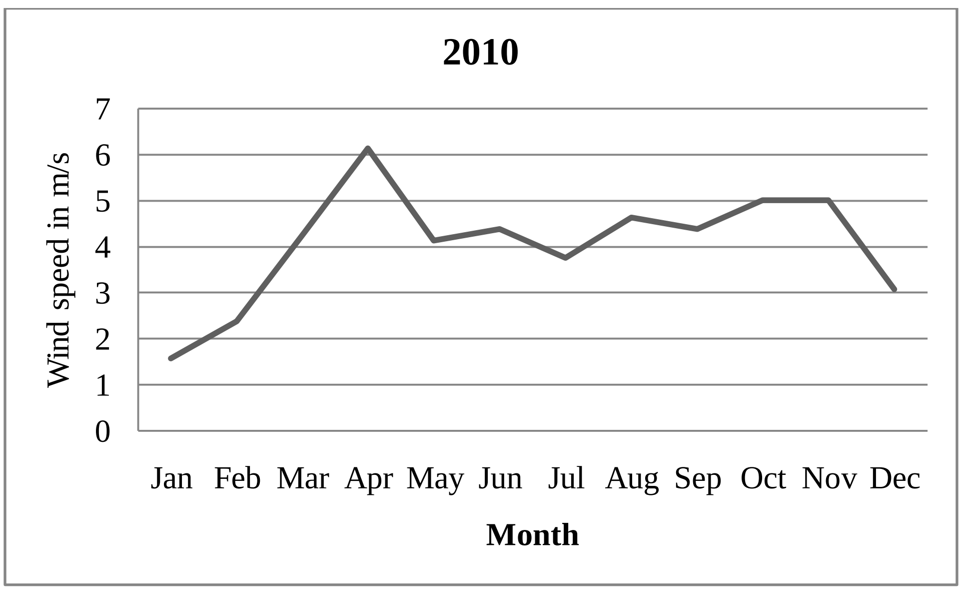

Figure 6.4: Monthly variation of wind speed for 2010

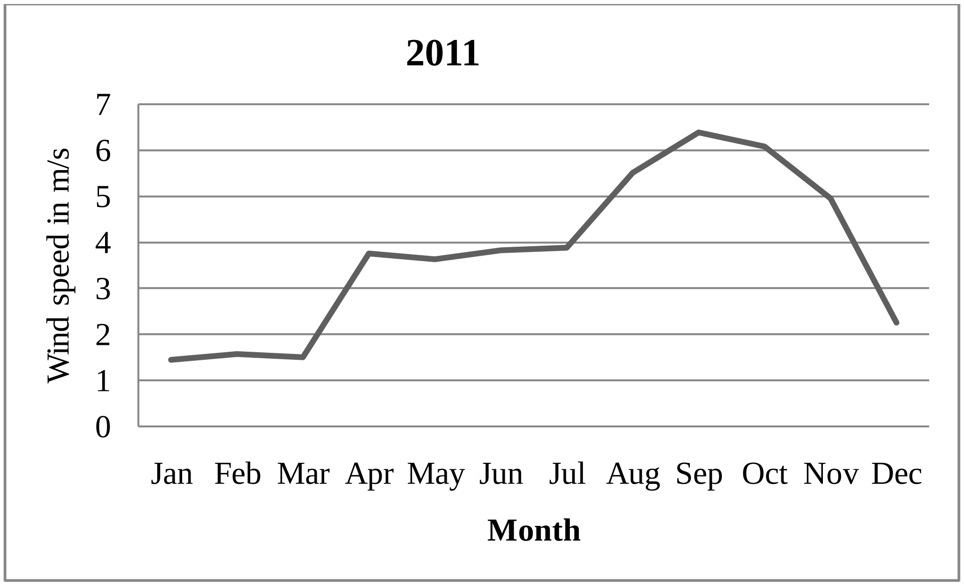

Figure 6.5: Monthly variation of wind speed for 2011

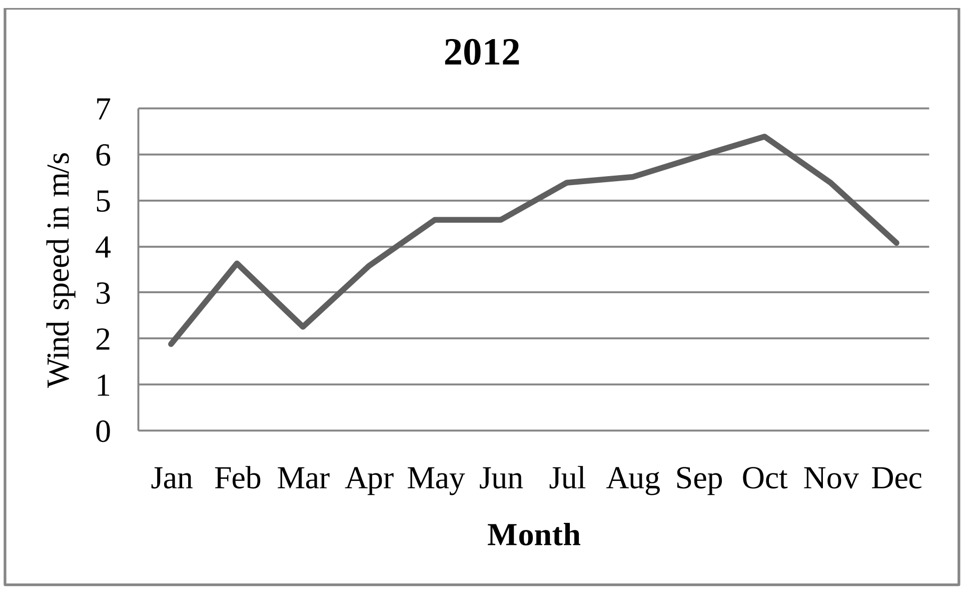

Figure 6.6: Monthly variation of wind speed for 2012

At least all years show similar patterns of wind speed. The wet months are characterized by low wind speeds while the dry months by strong winds.

4.2 Wind direction patterns

4.2.1 The wind rose

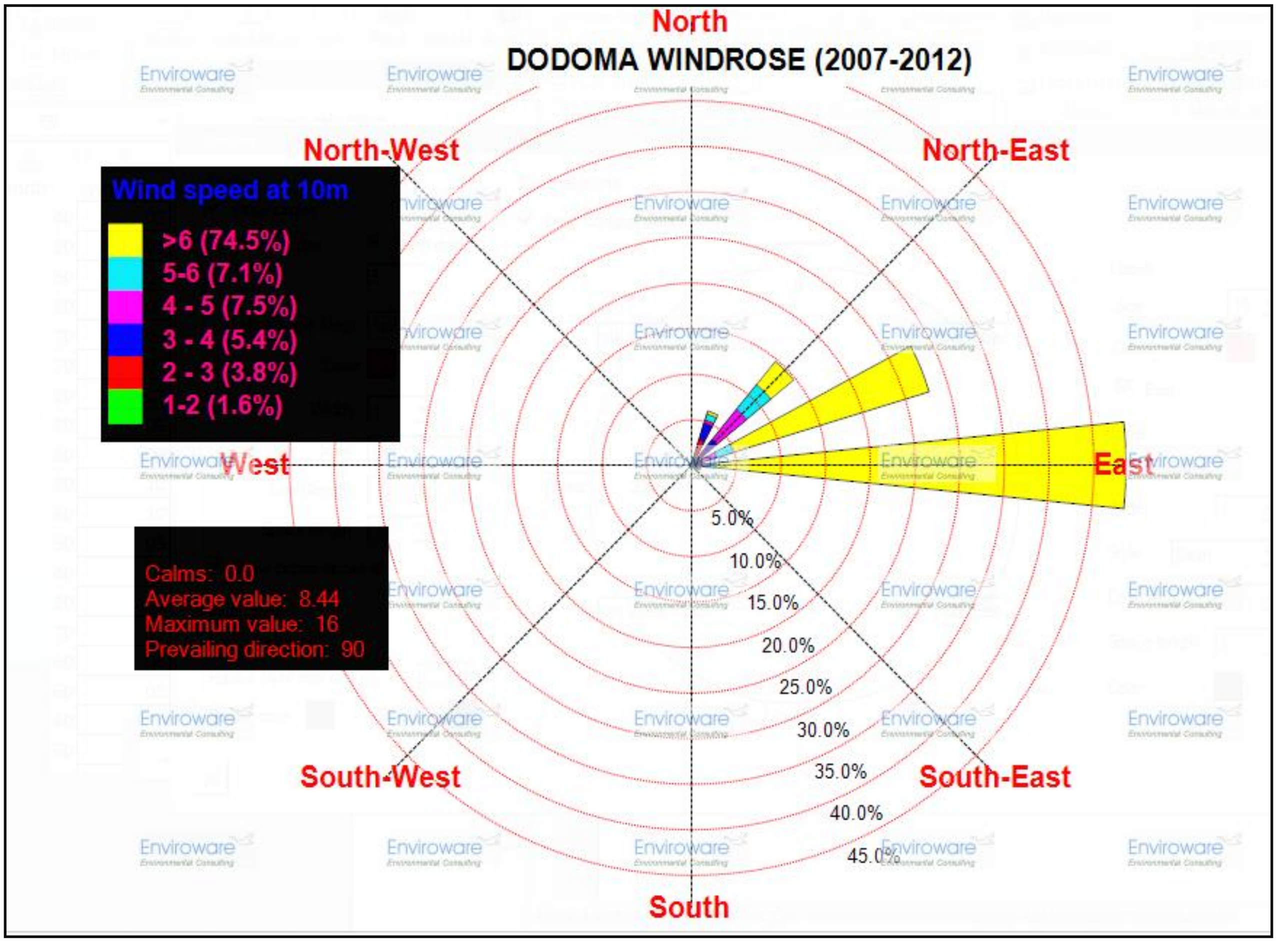

Figure 7: Wind direction frequency distribution

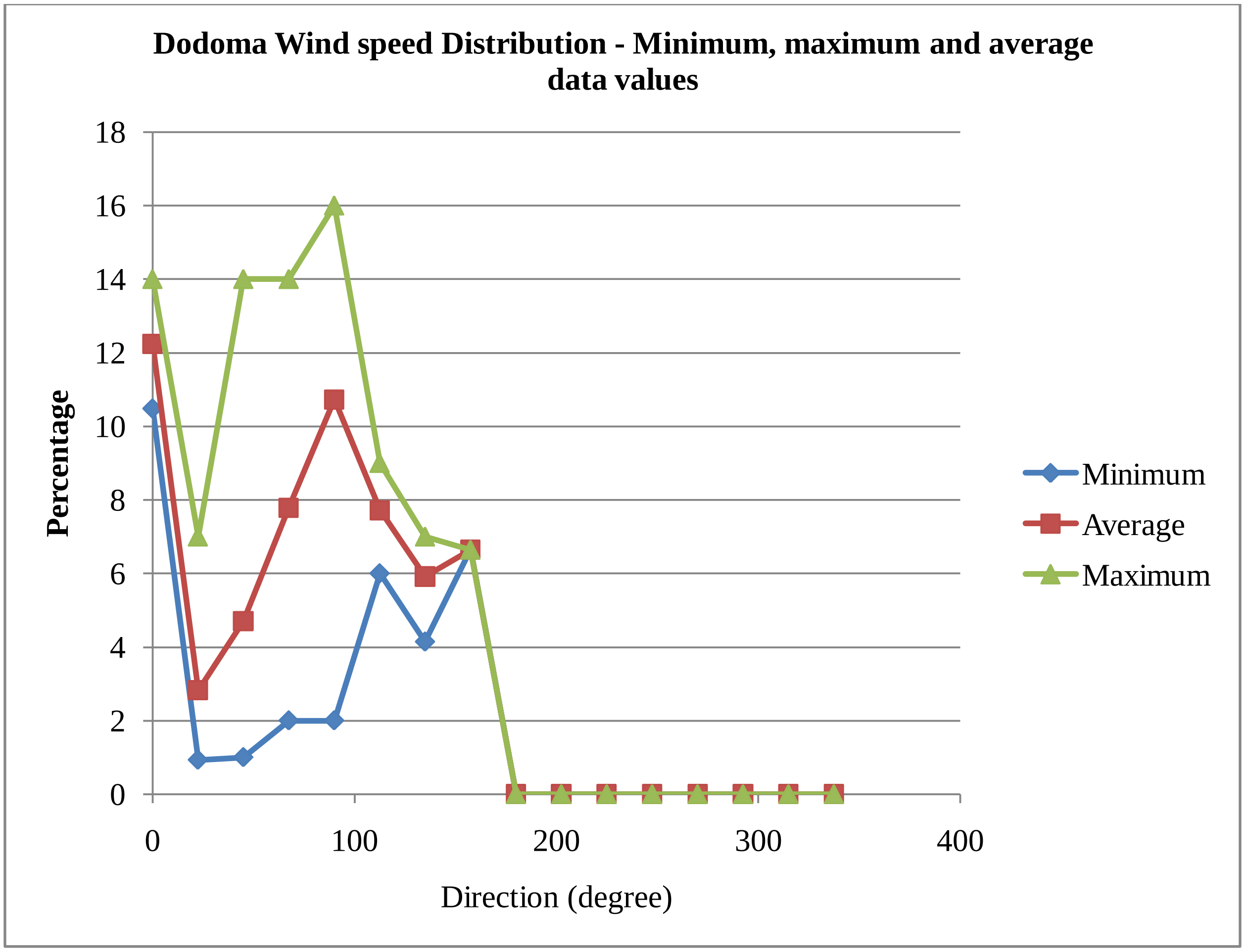

Figure 8: The frequency distribution of maximum, minimum and average data values

Dodoma's wind climate is characterized by low wind speed during summer (wet periods) and strong winds during winter (dry periods) and mostly from East and North-East. Figure 7 shows the Wind Rose based on 72 months data from January 2007 to December 2012 collected at 10 meters height and direction. This Wind Rose indicates that most of the time the wind direction was East to North-East. The annual average wind speed is 8.44 knots and the percentage of time when wind speed was more than 6.0 knots was about 74.5%. No month with average calm winds.

Both minimum, maximum and the average of data values (figure 8) show that the wind speed is higher between 70 and 100 degrees. The wind is stronger from its prevailing direction.

4.2.2 Wind speed distribution

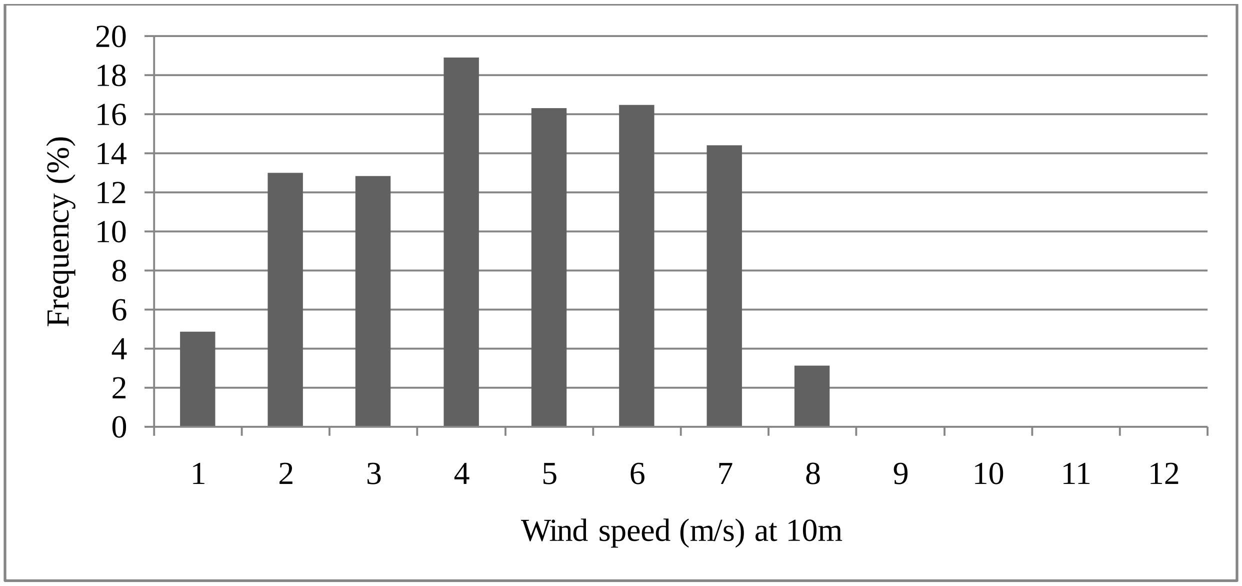

Figure 9: The wind speed frequency distribution

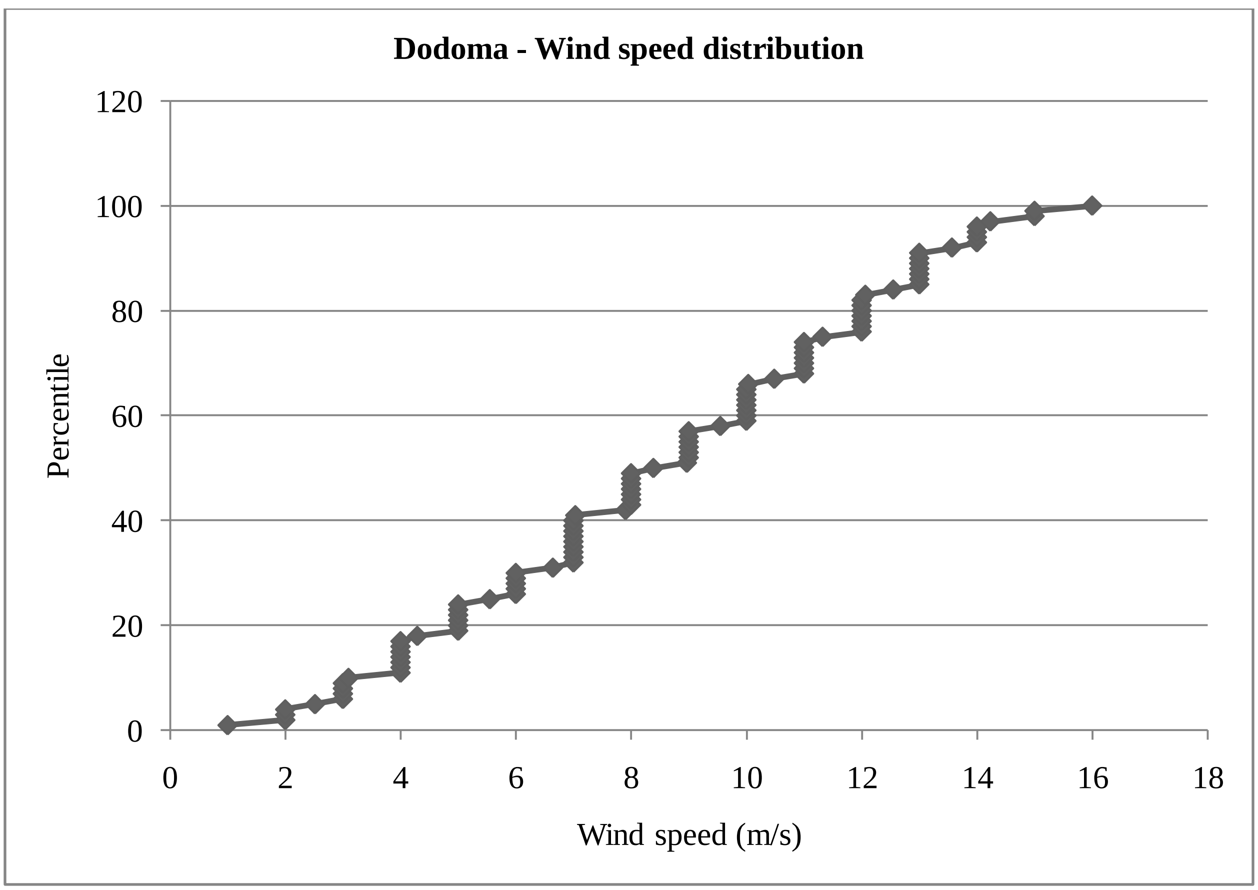

Figure 10: Cumulative wind speed distribution

Figure-9 gives this frequency distribution in percentage. At 10-meters we find that during 19% of time wind was at 4 m/s, 16.3% of the time at 5 m/s and 16.4% time it was at 6 m/s and 14.3% was at 7m/s. The region shows a marginal potential for wind power production since 66.1% of the time the wind is at the speed which can turn turbines. The cumulative frequency distribution of wind speed (figure 10) shows that the wind speed capable of turning a turbine was more than 50%. This gives a fair reliability of the energy produced by the wind in the region.

4.3 Potential Annual power that can be generated from the winds in Dodoma

With the relationship between wind speed and power output known for a turbine the wind speed measurements for Dodoma can then be converted into wind power out. This has been done for every three hour in the study period of 2007-2012. The energy in wind is calculated by using the following equation: **Energy = Power × Time (hrs)**

The annual average wind power as calculated from Eq. 2 and using the average annual wind speed of 5.5 m/s is 280.5 W/m^2. Annual electric energy that could be produced from this wind power is 23343.21 kWh.

4.4 Patterns of wind energy potential over the stations

Accurate estimation of wind speeds at the desired heights help in forecasting the likelihood of power generation from a wind farm. Using the estimated wind speed at 50 m, expected monthly energy output for Dodoma are shown in Table 2. Following the monthly gradual increase in wind speeds from March to October, the energy potential of the wind speeds also increases in the region. However, the drop in energy potential in December to February is sharper over the region

The wind power available during the windy season, which was from April to November, would, on the average, be 413.50 W/m2, while the corresponding energy during this period is 23,003.832 kWh. The calmest months, which are December to March, had monthly average power of 64.19 W/m^2, during which the energy available would be 1785.51 kWh.

Table 3: Average Monthly Wind Power output at Dodoma (50m)

Month	Average wind speed (m/s)	Power output (kW)
January	03	21
February	03	21
March	04	85
April	06	364
May	06	364
June	06	364
July	06	364
August	07	595
September	07	595
October	08	940
November	07	595
December	04	85
Annual	06	366

The monthly power outputs at 50-meters height are given in Table-3. This indicates that power output varies from 21kW in January to 940kW in October. We can further note that the power potential, as indicated from the values of the monthly power outputs, during the period from December to March is below 100kW, which is very low. But the annual power output of the area is 366 kW, which brings the area into the moderate class-4 category of power potential. Which means that, in spite of low wind potential during four months of the year, the area is suitable for moderate wind farms. According to Chaudhry (2008), the areas being developed today using large wind turbine are ranked as class 5 and above. Class 4 areas are also being considered for further development as wind turbines are adopted to run more efficiently a lower wind speeds. Class1 and class2 areas are not being deemed suitable for large machines, although a smaller wind turbine may be economical in areas where the value of the energy produced is higher

The amount of electricity that can be harvested from the wind energy in this region is reasonably high. Therefore, if proper wind turbines that can harvest wind energy at an optimum level are installed at a site in the region, the electricity produced can be connected to the national grid line to supplement the shortfall that arises during the dry season.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

Weather patterns are typically sustained over a region for periods of several days. Since winds are closely coupled to weather patterns, periods of high and low winds will also typically be maintained for periods of several days and alternate at regular intervals. Consequently, the contribution of wind power to the daily cycle is regular and fairly dependable. So since Wind power is variable, during low wind periods it can be replaced by other power sources.

Dodoma has been found to be a fairly promising site for wind harvesting because wind speed is fairly strong. December to March was a calm period with the average wind speed of 3m/s, but the winds are still strong enough to generate electricity when the cut-in wind speed of a wind turbine is at most 3 m/s and the hub height is assumed to be at least 50 m. Furthermore this period is the wet period whereby the dams have enough water to generate electricity. Most intense winds occurred from July to November, with August and October being the being the windiest. This windy season happen together with the time when most parts of Tanzania are usually dry making the use of wind energy, in electricity generation important. This can help to lessen the shortage of electricity from hydropower plants that normally prevails during the dry season

5.2 RECOMENDATIONS

It is recommended that by generating electricity from wind, the already limited hydrological resources in the country in general could be used for irrigation schemes instead of channeling them for developing new hydropower plant. During extended droughts and dry seasons, it usually is forbidden to irrigate farms that are situated upstream the hydroelectric dams, so that the little water available in the rivers is used for hydroelectric generation. The question is whether crop production is less important than production of electricity. It can be suggested that, possibilities of using renewable energy sources like wind should be investigated because such energy production systems are environmentally friendly and will reduce pressure on hydrologic resources. However, apart from the wind regime of the site, the economic viability of a wind farm also depends on, the performance of the wind turbines, the price at which the energy is sold and the capital and running costs of the project. When an economic assessment of a project is performed, estimates for each of the above must be provided for the analysis.

ACKNOWLEDGEMENT

Above all am thankful to Almighty God for being on my side during the time of my studies at the University of Nairobi. Blessed be your name.

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