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A Seasonal Analysis of Potential Wind Power for Armidale NSW, Australia

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ABSTRACT: In this study, wind characteristics and wind energy potential of Armidale, which is a regional rural city (the highest in Australia) in the Northern Tablelands of New South Wales (NSW) are examined and analysed utilizing mean daily wind velocity observations collected during the period 1994 to 2010. The wind velocity distribution curves of Armidale are obtained by utilizing the Weibull statistical probability density function based on the observed wind velocity data. Seasonal and monthly mean wind power at 10, 30, 50, and 70 metres heights. It concluded that Armidale is an eligible city for utilizing wind power as it has sufficient potential wind resource available. As a means of demonstrating such potential, a technical assessment is made for estimating electricity generation utilizing realistic wind turbine models of capacity 2300 kW, 2400 kW and 2500 Kw. The annual estimated electricity generation output and capacity factor produced for three different wind turbines are calculated and found to be significantly promising from generation and financial perspectives.

Keywords: Renewable energy; wind energy; Weibull distributions; Armidale city; regional rural Australia; electricity rates
JEL Classifications: C1; C2; C3; C6; C9

1. Introduction

Rapid worldwide population growth results in a continuous and rapid increase in energy demand. To maintain a high living standard in industrialized countries, as well, to improve the living standards in developing countries, energy consumption that cannot be avoided.

There is an intergenerational imperative to secure energy resources for the present time and for future generations. To achieve this goal, energy can be utilized much more efficiently. As well, there is need to explore new energy resources away from the traditional, but unsustainable fossil fuel-based energy sources of coal, oil, gas and petrol. Nowadays, renewable energy resources are booming as a sustainable clean energy alternative. Renewable energy sources such as solar, wind, bioenergy, geothermal, hydropower and ocean (wave, tidal and thermal) are versatile, particularly in combination.

Fortunately, wind is an inexhaustible renewable energy source, which could be used to provide significant amounts of energy to support the needs of continuous and growing energy demand. Wind velocity is a crucial factor of in determining wind potential Wind velocity is strongly dependent on specific site topography and characteristics (Sahin and Aksakal, 1998), such as altitude, latitude, climate, etc.

Today, the trend of utilizing wind energy technology is booming and developing very fast. Given that wind power is a natural, localized, inexhaustible, clean and sustainable resource, it is vitally important to conduct the specific technical and economic feasibility research in order to decide whether the level of wind potential at a certain location would be able to totally meet or partially provide the energy demand for such locations (Kose, 2004). If it is partial provision, then we need to know how much we can rely in with a high level of probability.

It is worth mentioning that wind energy conversion systems are characterised by their output power generation. Calculating this parameter is another difficult task, as it is closely related, not only to system's performance, but also to operating conditions, which include the wind characteristics of the area.

Australia is the world's 17th largest consumer of non-renewable energy resources and ranks 18th on a per capita basis. Australia's energy consumption primarily is composed of non-renewable energy resources (coal, oil, gas and related products), which represent 96% of total energy consumption. Renewables, the majority of which is bioenergy (wood and wood waste, biomass and biogas), account for the remaining 4 per cent of consumption. Renewable energy consumption, while low, has been growing strongly in recent years (Energy in Australia, 2013).

Australian's total electricity generation was around 255 Terawatt hours on 2010–11. Most of Australia's total electricity generation was around 255 Terawatt hours in 2010–11. Most of Australia's electricity is produced using coal, which is estimated to account for 70% of total electricity generation in 2011–12. This is because coal is a relatively low cost energy source in Australia. It also reflects the abundance of coal reserves along the eastern seaboard, where the majority of electricity is generated and consumed (Australian Energy Resource Assessment, 2010). Renewable energy accounted for around 4% of Australia's energy consumption in 2010–11, or around 260 Petajoules. While the composition is constantly changing, the overall share of renewables in Australia's energy mix has been reasonably constant over the past two decades. Hydroelectricity and various forms of bioenergy have been the dominant sources of renewable energy for a number of decades (albeit in a relatively small proportion of about 8%). In recent years, a number of new technologies such as wind and solar energy have emerged to gain increasing shares of the energy mix. There is also potential for growth in other emerging technologies such as geothermal and ocean energy in coming decades (Clean Energy Future, 2011).

Most wind energy development in NSW will be in rural and regional areas. Wind energy is especially attractive to these communities because of the potential for employment, industry development, income for landholders, and supplementing existing tourist attractions. An independent study commissioned by Sustainable Energy Development Authority of NSW (SEDA) (ACIL Consulting 2000) showed that employment created by sustainable energy development tended to be concentrated in rural and regional areas. The study found that: manufacturing wind turbines creates 3–6 jobs per Megawatt of installed capacity; installation creates 0.5–0.8 jobs per Megawatt; the operation and maintenance of wind turbines creates 0.05–0.5 jobs per Megawatt (NSW Wind Energy Handbook, 2002 and Australian Wind Energy Association, 2002).

Wind velocity distribution, one of the wind characteristics, is of great importance for not only structural and environmental design and analysis, but the assessment of the wind energy potential and the performance of a wind energy conversion system as well. There are several continuous mathematical functions, or the so-called probability density functions, that can be used to model the wind velocity frequency curve by fitting time-series measured data. In wind power studies, the Weibull and Rayleigh probability density functions are commonly used and widely adopted (Gökçek et al. 2007). Weibull parameters picture the wind energy potential of an area (Abernethy, 2002; Weibull, 1939, 1951). Hence, the article is to estimate the Weibull parameters of the wind velocity observation recorded in Armidale City during the period (1994-2010).

2. Mathematical Analysis

Wind velocity distribution is the greatest important wind characteristic not only structural and environmental design and analysis, but for the assessment of the wind energy potential and the performance of a wind energy conversion system, as well. There are multiple continuous statistical functions, or the so-called probability density functions, those functions are used to model the wind velocity frequency curve by fitting time-series measured data. Generally, in wind power research studies, the Weibull probability density functions are commonly used and widely adopted (Gökçek et al. 2007).

The Weibull distribution function, which is a two-parameter distribution, can be expressed as

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (1)$$

where v is the wind velocity, c is a Weibull scale parameter in m/s, and k is a dimensionless Weibull shape parameter. The cumulative probability function of the Weibull distribution is given as follows:

$$F_W(v) = 1 - exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (2)$$

In order to estimate Weibull k and c parameters, numerous methods have been proposed over last few years. In this study, the two parameters of Weibull distribution are determined by using mean wind velocity–standard deviation method (Gökçek et al. 2007).

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} (1 \leq k \leq 10) \quad (3)$$

$$c = \frac{\bar{v}}{\Gamma(1+1/k)} \quad (4)$$

where Γ is the gamma function. The mean wind velocity v and the standard deviation σ can be calculated as

$$\bar{v} = \frac{1}{n}\left(\sum_{i=1}^{n} v_i\right) \quad (5)$$

$$\sigma = \left[\frac{1}{n-1}\sum_{i-1}^{n}(v_i - \bar{v}^2)\right]^{0.5} \quad (6)$$

where *n* is the number of hours in the period of the considered time such as day, month, season, or year.

The power of wind can be estimated by using the following equation (Öztopal et al., 2000):

$$P_{(v)} = \frac{1}{2}\rho A\bar{v}^3 \quad (7)$$

where ρ is the mean air density, v^3 is the mean value of the third power of the wind velocity, and A is the swept area. The average wind power density of the site based on the Weibull probability density function can be expressed as

$$P_m = \frac{1}{2}\rho A\bar{v}^3 \frac{\Gamma(1+3/k)}{[\Gamma(1+1/k)]^3} \quad (8)$$

In addition, for a height less than 100 m, the power density of the wind above the ground level is given by (Shata and Hanitsch, 2008):

$$P_h = P_{10}\left(\frac{h}{10}\right)^{3\alpha} \quad (9)$$

where P_{10} is the corrected power available in wind at a height of 10 m and α is the roughness factor, usually in the range 0.05–0.5. Wind velocity data were extrapolated by using the following power-law formula (Eskin et al., 2008):

$$\frac{v_1}{v_2} = \left(\frac{h_1}{h_2}\right)^{\alpha} \quad (10)$$

where v_1 and v_2 are the wind velocities at heights h_1 and h_2, respectively.
The capacity factor C_f is one of the performance parameters of wind turbines that both the user and manufacturer need to know. It represents the fraction of the total energy delivered over a period, E_{out}, divided by the maximum energy that could have been delivered if the turbine were used at maximum capacity over the entire period, E_r = 8760 P_r. The capacity factor C_f of a wind turbine can be calculated as the following (Shata and Hanitsch, 2008):

$$C_f = \frac{E_{out}}{E_r} \quad (11)$$

3. Wind Data

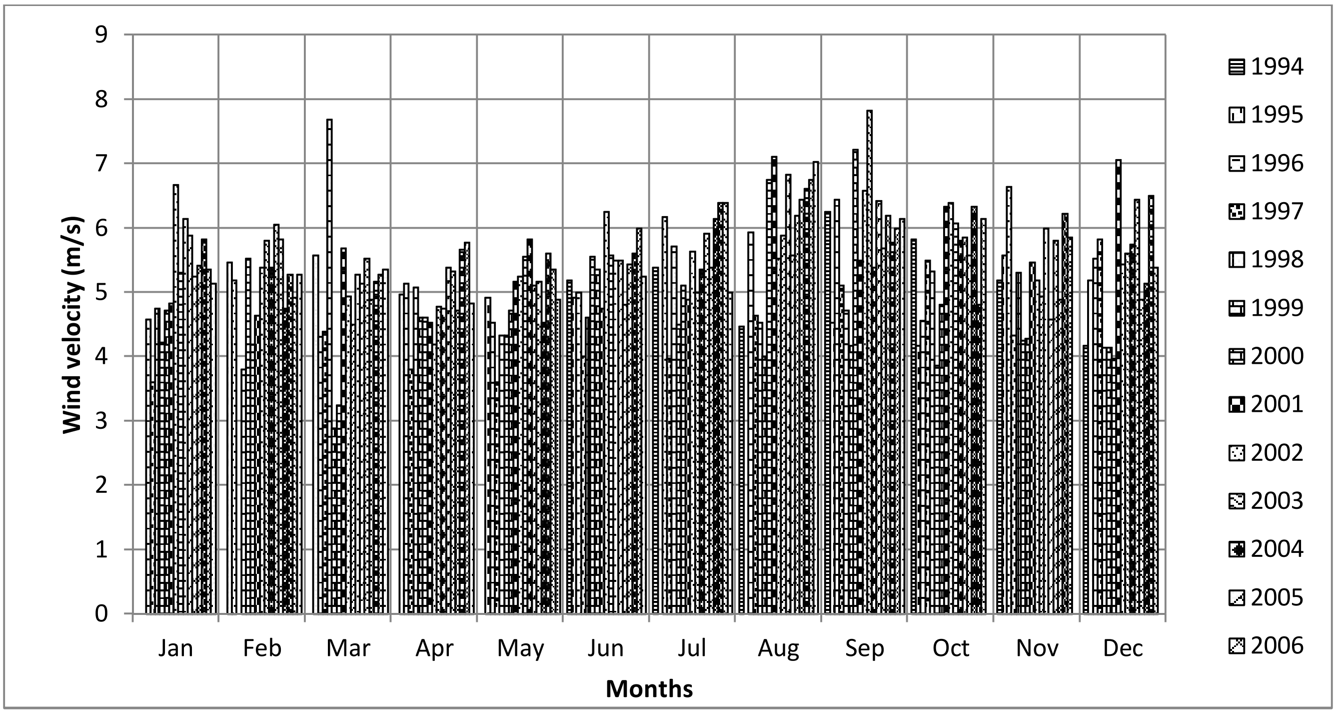
Armidale (30°30′S 151°39′E/ 30.500°S) is a city in the Northern Tablelands, New South Wales, Australia (Burr, 2002). Armidale is located on the Northern Tablelands in the New England region about midway between Sydney and Brisbane at an altitude ranging from 970 metre at the floor of the valley to 1,110 metres above sea level at the crests of the hills (Burr, 2002). Armidale has a cool temperate climate with the majority of rain falling in the summer months. Armidale's elevation results in a mild climate, with pleasant warm summers, extended spring and autumn seasons, and a long cold winter with some frosty nights. Figure 1 shows the location of Armidale.

In this study, mean wind velocity data was measured daily by Armidale Airport Automatic Weather Station under the authority of the Australian Bureau of Meteorology (BoM). Observed wind velocity data during the period (1994-2010) were obtained at 10 metres above ground level with an anemometer. These data were used to investigate the wind power potential of this region. Figure 2 shows the monthly mean wind velocity in Armidale region during the period 1994 to 2014. The highest monthly mean wind velocity of 7.83 m/s occurred in September 2003, while the lowest mean wind velocity of 2.89 m/s occurred in March 1999. The mean annual wind velocity in the period from 1994 to 2010 was 5.30 m/s.

Figure 1. Location of Armidale in New South Wales

Source: Google Maps

Figure 2. Monthly mean wind velocity in Armidale, NSW during (1994-2010)



4. Results and Discussion

4.1. Monthly wind velocity distributions

The daily average wind velocity in Armidale city during the period from 1994 to 2010 are shown in Figure 3. It is seen in Figure 3a that August has a maximum of 13.89 m/s wind velocity, while June has the lowest mean wind velocity of 1.67 m/s. In Figure 3b, the height daily mean wind velocity is 13.33m/s in October, while the lowest is 2.5m/s in September. In Figure 4a, the highest wind velocity is 14.44 m/s in January and the lowest is 1.94m/s in January as well. In Figure 4b, the highest wind velocity is 9.17 m/s in April and the lowest is 1.67 m/s in May. Geographical seasons in Armidale are distinct, a very cold winter includes June, July and August, a lovely spring includes September, October and November, a warm summer includes December, January and February and a mild autumn in March, April and May. It is shown in Figures 3a, 3b, 4a, 4b that the 'richest' windy months in Armidale are August and September which are the heart of the winter.

4.2. Probability density functions

The cumulative density distributions derived from the long term wind velocity data for all the months (arranged in order to present Armidale' seasons) for the investigated site are shown in Figures 5a-5d. It is shown from these figures that all the curves have a similar tendency of wind velocity on cumulative density. Figure 6. depicts the seasonal probability density distributions of the observed data along with Weibull functions for Armidale. It is seen from Figure 6a that the peak probability values in winter vary about 0.45 and 0.50 depending on the wind velocity for all the calculated distribution functions. Figure 6b shows that the peak probability values in spring vary between 0.25 and 0.3. Figure 6c shows that the peak probability values in summer vary between 0.3 and 0.35. Finally, Figure 6d shows that the peak probability values for autumn range between 0.35 and 0.35. Apparently the Weibull statistical analysis proves that wind potential in Armidale is the highest in winter, with almost the same potential for summer and autumn and the lowest potential in spring, which coincides with the climate's characteristic history of Armidale. Seasonal Weibull parameters and standard deviations at10 m height at the site are given in Table 1. As seen from Table 1, the highest mean wind velocity is 6.94 m/s occurs in winter, while the lowest is in autumn with 5.28 m/s. The value of Weibull shape parameter *k* is between 5.04 and 6.4, while the scale parameter *c* varies between 5.75 and 6.47.

Figure 3a. Daily mean wind velocity in Armidale: June, July & August

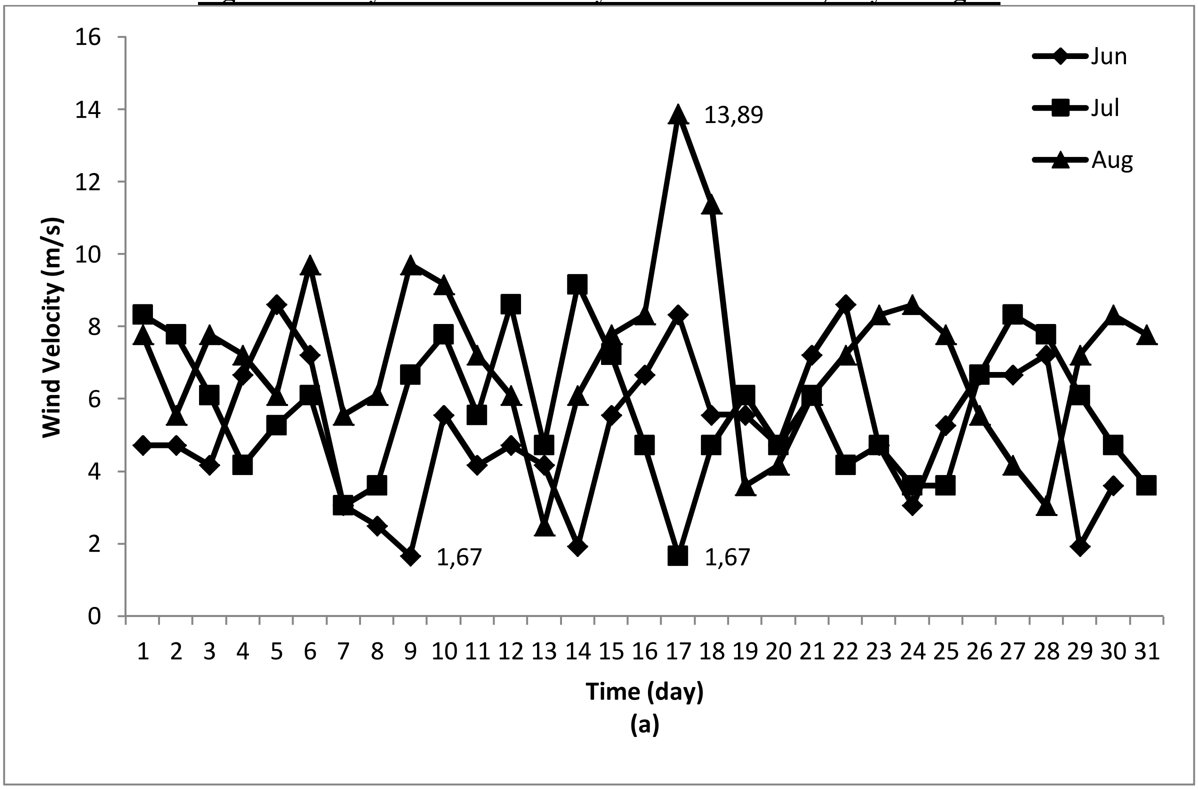


Figure 3b. Daily mean wind velocity in Armidale: September, October & November

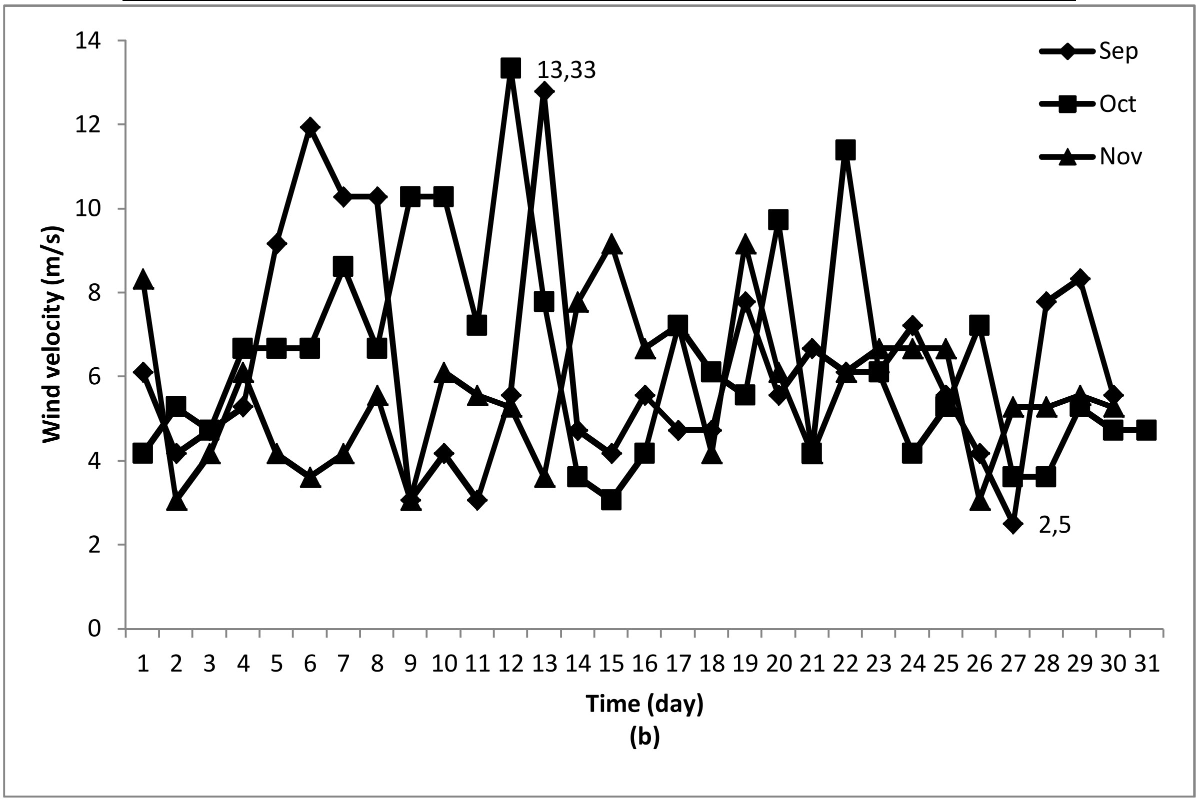


Figure 4.a Daily mean wind velocity in Armidale: December, January & February

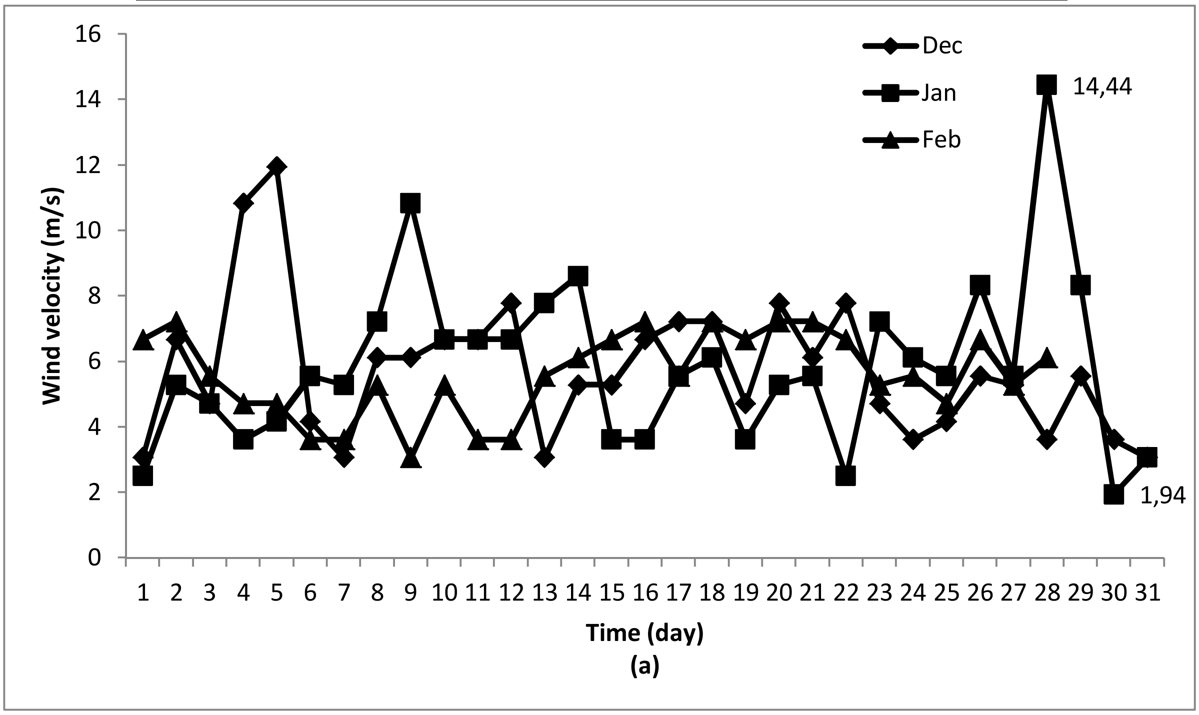
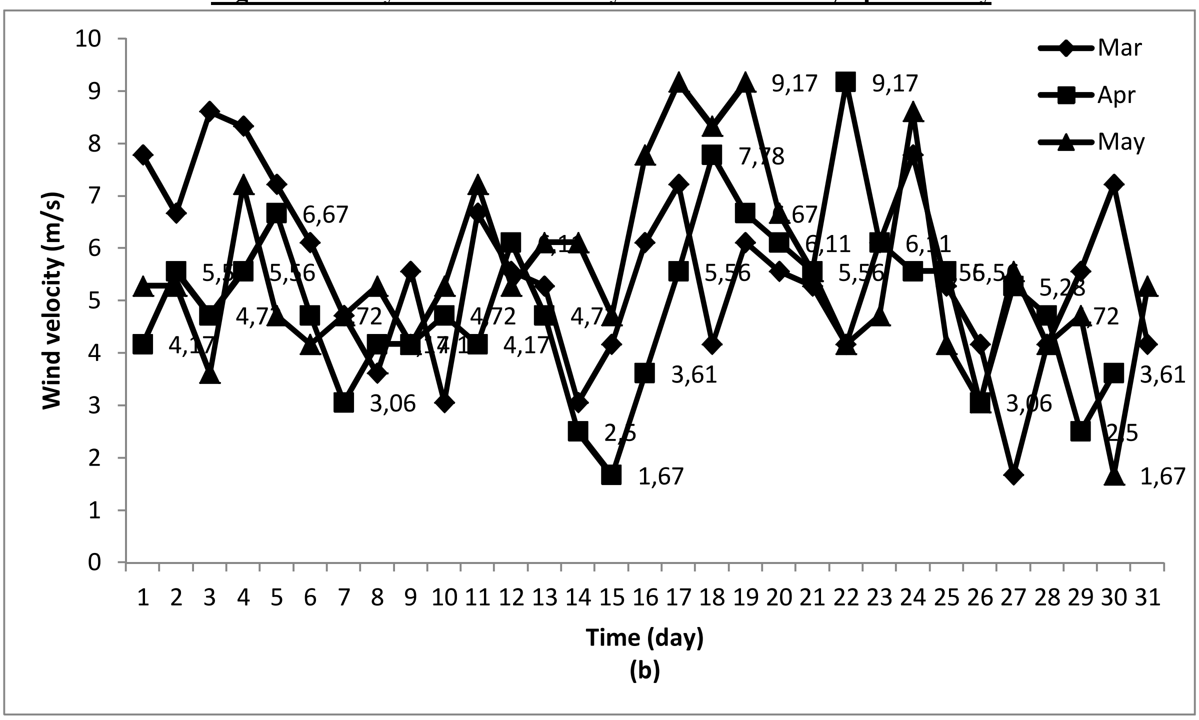


Figure 4.b Daily mean wind velocity in Armidale: Mar, April & May



The highest c value is found in spring and the lowest value is in autumn. The lowest standard deviation of 1.54 is calculated for the winter season. The calculated values of Weibull parameters (k and c) at different heights (10, 30, 50 and 70 metres) for the site are shown in Table 2 along with the estimated relevant mean wind velocity. It can be derived from Table 2 that the greater height above ground, the faster wind velocity.

Figure 5a. Wind velocity cumulative probability distributions in Armidale: Winter [June, July & August]

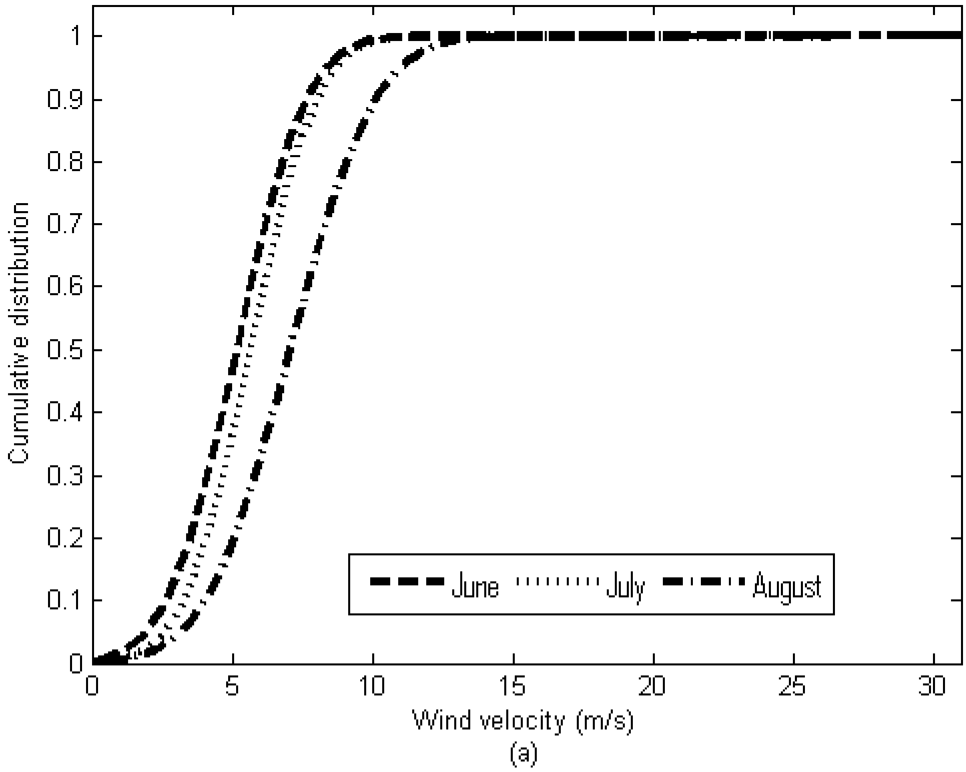


Figure 5b. Wind velocity cumulative probability distributions in Armidale: Spring [September, October & November]

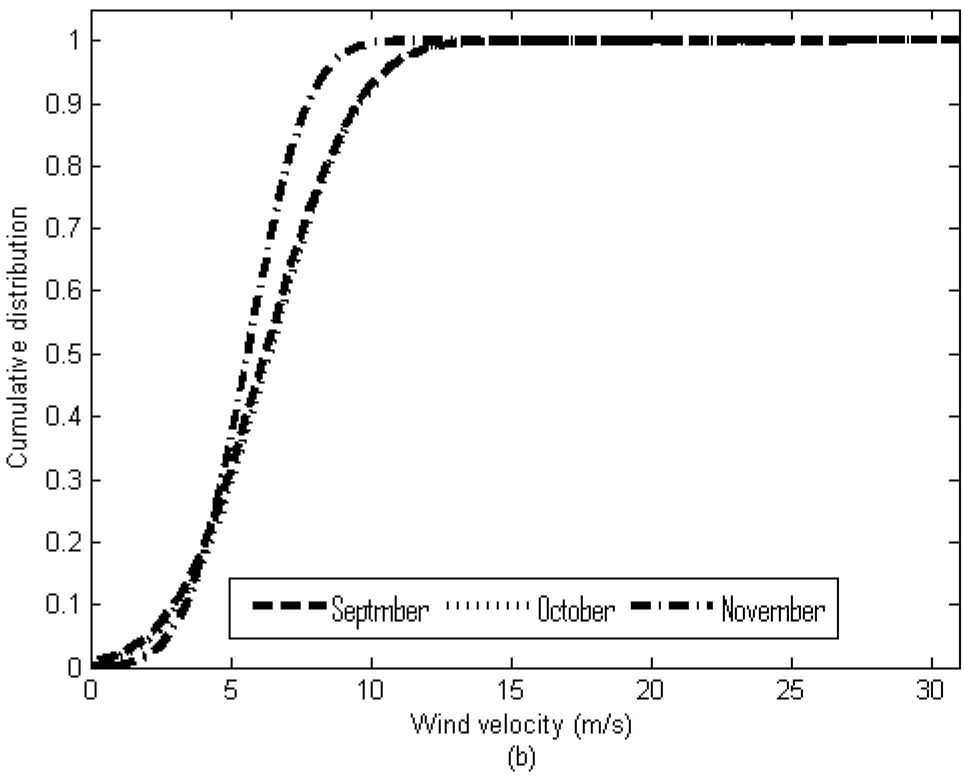


Figure 5c. Wind velocity cumulative probability distributions in Armidale: Summer [December, January & February

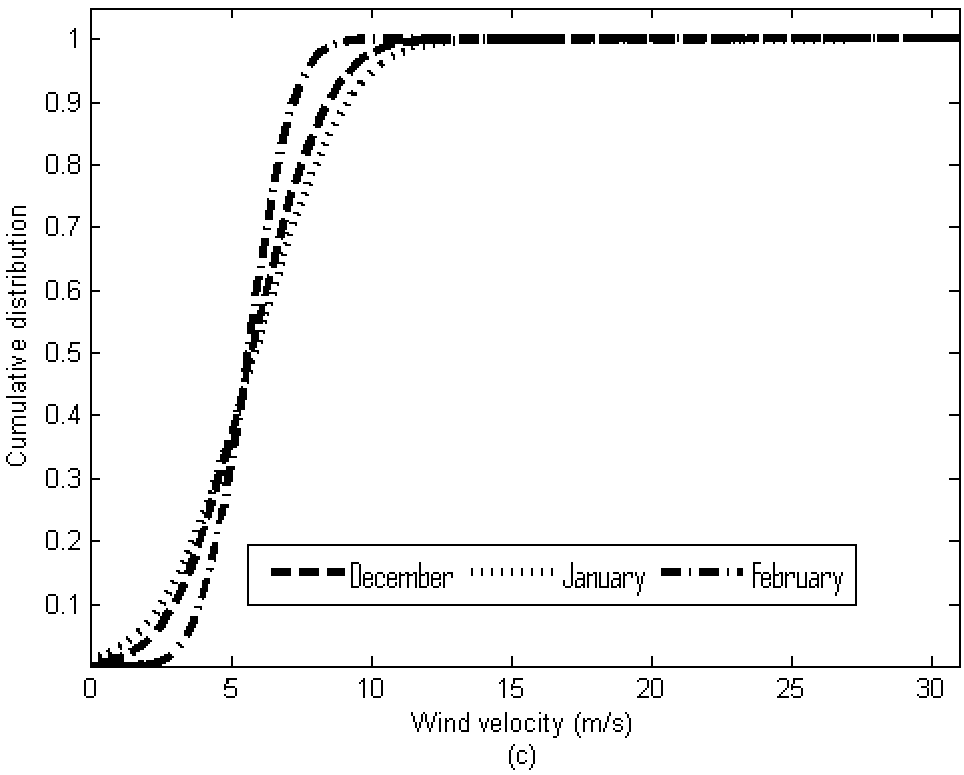


Figure 5d. Wind velocity cumulative probability distributions in Armidale: Autumn [March, April & May]

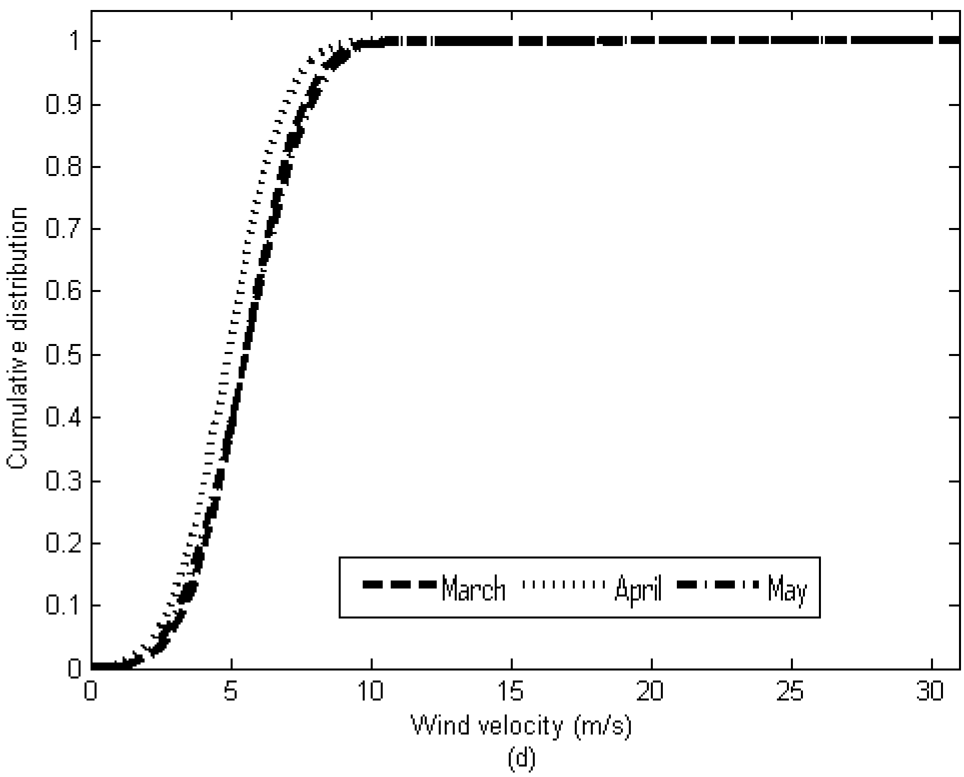


Figure 6a. Comparison of seasonal probability density distributions for the observed data, Weibull functions for Armidale: Winter

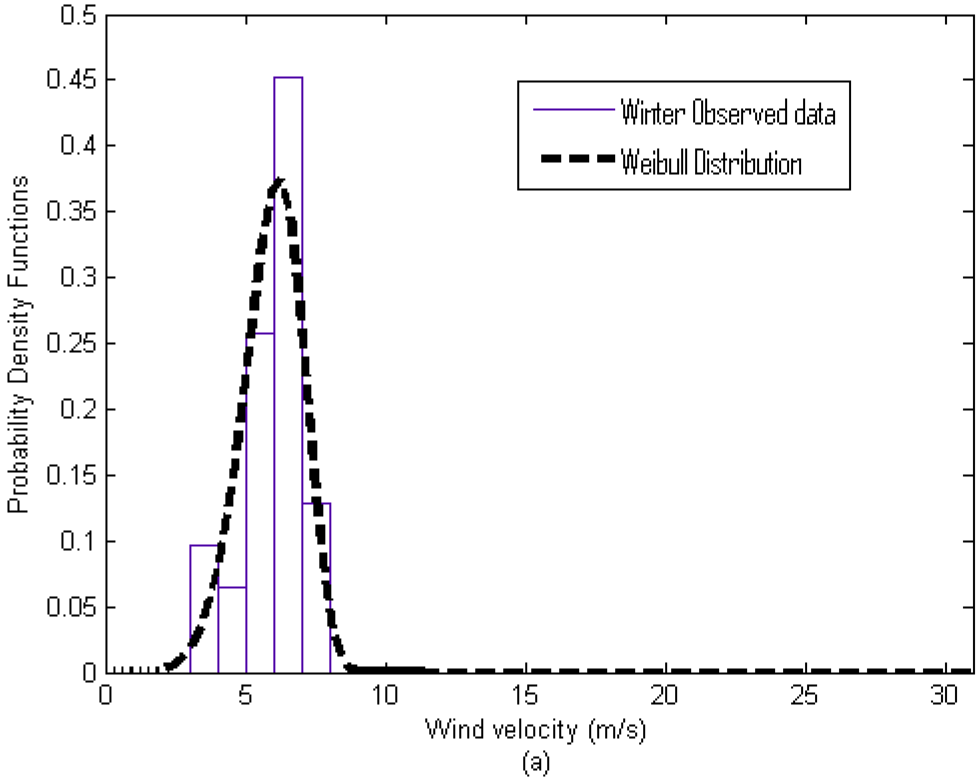


Figure 6b. Comparison of seasonal probability density distributions for the observed data, Weibull functions for Armidale: (b) Spring

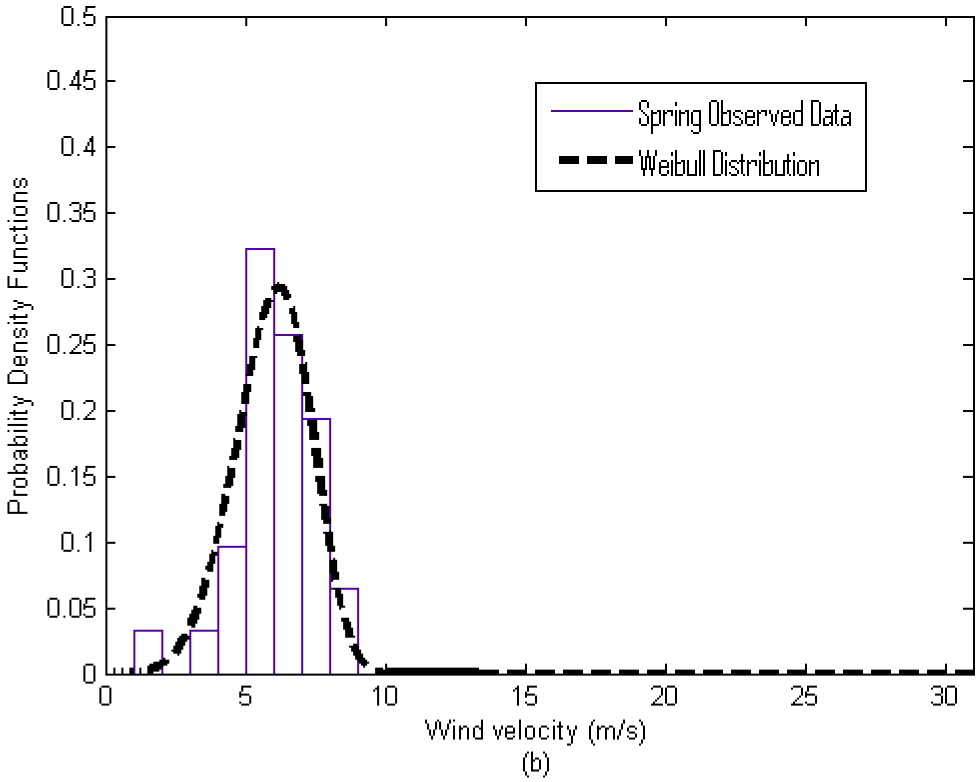


Figure 6c. Comparison of seasonal probability density distributions for the observed data, Weibull functions for Armidale: Summer

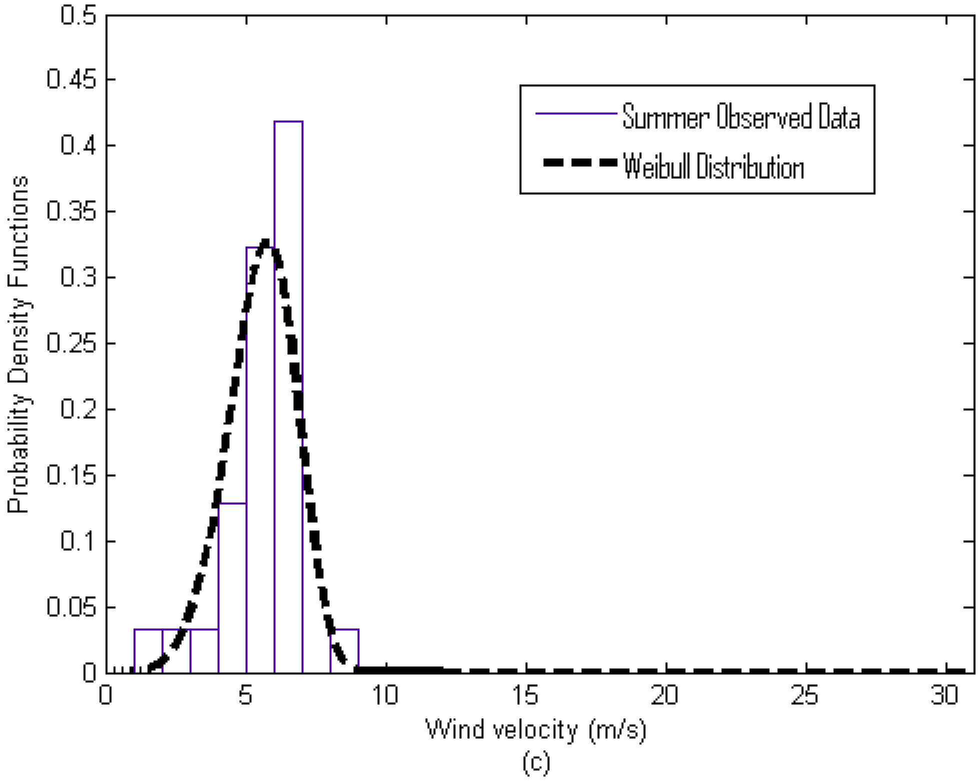
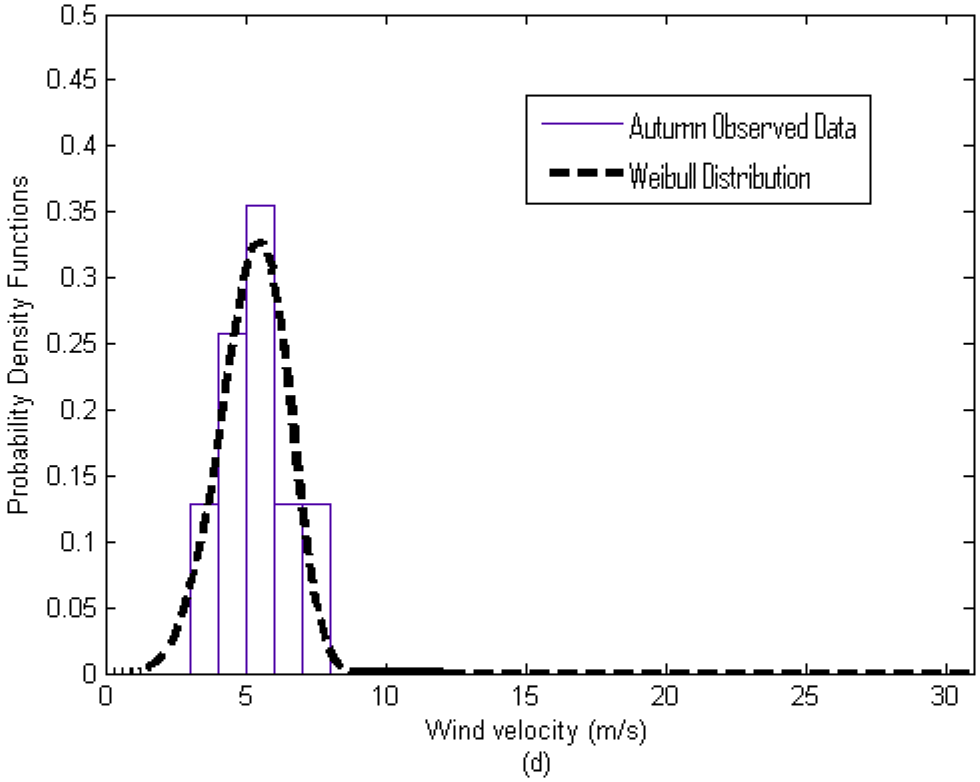


Figure 6d. Comparison of seasonal probability density distributions for the observed data, Weibull functions for Armidale: Autumn



4.3. Wind power density

Figure 7 shows the changes of monthly mean wind power at heights of 10, 30, 50, and 70 metres, respectively. Monthly mean specific wind power is in the range from 293 to 900 W/m2 at 30 m height above ground level. Monthly mean specific wind powers are between 542–1660 W/m2 and 812–2487 W/m2 at heights of 50 m and 70 m, respectively. Apparently August has the highest wind power density. Since the wind power is proportional to the cube of wind velocity, therefore, a small variation of wind velocity in the higher wind velocity conditions can cause a larger variation in the wind power.

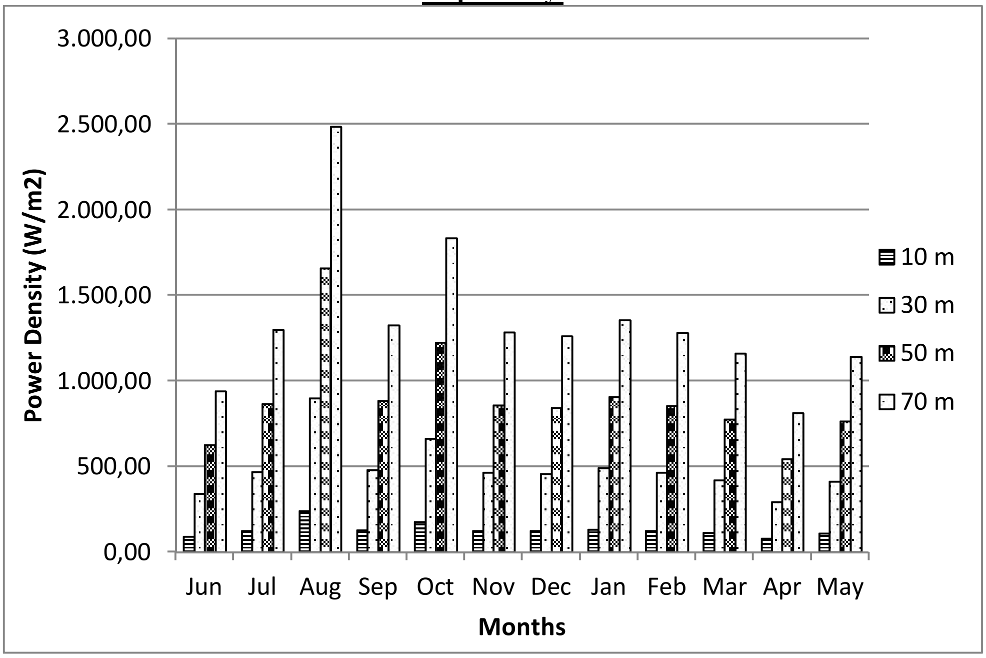
Table 1. Seasonal Weibull parameters and standard deviations at 10 m height above ground level for Armidale NSW

Season	$v_m(m/s)$	k	c	σ
Winter	6.94	6.40	6.37	1.54
Spring	6.39	5.09	6.47	2.38
Summer	5.83	5.28	6.03	2.63
Autumn	5.28	5.04	5.75	1.70
Annual Average	5.6	9.58	5.98	1.33

Table 2. Calculated values of Weibull parameters (k and c) at different heights above ground level for Armidale NSW

Season	Height (m)	k	c	$v_m(m/s)$
Winter	10	6.40	6.37	6.94
	30	6.60	9.88	10.77
	50	6.71	12.12	13.21
	70	6.80	13.87	15.12
Spring	10	5.09	6.47	6.39
	30	5.30	10.05	9.92
	50	5.43	12.32	12.16
	70	5.52	13.00	13.92
Summer	10	5.28	6.03	5.83
	30	5.49	9.36	9.05
	50	5.50	11.48	11.10
	70	5.58	13.14	12.70
Autumn	10	5.04	5.75	5.28
	30	5.26	8.91	8.19
	50	5.37	10.94	10.05
	70	5.45	13.06	12.00

Figure 7. Monthly mean wind power density at the heights 10, 30, 50, and 70 m above ground level, respectively.



4.4. Wind power of selected turbines and energy output

In order to verify results obtained from the preceded mathematical and statistical analysis of Armidale's historical wind velocity record throughout the year, another approach is applied considering the available current technology of wind turbines which are examined using the same historical wind velocity. Three wind turbines models (N90/2500 IEC I, N100/2400 IEC II and N117/2300 IEC III of rated power 2500 kW, 2400 kW and 2300 kW respectively were examined and the relevant energy output of each turbine has been calculated annually. Annual energy output and capacity factor of the said wind turbines are summarized in Table 3. Turbines we deliberately selected with various cut-in and cut-out velocity and various swept areas in order to examine different generating conditions. As derived from Table 3, the capacity factor is greater for wind turbines with lower rated wind velocity. Although Armidale has a considerable high elevation (the highest city in Australia about1000 metres above sea level) which results in less air density compared with lower elevations, this negligibly affected the wind energy could be generated as the larger air velocity at those selected heights sustain that effect. Thus, the estimated energy for each turbine does prove the eligibility of Armidale to utilize wind power both feasibly and efficiently.

Table 3. Estimated Annual energy output and capacity factor for selected wind turbines at different heights different heights for Armidale

Nordex Turbine Model	Cut-in wind velocity (m/s)	Cut-out wind velocity (m/s)	Rated wind velocity (m/s)	Swept Area (m^2)	Rated power (kW)	Energy output at heights (MWh/year)				Capacity Factor (%)
						10 m	30 m	50 m	70 m	
N90/2500 IEC I	3	25	14	6362	2500	245	912	1680	2512	30
N100/2400 IEC II	3	25	13	7823	2500	301	1123	2075	3110	35
N117/2300 IEC III	3	20	13	10715	2400	412	1539	2842	4259	33

4.5. Wind energy economics for wind turbines

The feasibility of wind power production and the wind energy economics have been temporally studied for Armidale wind velocity based on the three turbine models N90/2500 IECI, N100/2400 IEC II and N117/2300 IEC III at 50 m and 70 m turbine above ground level. The wind power outputs from the wind turbines were approximated using quadratic modelling (Sahin and Aksakal, 1999), which calculates power output between the cut-in V_o and rated V_r wind velocity using the following:

$$P(V) = A + BV + CV^2 \tag{12}$$

The A, B and C constants can be found solving the following equations,

$$A + BV_O + CV_O^2 = 0 \tag{13}$$

$$A + BV_r + CV_r^2 = P_r \tag{14}$$

$$A + BV_x + CV_h^2 = \left(\frac{V_x}{V_r}\right) P_r \tag{15}$$

where $V_x = (V_o + V_r)/2$

The cut-in and rated wind velocity and the rated power outputs are given in Table 3 for the wind turbines used.

4.6. Unit Cost of Electricity

The cost analysis a 20-year of system lifetime, which includes the manufacturing, installation and the maintenance and insurance expenses, is considered for the selected three wind turbine generators. The monthly electrical energy outputs, calculated using the above quadratic modelling and the time-series wind data. The cost of electricity per kWh is considered as the main parameter for a techno-economic assessment for the wind energy systems under evaluation.

It has been found that the cost of electricity per kWh changes only based on the turbine height, the higher turbine height, the more power generated the less kWh price and vise versa. Approximate average price for the unit kWh ranges between (0.3 to 0.36) Australian Dollar (AUD) for the 50 m turbine heights for the three selected wind turbines, on the other hand it ranges between (0.28 to 0.33) AUD for the 70 m turbine height. It is worth mentioning that currently at the time of writing this paper, the public electricity rate in Armidale for residential applications is 0.35 AUD. Thus, It could be concluded that the cost of electricity per kWh from these wind generator is competitive to the electricity from the utility in Armidale.

5. Conclusion

In this study, the monthly and annually wind velocity distribution and wind power density during the period of 1994 to 2010 in Armidale were examined and evaluated. The wind velocity frequency distribution of Armidale was found by using Weibull distribution functions. It can be concluded as follows:

1. The highest monthly mean wind velocity of 7.83 m/s was in September 2003, while the lowest mean wind velocity of 2.99 m/s was in March 1999. It was found that the mean annual wind velocity in the period 1994 to 2010 was 5.30 m/s, at 10 metres above ground level.
2. The highest mean wind velocity was 6.94 m/s in winter, while the lowest value was in autumn with 5.28 m/s, at 10 metre height.
3. The value of Weibull shape parameter k was between 5.04 and 6.40, while the scale parameter c varies between 5.75 and 6.47, at 10 metre height.
4. Monthly mean specific wind power was in the range of 293 to 900 W/m^2 at a height 30 m above ground level. Monthly mean specific wind powers are between 542–1660 W/m^2 and 812–2487 W/m^2 at heights of 50 m and 70 m, respectively.
5. The cost analysis of wind generators made over a 20-year system lifetime of nominal power of 2.5 MW approximately at 50 m and 70 m turbine heights was shown to return a very competitive unit kWh price compared with reticulated utility electricity in Armidale. Considering the current booming technology in wind turbines, it can be forecast that by utilising Megawatt wind turbines in Armidale is a viable and feasible option compared with public reticulated utility electricity.

This study relied on publicly available meteorological data for Armidale for a relatively reliable period (1994-2010) recorded at a weather station at an airport where there are no surrounding obstructions The study used Weibull statistical analysis, which proved and closely correlated with the meteorological data, it lead that Armidale has a wind potential source, especially during the winter season, a technical assessment of selected wind turbines has been conducted which proved this eligibility as well. On the other hand, further research is needed to examine the economic aspect in terms of utilising wind power generation at Megawatt level in Armidale considering the current market conditions of wind turbines and reticulated electricity prices.

Nomenclature

A	Sweep area (m^2)
c	Weibull scale parameter (m/s)
Cf	Capacity factor
E_{out}	Energy output (kWh/year)
h	Height (m)
k	Weibull shape parameter (dimensionless)
P	Power of wind per unit area (W/m^2)
P_r	Rated power (W/m^2)
v	Wind velocity (m/s)
v_i	Wind velocity in the stage i (m/s)
v_r	Rated wind velocity (m/s)
ρ	Air density (kg/m^3)
Γ	Gamma function
σ	Standard deviation

References

Abernethy, R.B. (2002), The New Weibull Handbook, 4th Ed. North Palm Beach, Florida.

ACIL Consulting. (2000), Employment Indicators for Australia's Renewable Energy Industries, ACIL, Canberra.

Australian Energy Resource Assessment. (2010), Australian Government, Department of Resources, Energy and Tourism. Geoscience Australia.

Australian Wind Energy Association. (2002), Best Practice Guidelines for the Implementation of Wind Energy Projects in Australia, AusWEA.

Burr, P. (2002), Climate statistics, Armidale, N.S.W.: a compilation of weather data from Bureau of Meteorology and University of New England weather stations at Armidale NSW. Armidale : Faculty of Education, Health and Professional Studies, UNE, Australia.

Clean Energy Australia. (2011), Clean Energy Future. Australian Government

Energy in Australia. (2013), Australian Government, Department of Resources, Energy and Tourism. Bureau of Resources and Energy Economics.

Eskin, N., Artar, H., Tolun, S. (2008), Wind energy potential of Gokceada Island in Turkey. Renewable and Sustainable Energy Reviews, 12, 839–851.

GÖkcek, M., Bayulken, A., Bekdemir, S. (2007), Investigation of wind characteristics and wind energy potential in Kirklareli, Turkey. Renewable Energy, 32, 1739–1752.

Kose, R. (2004), An evaluation of wind energy potential as a power generation source in Kutahya, Turkey. Energy Conversion and Management, 45, 1631–1641.

NSW Wind Energy Handbook. (2002), Sustainable Energy Development Authority of NSW (SEDA)

Öztopal, A, Sahin, A.D, Akgün, N., Sen, Z. (2000). The regional wind energy potential of Turkey. Energy, 25,189–200.

Sahin, A.Z., Aksakal, A. (1998), Wind power energy potential at the Northeastern region of Saudi Arabia. Renewable Energy, 14, 435–440.

Sahin, A.Z., Aksakal, A. (1999). A statistical analysis of wind energy potential at the eastern region of Saudi Arabia. International Journal of Energy Research, 23, 909–917.

Shata, A., Hanitsch, R. (2008). Electricity generation and wind potential assessment at Hurghada, Egypt. Renewable Energy, 33, 141–148.

Weibull, W. (1939), A statistical theory of the strength of materials. Ingeniors Vetenskaps Akademiens Handlingar. Royal Swedish Institute for Engineering, 151, 1–45.

Weibull, W. (1951), A statistical distribution function of wide applicability. Journal of Applied Mechanics – Transactions of the ASME 18, 292–297.