Evaluation of Noise Levels of Micro-Wind Turbines Using a Randomised Experiment.

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Abstract
One of the biggest environmental concerns of a wind turbine is the wind turbine noise (Prospathopoulos and Voutsinas, 2007). This study assesses the noise impacts of wind turbines on the environment by comparing the micro-wind turbine noise to traditional accepted surrounding sounds. The collection of the sound level data was done by using a randomised experiment. Then General Linear Model was fitted to the sound level data to determine the relationship between the sound levels generated at a given site to the time of day, wind speed, wind direction and distance from the sound source.

Keywords: Micro-wind turbine noise, randomised experiment, General Linear Model, wind speed.

1. Introduction

Energy is an important aspect of social and economic development in South Africa. The demand for electricity has increased over the years and the challenge is to promote renewable energy in South Africa (Winkler, 2005).

Eskom, the predominate supplier of electricity in South Africa, has implemented a number of price increases over the past few years, causing a growing concern in the country. In light of the current electricity shortage there is a need to consider alternative energy sources. Solar, water, wind and nuclear power are generating interest as future sustainable sources of power.

One of the most developed and cost effective renewable energy source has been shown to be wind energy (Prospathopoulos and Voutsinas, 2007). Wind turbines are one of the cleanest energy production machines (Islam, 2010). Tommaso, Miceli and Rando refer to a study conducted by Greenpeace (2010) where it was estimated that in the year 2020, 12% of the world’s energy will be by means of wind energy.

One of the biggest environmental concerns of wind turbines is the wind turbine noise (Prospathopoulos and Voutsinas, 2007). Excessive exposure to noise has been shown to cause several health problems. The most common health problems are hearing loss, headaches, and fatigue (caused by sleep disturbance) (Alberts, 2006). Extremely high noise exposure may even cause constricted arteries and a weakened immune system (Alberts, 2006). This study assesses the noise impacts of wind turbines on the environment by comparing the wind turbine noise to traditional accepted surrounding sounds.

1.1. Noise and sound fundamentals

Sound is a travelling wave which is characterised by its frequency and magnitude.

Frequency is defined as the number of oscillations per unit time. Acoustic frequency, expressed in Hertz (Hz), is a measure of one wave cycle per second. The frequency is often referred to as the “pitch” of the sound. Sounds that are heard on a daily basis are often not just a single frequency. The frequency range of human hearing is 20-20 000Hz (Rogers, Manwell and Wright, 2006).

The magnitude of a sound is measured by the sound power level and the sound pressure level. Sound power level is defined as the power per unit area of the sound pressure wave and indicates the total acoustic power of the sound source. Sound pressure refers to the instantaneous difference between the actual pressure created by the wave and the average pressure at the given point in space. The sound pressure level (SPL) is logarithmic measure of the effective sound pressure of the sound relative to a reference and is measured in decibels (dB) (Bolin, Nilsson and Khan, 2010).

A-weighting, denoted by dBA, is a filter that is often related to sound pressure levels. It decreases or amplifies at certain frequencies. This is in accordance with the international standards to approximate the frequency dependence of average human hearing. A-weighting readings are intended for measurements of low-level sounds (e.g. environmental noise and industrial noise) (Howe, Gastmeier and McCabe, 2007).

Noise is defined as unwanted sound. For noise to cause annoyance or interference it does not have to be excessively loud. For sound to be perceived as noise it depends on the duration and amplitude of the sound (Kamperman and James, 2008).

Noise annoyance is a feeling of displeasure that is created by noise. Noise annoyance is related to sound pressure levels, sound properties and also depends on the individual, situational and noise source related factors (Pederson, 2007).

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1.1.1. Sounds from wind turbines

Sounds from wind turbines can be divided into two groups: mechanical sounds and aerodynamic sounds.

Mechanical sounds are described as sounds that are related to the interaction of wind turbine components. The source of this sound comes from the gearbox, generator, yaw drives, cooling fans and auxiliary equipment (Rogers et al, 2006). Small wind turbines are more likely to produce more noticeable mechanical noise.

Aerodynamic sounds are generated by the interaction between the wind flow and the wind turbine components, namely the blades of the wind turbine and the wind turbine tower. Depending on the wind turbine and the wind speed, aerodynamic noise has been described as a buzzing, whooshing, pulsing and even a sizzling sound (Alberts, 2006). When the wind turbines blades are downwind of the tower it is known to make a thumping sound as each blade passes the tower.

1.1.2. Previous studies

Other researchers (Pedersson, 2007) claim that noise associated with wind turbines may just be a perception. Factors that add to noise perception are visibility, economic benefit from wind turbine farms and place of residence. Pedersson (2007) showed that there is an increase in the irritability of noise when residents can see the wind turbines. Furthermore, Pedersson (2007) showed that one in two respondents was positive towards wind turbines, but only one in every five was positive towards their impact on the landscape scenery.

Bolin, Nilsson and Khan (2010) investigated whether natural sounds are able to mask wind turbine noise. Their results showed that there was a reduction in the perceived loudness of wind turbines due to the masking of natural sounds. Wind turbine farms are normally placed in rural areas with low ambient noise. This may contribute to the perception that wind turbines are noisy. The research of Bolin et. al. (2010) impacts this study as it provides evidence that placing a wind turbine in an environment with high ambient noise levels may have the ability to mask the wind turbine noise.

Most studies conducted internationally on the noise emission of wind turbines have been survey studies. These types of studies deal with the perception of noise and focus on large scale wind turbine farms near residential areas. Since there are no operational wind turbine farms near residential areas in South Africa a survey study is not possible. However, micro-wind turbines are a growing area of interest in the Port Elizabeth (PE) region. There has been an increase in the installation of micro-wind turbines and solar panels in households. As such, this study evaluates actual noise measurements from operational micro-wind turbines in PE.

1.2. Objectives

The study has the following objectives:

- To design an experiment to collect sound level data from different sites in the Summerstrand, Port Elizabeth region.
- To propose a method for comparison of wind turbine noise to traditional surrounding sounds.
- To identify the factors influencing the sound levels of micro-wind turbines by comparing the sound levels at different sites.
- To determine whether wind turbines are noisy by looking at the following:
  - Comparing wind turbine sound to traditional accepted surrounding sounds.
  - Using the Nelson Mandela Metropolitan Municipality 7 dBA rule to identify whether a sound source is noisy.

The Nelson Mandela Metropolitan 7 dBA states that if a sound source is more than 7 dBA louder than the ambient environment, the sound source is defined as being too noisy for that environment.

2. Proposed model or Conceptual method

The following general linear model was proposed to be fitted to the sound level data collected during the randomised experiment.

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_{14} x_{14}$$

where

$y \equiv$ Average Decibel measurement (dBA)

$x_1 \equiv$ Wind Speed (m/s)

$x_i \equiv$ Site, $i = 2,...,7$

$x_j \equiv$ Time $j = 8,\ 9,\ 10$

$x_l \equiv$ Direction, $i = 11,\ 12,\ 13$

$x_{14} \equiv$ Distance

3. Research methodology

One of the aims of the study was to design a method for the collection of sound level data across a number of sites.

An experimental design is a type of study formulated in order to save time and money by obtaining more information about a sample in a shorter period of time. A randomised experiment was designed to collect sound level data randomly from several sites in the Port Elizabeth (PE) region.

Sound level data was collected via MT975 sound level meter. Readings were taken over a 70 day period. The site and time for each reading were selected randomly and four measurements were taken at each site and time. The reason that only four sets of measurements were taken at each site and time was due to the time constraint. The randomised selection process of each site and time was created in the open source statistical software package called R.

The sites that were selected for the experiment are shown in Table 1. The seventh site was the ambient measurement for the vertical axis micro-wind turbine. The ambient measurement for the horizontal micro-wind turbine was not able to be taken as the horizontal wind turbine was not able to be switched off during the experiment.

Table 1: Site Description

Horizontal Axis Wind Turbine e300[1] (1kW): Hobie Beach, Port Elizabeth. Co-ordinates: 33°S 58.881’25°E 39.530’ 	**Vertical Axis Wind Turbine 1kW:** NMMU South Campus, Port Elizabeth. Co-ordinates: 34°S 0.523’25°E 39.908’ 
Residential Area: Cathcart Road, Port Elizabeth. Co-ordinates: 33°S 58.801’25°E 38.441’ 	**Beach Front:** Pollock Beach, Port Elizabeth. Co-ordinates: 33°S 59.065’25°E 40.279’ 
Rural environment: NMMU South Campus, Port Elizabeth. Co-ordinates: 34°S 0.509’25°E 39.744’ 	**Street:** Beach road, Port Elizabeth. Co-ordinates: 33°S 58.607’25°E 38.870’ 

Measurements were taken at 08h00, 12h00, 17h00 and 22h00. The reasons for the choice of these four times were that they were believed to include a typical day’s activity. The 08h00 and 17h00 times represent periods of busy community activity, the 12h00 time represents a period of midday relaxation, while the 22h00 time represents a quiet period with little community activity.

For each treatment level two separate readings were taken. These recordings were related to the distance from the sound source. The first measurement was taken close to the sound source. The second measurement was taken approximately 10 m from the source sound.

Sound measurements were recorded in decibels with an A-weighting over a period of two minutes. In the two minute period decibel measurements were recorded every five seconds making a sample size of 240. This was assumed to be a large enough sample to obtain an accurate decibel recording for each measurement. According to the IEC (International standards: Wind turbine generator systems Part11: Acoustic noise measurement techniques) document at least 30 measurements are required in a one minute period to determine an accurate average decibel for a wind turbine evaluation.

Once the sound data was collected the average decibel level over the 240 measurements was calculated in MS Excel. The 25% trimmed means were also calculated in the same manner. The trimmed mean is a measure of central tendency which disregards a given percentage of extreme observations from the sample when the mean is calculated. The trimmed mean is a useful estimator as it is less sensitive to outliers and gives a robust estimate of the central tendency.

The following information was collected concurrently with the noise levels at each site:

- Wind speed (m/s)
- Wind direction

A WSD-100 Wind Speed and Direction Sensor was used to record the average wind speed in m/s and the average wind direction for each measurement. The WSD-100 Wind Speed and Direction Sensor was set up at the Centre of Energy Research (CER) on the Nelson Mandela Metropolitan University South Campus. It was assumed that this measurement recorded at the CER was an accurate average measurement for wind speed and direction for the Summerstrand region in PE, where all measurements were taken. Wind speeds and wind direction were logged instantaneously every 5 minutes. The average wind speed and wind direction were calculated over a 15 minute period during the time that the sound measurements were taken.

The wind direction was defined as a qualitative variable as the data was recorded in the followings format North (N), North North East (NNE), North East (NE), East North East (ENE), East (E), East South East (ESE), South East (SE), South South East (SSE), South (S), South South West (SSW), South West (SW), West South West (WSW), West (W), West North West (WNW), North West (NW) and North North West (NNW). Due to the small sample of measurements in some directions, wind direction measurements were grouped into 4 categories, North, South, East and West. If a direction was found between N and NE (including NE) it was categorised as N. If a direction was found between N and NW (including NW) it was categorised as N. If a measurement was found between S and SE (including SE) it was found to be S and if the direction was found between S and SW it was categorised as S. If a direction was found between NW and SW it was categorised as W and if the direction was found between NE and SE the direction was categorised as E.

4. Results

The results in section 4 pertain to the sound level data that was collected during the randomised experiment.

The descriptive statistical analysis is given in Section 4.1 with results presented in tabular and graphical form followed by discussion. The fitting of the General Linear Model is given in section 4.2.

4.1. Descriptive statistics

A basic descriptive analysis of the quantitative variables was done in STATISTICA. The analysis is presented numerically and graphically. The following variables were defined as quantitative variables:

- Average decibel (dBA)
- Trimmed mean (25%)
- Wind speed (m/s)
- Direction

Presented in Table 2 are the descriptive analysis results of all seven sites under evaluation.

Table 2: Descriptive Statistics.

	Horiz. wind turbine	Vert. wind turbine	Resid. area	Beach front	Rural	Street	Ambient site
Mean	62.39	46.12	50.91	60.49	48.37	65.99	43.80
Trim (25%)	62.25	45.52	50.93	60.33	47.58	65.97	43.94
Median	62.62	44.60	50.24	60.00	46.33	66.91	43.15
Variance	17.77	36.21	17.24	25.61	60.79	14.10	23.16
Std Dev	4.22	6.02	4.15	5.06	7.80	3.75	4.81
n	16.00	15.00	16.00	16.00	16.00	16.00	16.00

Table 2 indicates that the Street had the highest average decibel reading of 65.99 dBA. The sound levels from traffic are influenced by heavy trucks using the street, speed of vehicles and the change in engine speeds for traffic lights, hills and intersecting roads. From an observational study the street is used by heavy trucks during the day and has a busy traffic intersection with robots. These factors could contribute to the high average sound level present at this site. The horizontal wind turbine had an average decibel reading of 62.39 dBA. This was the second highest average sound level found across the sites. From an observational study the wind turbine made sounds that can be described as a “whoosing” and “swishing” sound. This type of sound can be characterised as an aerodynamic sound. Aerodynamic sounds are produced by the interaction between the blades of the wind turbine and the air flow around the blades. The lowest average decibel reading was the ambient sound level at the vertical axis wind turbine site. The second smallest average decibel reading was found at the vertical wind turbine with a value of 46.12 dBA. Although the ambient reading for this wind turbine had the lowest average decibel reading the vertical axis wind turbine reading did not exceed 7 dBA from the ambient measurement which complies with the NMMM noise regulations. The beach front site had the third highest average sound level of 60.49 dBA. This average sound level is comparable with the horizontal axis wind turbine and the street. The residential site had an average sound level of 50.91 dBA. This average was 4.79 dBA higher than the average sound level found at the vertical wind turbine site. This observation motivates the vertical wind turbine application is this area.

The estimated variance of the decibel readings at the rural site is 60.79 $(dBA)^2$. This value is considerably greater than the next highest estimated variance of 36.21 $(dBA)^2$ at the vertical wind turbine site. This result is not surprising as the rural site is quiet and any external sound in the environment will have a big influence on the variance. The outside influences that could have affected the readings are high wind speeds, moving of the decibel reader or even moving trees or bushes. However, the trimmed mean (25%) of 47.37 dBA did not vary much from the mean sound level of the rural site. This indicates that although there was an influence of an external source it did not affect the average decibel level a great deal. The street site had the lowest variability estimate of 14.10 $(dBA)^2$ which indicates that the sound levels at the street remain constant and relatively loud at 65.99 dBA. Both the horizontal wind turbine and residential site had relatively low variability of 17.77 $(dBA)^2$ and 17.24 $(dBA)^2$ respectively, indicating that the average sound levels at these site can be represented by the average sound level calculated. This observation is motivated by the trimmed means (25%) calculated for both sites, as the trimmed means vary only slightly from the estimated average decibel calculated. The vertical wind turbine had a large variance of 36.21 $(dBA)^2$. Wind turbine sounds vary with wind speeds. Therefore any changes in wind speeds will affect the noise of the wind turbine causing variability in noise recordings. Although there was a slight difference in the trimmed mean and the mean, it was reasonably small and the mean still provided a good indication of the average sound level found at this site. The beach front also had a high variance of 25.61 $(dBA)^2$. These sites' sound levels are also greatly affected by wind speeds. There was a small difference in the mean value and the trimmed mean for this site, therefore the average decibel was still assumed to be a good estimate of the true value found at this site.

The missing sample measurement occurred at the 08h00. This missing measurement was due to a malfunctioning of the vertical axis wind turbine.

Figure 1 shows the changes of the average sound level over time for the different sites. Figure 1 indicates that the sound levels are low at the residential site, ambient site of the vertical wind turbine, vertical wind turbine and rural environment. Figure 1 shows that the vertical axis wind turbine average sound levels are lower than the residential area. This suggests that the vertical wind turbine sound may not be noticeable in this environment.

As mentioned in the literature review, environments with high sound levels may be able to mask wind turbine noise. This masking may decrease the perception of noise irritability of wind turbines. The sites with the highest sound levels are the street and the beachfront. This suggests these sites as good environments in which to place a wind turbine with high sound levels such as a horizontal axis wind turbine. The horizontal wind turbine had the highest average noise level at 12h00 across all sites. This could be because fewer cars are on the road at 12h00 and wind speeds were high on the days measurements were taken at the horizontal axis wind turbine.

The residential area decreases in noise levels during the day. A residential environment has low ambient sound levels. This could indicate that this environment will not be able to mask wind turbine noise if the wind turbine generates high sound levels. However, the vertical axis wind turbine has shown to have low sound levels.

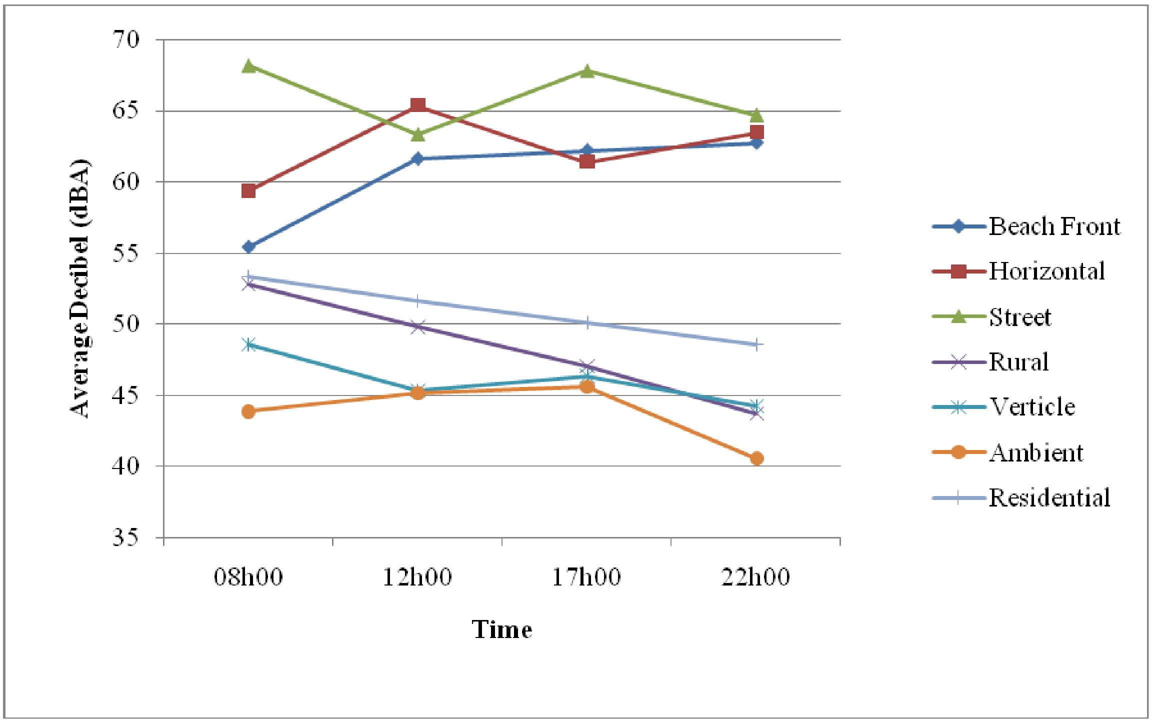

Figure 1: Change in the average decibel over time for each site.

Figure 2 and 3 show the relationship between the average decibel for time and wind direction respectively.

Figure 2 shows the difference in sound levels over time. Figure 2 shows that the average sound level over the seven sites is the lowest at 22:00. This is due to the decrease in traffic noise, construction noise, wind speed and human activity. The average sound level across the remaining three times is between 54 dBA and 55 dBA.

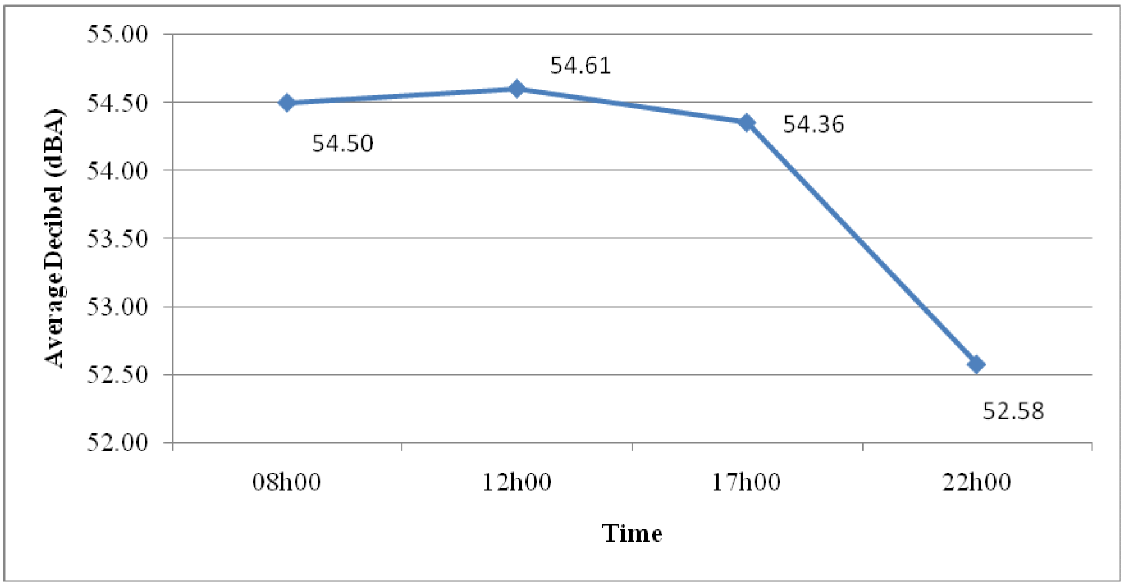

Figure 2: Relationship between the average decibel and time.

Figure 3 shows the relationship between average decibel and wind direction. It is clear that the lowest sound level occurs when wind direction is North.

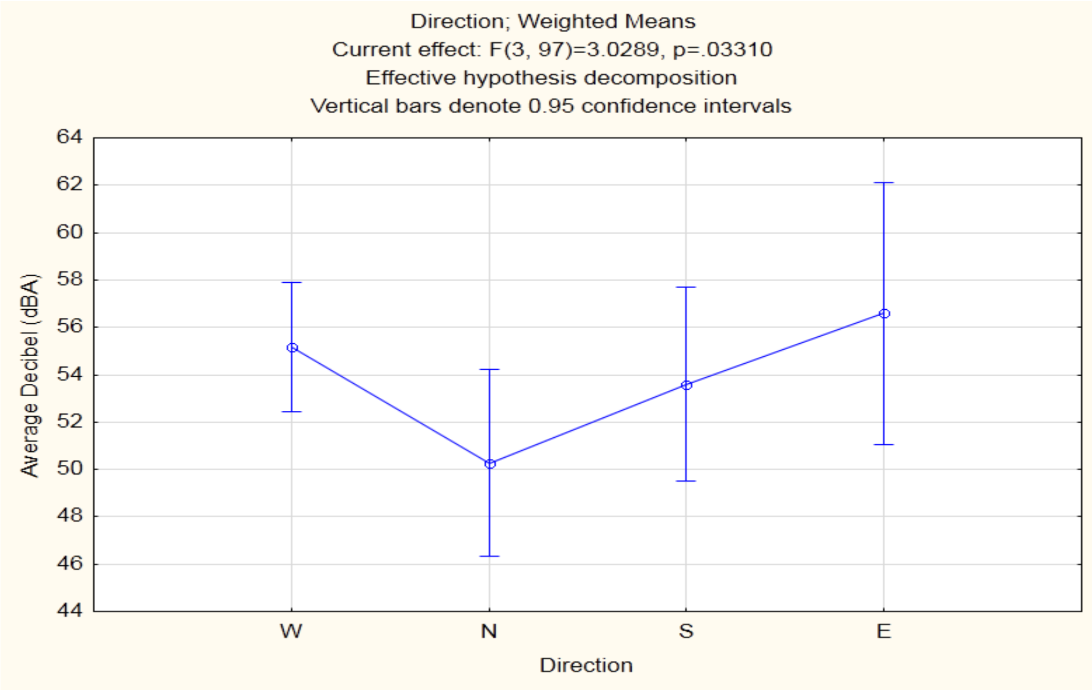

Figure 3: Relationship between average decibel and wind direction.

The wind direction found in the Summerstrand, PE region is predominantly South-westerly. This is motivated by Figure 4 which shows a wind rose. The wind rose displays the frequency distribution of wind direction from January 2011 to September 2011.

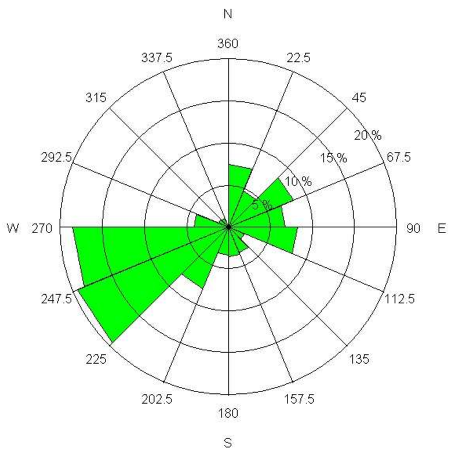

Figure 4: Wind Rose

Shown in Figure 5 is the frequency distribution of wind speeds found in the Summerstrand, Port Elizabeth region. A Weibull distribution was fitted to the wind speed data collected from January 2011 to September 2011. Figure 5 shows that the most dominant wind speeds are found from 1 m/s to 4 m/s.

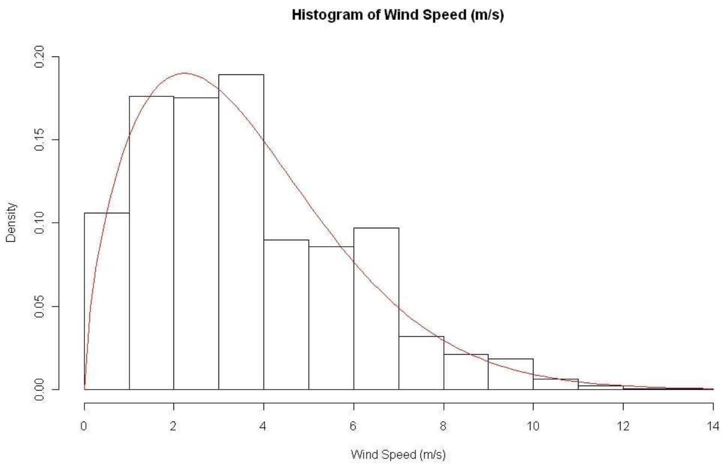

Figure 5: Weibull Distribution Plot of Wind Speeds

4.2. General Linear Model

The model discussed in section 2 was fitted to the sound level data collected during the randomised experiment. The results of the regression analysis are tabulated in Table 3

Table 3: Regression analysis for Complete model.

Multiple R	0.87
Multiple R^2	0.76
Adjusted R^2_a	0.74
SS Model	14444.15
df Model	14
MS Model	1031.72
SS Residual	4607.15
df Residual	207
MS Residual	22.26
F	46.36
p	0.00

The coefficient of correlation (R), coefficient of determination (R^2) and adjusted coefficient of determination (R^2_a) of 0.87, 0.76 and 0.74 respectively, all indicate a good fit of the model. The *F*-test was used to determine the utility of the model and had a statistically significant *p*-value of 0.00. This value indicated that the model is useful for predicting the average sound level for a given site. The effects of the individual parameters are given in Table 4.

Table 4: Effects of individual parameters for GLM.

Effect	SS	df	MS	F	p
Intercept	111572.60	1	111572.60	5012.97	0.00
Wind Speed (m/s)	1244.50	1	1244.50	55.91	0.00
Site	11035.80	6	1839.30	82.64	0.00
Time	91.90	3	30.60	1.37	0.25
Distance	34.50	1	34.50	1.55	0.21
Direction	329.50	3	109.80	4.93	0.00
Error	4607.20	207	22.30		

The *p*-values for the time and distance variables indicated that the variables may have insignificant influence in predicting the average sound levels. The time and distance variables were omitted from the model and a regression summary output for the reduced model is given in Table 5.

Table 5: Regression analysis for reduced model

Multiple R	0.87
Multiple R^2	0.76
Adjusted R^2_a	0.74
SS Model	14317.75
df Model	10
MS Model	1431.78
SS Residual	4733.56
df Residual	211
MS Residual	22.43
F	63.82
p	0.00

Although there was a slight decrease in the R, R^2 and R^2_a the model still indicated a good fit to the average sound level data. This decrease was due to the decrease in the number of parameters in the model. The *F*- test had a statistically significant p-value of 0.00 which indicated a good fit for the model. The effects of the individual parameters are given in Table 6.

Table 6: Effects on individual parameters with omitted time and distance variables.

Effect	SS	df	MS	F	p
Intercept	125026.10	1	125026.10	5573.08	0.00
Wind Speed (m/s)	1387.60	1	1387.60	61.85	0.00
Site	11386.50	6	1897.80	84.59	0.00
Direction	351.60	3	117.20	5.22	0.00
Error	4733.60	211	22.40		

The *p*-values for the reduced model all showed to be statistically significant in the prediction of the average decibel in the model.

The Nested F-Test was used to compare the complete model to the reduced model (time and distance omitted).

The following hypotheses were tested for the contribution of the time variables x_8, x_9, x_{10} and the distance variable x_{11}

H_0: $\beta_8 = \beta_9 = \beta_{10} = \beta_{11} = 0$

H_1: At least one of the β parameters being tested is nonzero

The test statistic was found to be 1.40 and the *F* statistic at a significance level of 0.05 was found to be 2.42. Since $F < F_\alpha$ the null hypotheses was not rejected and it was concluded that at a significance level of 5% that the time and distance variables do not contribute towards the prediction of the average sound level.

Omitting the time and distance variables from the model contradicted theory as it was believed that wind speeds increase over time and would affect the sound levels for a given site. It was also thought that increasing the distance from a sound source would decrease the average decibel.

To determine the statistical significance between the average decibel for the different times and distances, the Bonferroni values were calculated. The Bonferroni statistics are shown in Table 7.

Table 7: Bonferroni values for time.

Time:	**08h00 Average Decibel: 54.72 dBA**	**12h00 Average Decibel: 54.61 dBA**	**17h00 Average Decibel: 54.36 dBA**	**22h00 Average Decibel: 52.58 dBA**
08h00		1.00	1.00	0.24
12h00	1.00		1.00	0.04
17h00	1.00	1.00		0.58
22h00	0.24	0.042	0.58	

The Bonferroni values indicated that there was a difference between the average decibel levels for times 22h00 and 08h00, 12h00 and 17h00. However it was only statistically significant between time 22h00 and 12h00. This observation is motivated by Figure 2.

The Bonferroni values for distance are shown in Table 8.

Table 8: Bonferroni values for distance.

Distance	**1 54.06**	**2 53.27**
1		0.21
2	0.21	

Bonferroni values for distance show that there is no statistical significant difference between the average decibel for distance 1 and distance 2. The relationship between the average decibel for time and distance could indicate why these variables have no statistical significance in the model.

A residual plot was drawn to determine whether outliers were present in the sound level data. A residual plot for the model is given in Figure 6. The highlighted residuals were thought to be outliers and were tested using Cooks distance.

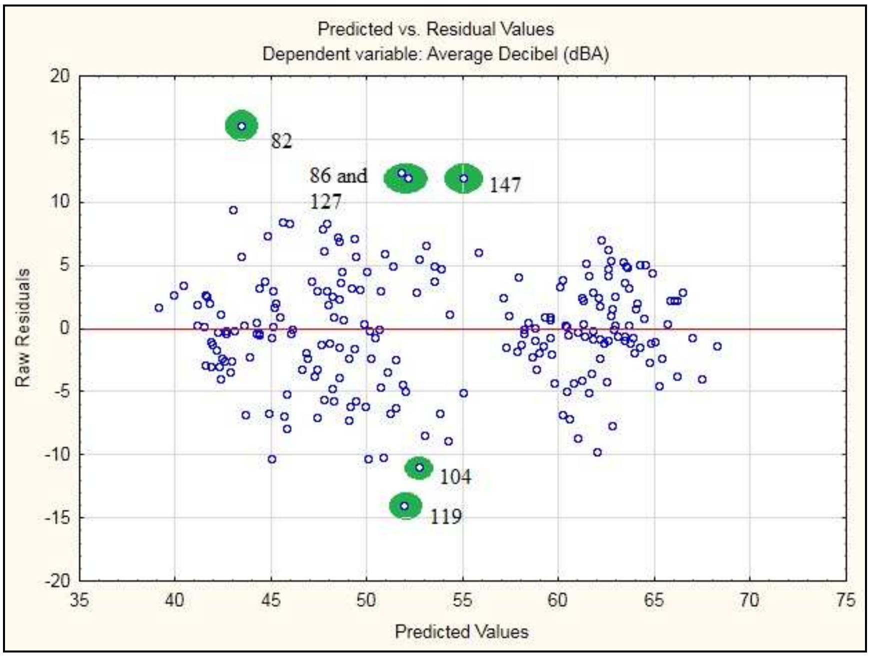

Figure 6: Residual Plot

The values for Cooks distance for highlighted variables are given in Tables 9.

Table 9: Cooks distance

Case Number	Cooks Distance
119	0.06
82	0.05
86	0.04
147	0.04
104	0.04
127	0.03

The values for cooks distance showed that the identified residuals were not outliers as the Cooks distance values were smaller than 1.

From the results it was concluded that the reduced model was the better fit to the sound level data.

5. Conclusions and recommendations

The aim of the study was to provide a comparison between wind turbine noise to traditional accepted surrounding sounds. The collection of data was done using a randomised experiment. Seven sites and four different times were selected. A General Linear Model was then used to determine the relationship between the noise generated at a given site and the different times of day, wind speed, wind direction and distance.

The general linear models showed a very good fit to the sound level data. This conclusion was made according to the high R, R^2 and R^2_a values. The omission of the time and distance variables seems to contradict theory. This contradiction may be due to the relationship between average decibel at the time and distance observations, according to the Bonferroni values. This contradiction may be resolved by increasing the size of the sample data. Increasing the size of the sample data may also improve the fit of the general linear model.

The absence of the ambient noise measurement of the horizontal micro-wind turbine was a drawback in the randomised experiment. This measurement would have given an indication of how the sound levels of the environment might increase due to the presence of a horizontal micro-wind turbine.

Some noise reduction strategies that are given in theory are listed below:

- *Masking*. Bolin has shown that the masking of wind turbine noise by adding "positive" noise from natural sources (trees, waves) can reduce the perception of the wind turbine sound. Placing a wind turbine in an environment with high sound levels may increase the acceptance of wind turbines. From this study the sound levels of the sea provide a natural accepted sound source with high levels which has the ability to mask the wind turbine noise.
- *Blade speed*. A method for reducing the emitted sound levels is to decrease the angular speed of the rotor. Applying this method will decrease the aerodynamic sound by decreasing the "buzzing", "swishing" and "sizzling" sounds observed during an observational study. Although the drawback from this method involves reducing the production of generated electrical power.
- *Shape of the blade*. Increasing the angle of attack and thick airfoils lead to increased sound levels. Decreasing this angle may provide a quieter wind turbine model.

The horizontal axis micro-wind turbine had much higher sound levels than the vertical axis micro-wind turbine. This wind turbine should be placed in an environment with high sound levels. From this study the street and the sea showed to be good environments to place the horizontal wind turbine. The vertical wind turbine showed to have low sound levels. The residential environment had higher sound levels than the vertical axis wind turbine. According to the 7 dBA rule the vertical axis wind turbine would be ideal for household applications in conjunction with PV cells.

There is a wide area for future research in the field of wind turbine acoustics. From this study, increasing the sample size may allow for better fit for the general linear model and may also better describe the effects of time and distance on sound levels. Adding more parameters such as rainfall, topography, height, ambient noise, temperature and other distance measures to the randomised experiment may allow for a more accurate and informative model to be developed. Increasing the number of micro-wind turbine models in the experiment may provide more information about the wind turbine acoustics. For further development of the general linear model, interaction terms may be added to determine whether interaction is present between variables. If interaction is present the model may provide a better fit to the sound level data.

In conclusion, an entirely new prospective methodology for collecting of sound level data was developed. This methodology allowed for accurate models to be fitted to sound level data. Site, time, wind speed and wind direction were identified as factors influencing the sound levels in an environment. This study has thus provided additional knowledge into the field of renewable energy and, in particular, wind turbine acoustics.

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