

**Title:** MICRO SITING, A MAJOR FACTOR INFLUENCING ECONOMIC VIABILITY OF WIND ENERGY SYSTEMS

**Authors:** M W Leelaratne and M Narayana

**Institution:** National Engineering Research and Development Centre of Sri Lanka

**Country:** Sri Lanka

**E-mail:** [leelaratne@nerdc.lk](mailto:leelaratne@nerdc.lk) and [narayana@nerdc.lk](mailto:narayana@nerdc.lk)

## 1 Introduction

Since recent times, large-scale exploitation of Wind Energy has been gaining interest in Sri Lanka. So much so that the first ever grid connected wind energy system was installed at Hambantota in down south of Sri Lanka, in 1999. The 3MW wind park consisted of five numbers NEG-Micon NM600- 43 (600kW) wind turbines. The high investment and the risk associated with the development of such wind parks, due to varying wind climate in the area, has created demand for methods and techniques of proper and accurate assessment of wind energy resources as a pre-requisite to develop wind energy based power generation in an economically viable manner. The WAsP computer-modeling software has been developed just for this purpose and for taking investment decisions in large-scale wind energy based power generation.

This study assesses the WAsP modeling software in relation to the location and performance of the Hambantota 3MW wind park. The Hambantota meteorological station and Kajuwatta wind mast provided two sets of local wind data, which were used as inputs to the WAsP for the analysis and prediction of performance at the turbine site.

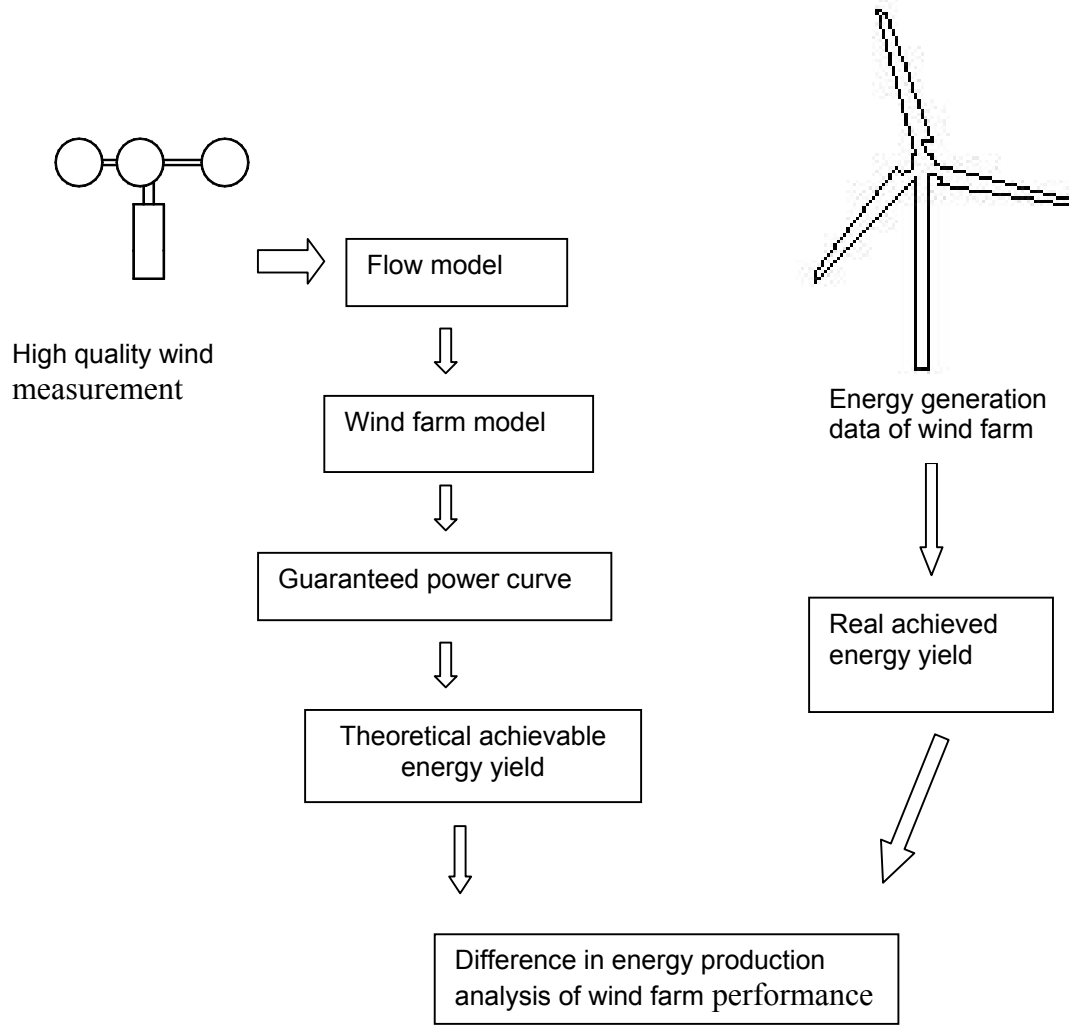
## 2 Methodology

The method is essentially to predict the wind generation potential of the existing wind park at Hambantota using the WAsP model based on the wind measurements data from Hambantota Met Station and Kajuwatta wind mast. The idea is to predict the overall performance of the wind farm rather than the individual machines.

Figure 1 depicts the model used in the analysis. The analysis commences with the local wind data (wind velocity and direction) recorded at location/s nearest to the proposed wind park, in this case Hambantota Met Station and Kajuwatta Wind Mast, and then predicting the local wind climate at the Hambantota wind park site using a suitable flow model. The next step would be to apply these site-specific wind climate to the wind farm model where a specific number of particular wind turbine are installed, in this case five numbers of NEG-Micon NM600-43 (600kW) wind turbines. The specific models (i.e. flow model and wind farm model) used in this study are based on WAsP 7.3 (Ref 2).

To increase the accuracy of predictions, the analysis are made monthly basis, where monthly-recorded wind data are applied to the model and monthly-predicted energy yield is calculated. This process is done for twelve months to cover a period of one year. The year under consideration in this study is 2000. As we

use the wind farm model rather than an individual turbine model, the losses due to mutual shading effect of turbines are taken into consideration and could be estimated separately.

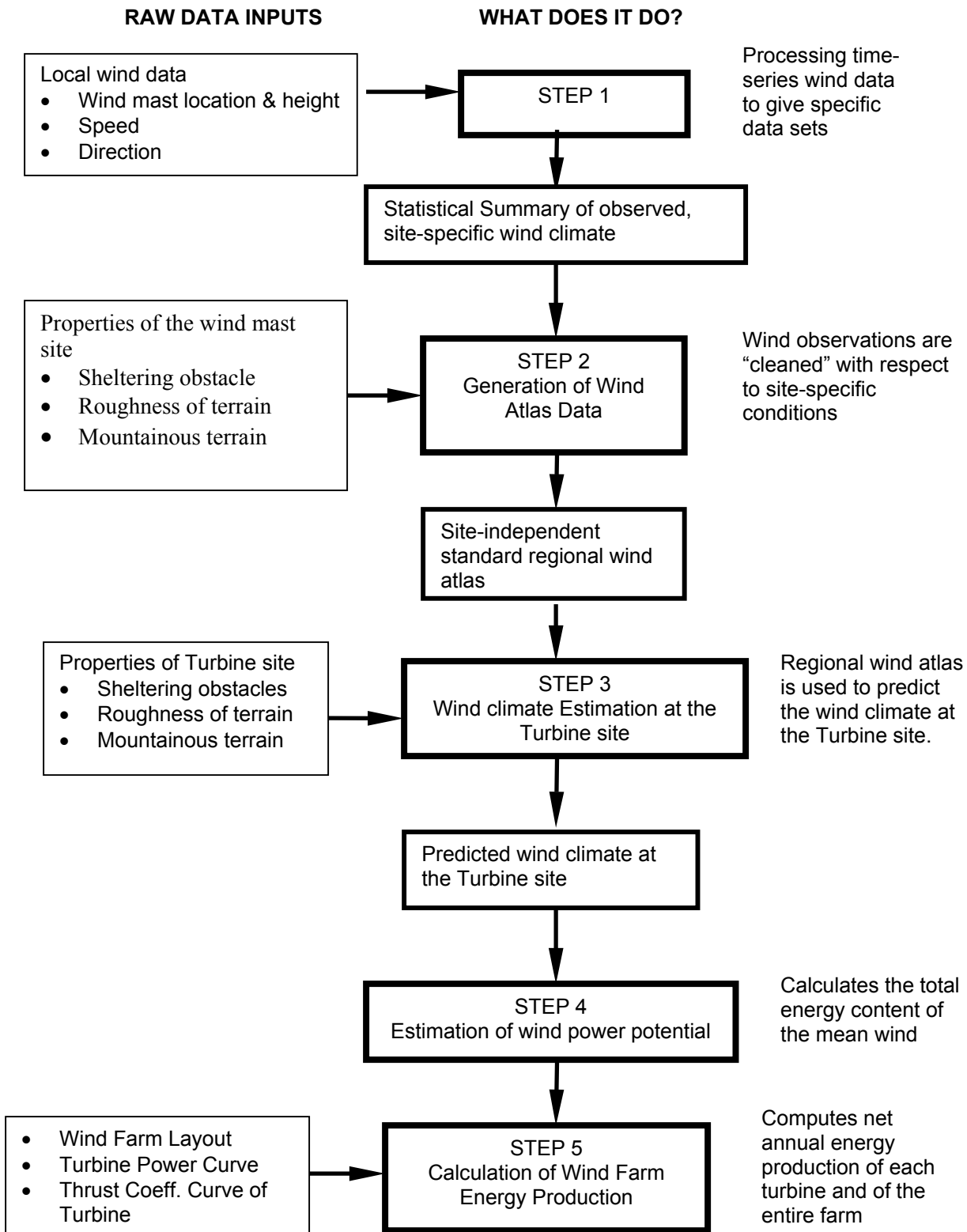


**Figure. 1**

The theoretical energy yielded from the wind farm model and corrected for the turbine shading effect would give the estimated annual energy generated by the wind farm. This yielded energy from wind farm, corrected by the transmission losses up to the point of feeding the grid should give the estimated energy fed to the national grid. Then these estimated figures could be compared with the actual energy fed to the grid as recorded at the Hambantota wind park.

The WAsP model does not include the non-availability of wind turbines for generation and grid failures where generated energy could not be fed to the grid; hence these uncertainties should be eliminated from this verification process.

### 3 WAsP Model



**Figure 2**

Source: Mortensen, N. G. et al (2001), Getting Started with WAsP 7, RISØ, Denmark.

The Wind Atlas Analysis and Application Program (WAsP) is one of many models developed for complete analysis of wind energy based power generation systems. It is a PC based program for horizontal and vertical extrapolation of wind data developed by RISØ laboratories, Denmark in 1987. According to RISØ laboratories, over the years, the WAsP has become the industry standard for wind resource assessment and siting of wind turbines and wind farms. WAsP 7.3 is used in this study.

The WAsP 7.3 contains a complete set of models to calculate the effects on the wind of sheltering obstacles, surface roughness changes and terrain height variations. The analysis part consists of a transformation of an observed wind climate (speed and direction distribution) to a wind atlas data set. The wind atlas data set can subsequently be applied for estimation of the wind climate and wind power potential, as well as for siting of specific wind turbines (Ref. 3). Figure 2, shows the pictorial view of the process flow and application of specific models for prediction of wind climate at a specific location, given the wind climate of a measuring station.

#### 4 Data

##### 4.1 Wind Measurements

Wind measurements at two locations, viz. Hambantota Met Station and Kajuwatta Wind Mast, are used in the analysis and the two predictions were generated for the two raw wind measurements. Table 1 gives the descriptions of the wind masts and the measurement periods for each mast. Exact locations of the wind masts were verified by on the spot GPS measurements.

**Table 1: Descriptions of Wind Masts**

Location	Mast Height – m	Position		Measurement Period	Remarks
		Latitude	Longitude		
Hambantota Met Station	32.5m	E 81.13	N 6.13	1992 to 1997	3.25km away from wind farm
Kajuwatta Wind Mast	34m	E 81.11	N 6.14	1996 to 1999	Inside the wind farm

##### 4.2 Sheltering Obstacles, Surface Roughness Changes and Terrain Height Variations

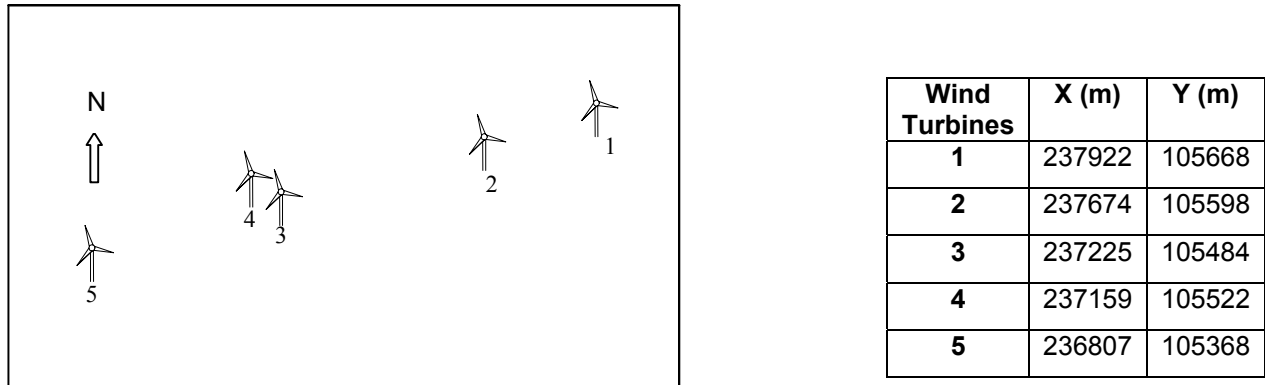
Sheltering obstacles includes permanent structures such as tall buildings, tall trees belts, etc. and are taken from survey maps and on the spot observations. Locations of observed structures were verified by GPS measurements.

Surface roughness changes were also taken from information given in survey maps and verified by site observations. Standard roughnesses values are given in the WAsP programme for specific terrain conditions and are used in this analysis. Terrain height variations of the area are taken from contour maps provided by the Survey Department of Sri Lanka. All these information were fed into the program for an

area of about 400km<sup>2</sup> covering both the Wind Masts and the Wind Park. The survey maps used are of 1:50,000.

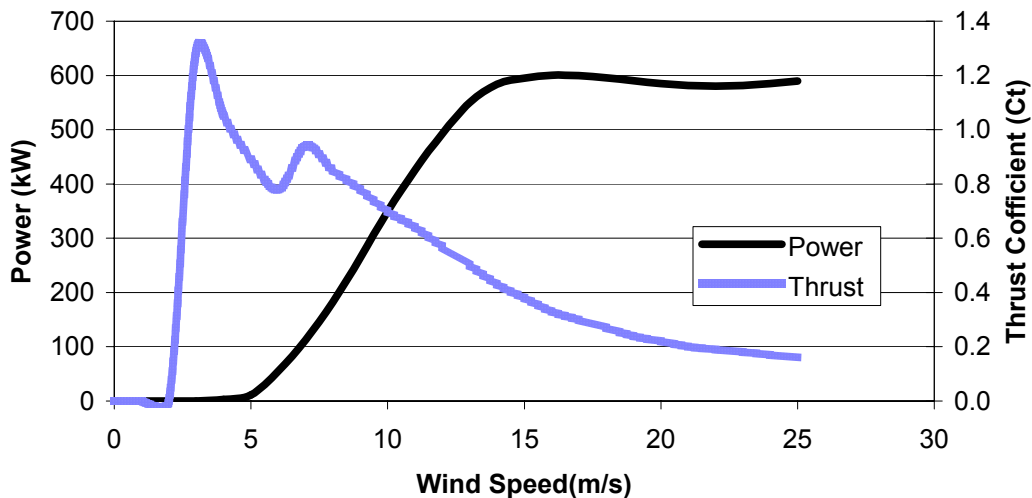
#### 4.3 Turbine Power Curve, Wind Farm Layout, Thrust Coefficient of Turbine

Wind Farm Layout, giving exact locations of Turbines, at Hambantota was established by taking on the spot measurements using GPS. Figure 3, shows the exact locations of the five Wind Turbines and their layout plan.



**Figure 3: Setting of wind turbines in the Hambantota wind farm**

Manufacturers provided the guaranteed power curve and the Thrust Coefficient of the Turbine Model NEG-Micon NM600-43 (600kW). In fact WASP software is already loaded with these information for several common turbine models. Figure 4, shows the power curve and the thrust coefficient of the turbine

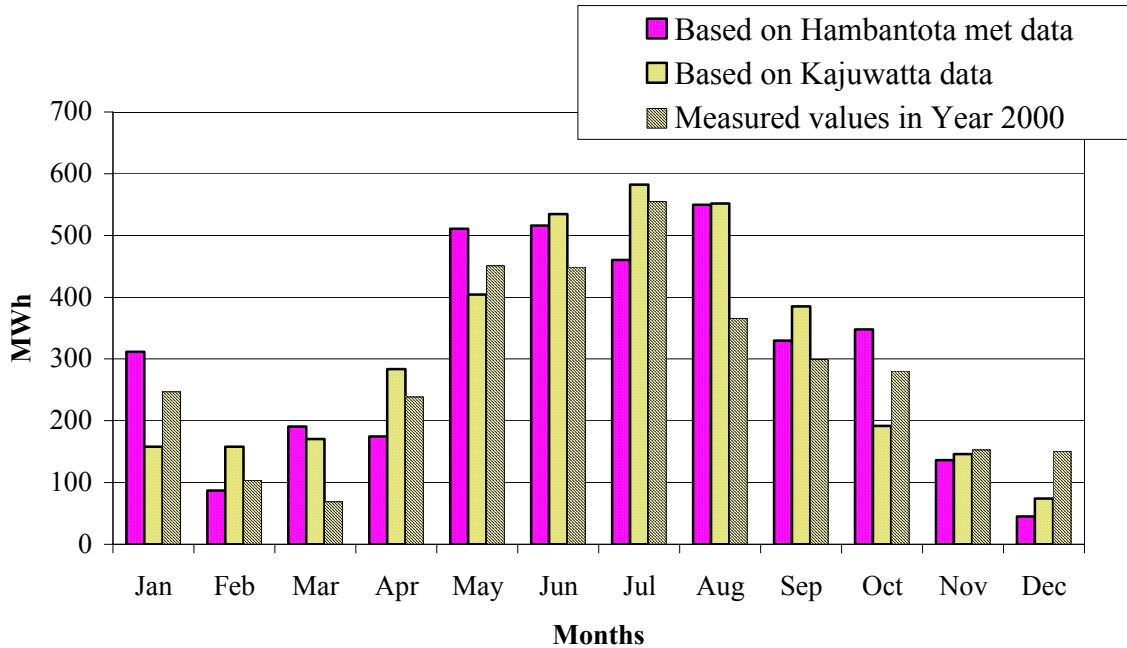


**Figure 4: NEG Micon NEM600-43 Power & Thrust curve**

#### 4.4 Plant Un-utilised Time

To validate real energy production of wind farm by WASP model, WASP prediction should be corrected with availability of wind turbines at the site. In this study plant availability was taken by the recorded grid OK hours in each months of the year 2000. Recorded energy production in the year 2000 and WASP predictions by using Hambantota met station data and Kajuwatta data is presented in the Table. 2.

Graphical presentation of predicted and measured energy performance of 3MW Pilot Wind Power Project is shown in Figure 5.



**Figure. 5: Predicted and real energy performance of 3 MW Pilot Wind Power Project**

### 5 Causes for differences between real and WASP calculation energy generation

Possible reasons for a discrepancy between real and predicted wind farm energy production are:

#### 5.1 Insufficient wind resource assessment

Inadequate site assessment is the source for unexpected energy production of wind farms. Unknown quality and conditions of wind measurements may give incorrect prediction. Especially using of the incorrect terrain condition for the meteorological model calculations is arising variation between actual and predicted energy production values. Another source of uncertainty is the application of flow simulation codes not designed for the terrain in question (terrain inclination, atmospheric stability, transitional region between land and sea). If data from a meteorological station are representative for the investigated site; the wind climate can change drastically on short distances, e.g. 1km. Further more, wind data offered by most meteorological services often attribute to higher uncertainties than required for wind engineering and are often measured at too low heights (mostly 10m).

**Table 2: Monthly Wind Speed & Energy Generation of 3 MW Pilot Wind Power Project in Year 2000**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total or average
Total Hours in the period (days × 24)	744	696	744	720	744	720	744	744	720	744	720	744	8784
Mean Wind speed, m/s at 46m (hub height)	5.4	3.8	3.2	4.8	6.4	6.4	7	6.7	6	5.8	4.5	4.3	5
Operating hours	724	643	711	684	709	673	669	564.5	537.7	630	679.7	634	7859
Free wheeling hours	48	110	222	115	13	17	7	23.9	20	74.2	118.9	101	870
Grid OK hours	744	697	724	716	733	705	733	740.6	713.4	742	717.6	738	
Turbine Stop hours	20	36	28	31	34	32	74	187.4	177	112	40.5	105	877
Plant availability factor	97%	93%	96%	95%	95%	94%	87%	74%	75%	95%	94%	96%	
Grid availability factor	100%	98%	97%	99%	99%	98%	99%	99.8%	99%	100%	100%	99%	
<b>Total gross energy generation MWh</b>	<b>246.94</b>	<b>103.86</b>	<b>68.98</b>	<b>238.71</b>	<b>451.37</b>	<b>449.01</b>	<b>554.57</b>	<b>365.55</b>	<b>299.15</b>	<b>280.43</b>	<b>152.96</b>	<b>151.08</b>	<b>3362.60</b>
Var consumption MVArh	127.16	55.97	33.05	47.65	72.64	71.33	78.30	55.67	50.54	58.63	58.63	46.20	741.62
MVArh / MWh %	51%	54%	48%	20%	16%	16%	14%	15%	17%	21%	38%	31	22%
No. of Auto stops	96	118	101	83	70	111	83	114	85	100	78	97	1136
Plant Factor %	11%	5%	3%	11%	20%	21%	25%	16%	14%	13%	7%	7%	13%
<b>WAsP model prediction by using Hambatota met station data (MWh)</b>	<b>311.69</b>	<b>86.99</b>	<b>190.80</b>	<b>174.98</b>	<b>510.54</b>	<b>515.75</b>	<b>460.24</b>	<b>549.86</b>	<b>329.91</b>	<b>347.80</b>	<b>136.40</b>	<b>45.05</b>	<b>3660.01</b>
<b>WAsP model prediction by using Kajuwatta data (MWh)</b>	<b>158.26</b>	<b>157.96</b>	<b>170.48</b>	<b>283.77</b>	<b>404.58</b>	<b>534.68</b>	<b>582.08</b>	<b>551.93</b>	<b>385.08</b>	<b>191.80</b>	<b>146.01</b>	<b>74.38</b>	<b>3366.16</b>

*Source: 3 MW Pilot Wind Power Project, Semi - Annual Report on the Performance, July - December 2000,*

The uncertainties attributed to energy predictions can be reduced drastically by performing wind measurements at the potential wind farm site at least for the period of one year. However, in this study the wind resources are estimated by using energy based wind measurements.

### 5.2 Differences in annual wind potential.

The technical available wind potential can change from year to year by about 10%. Sometimes wind indices are taken into account when comparing the real wind farm production within a certain period to the long-term prediction. It must clearly be stated, that a global wind index describing the yearly wind potential fluctuations for single wind farm locations does not exist. (Ref. 1) The annual differences in wind potential can be very site specific, they may vary drastically within some ten kilometres distance, and hence a wind index should not be applied to judge the energy production data. Accurate input data for an evaluation of the energy potential during certain periods can be gained from a long term monitoring of wind conditions directly at the wind farm location during the whole lifetime of the wind farm.

### 5.3 Differences between real and guaranteed wind turbine power curve.

Some power curves provided by manufactures are unrealistic, which have not been measured according to quality insuring international accepted guidelines. High reliability and quality of measured power curves are guaranteed by qualified institutions only (accreditation according to EN 45001, MEASNET-members (2)). Most wind turbines manufacturers offer their products based on power curves measured at prototype turbines. Thus further sources of uncertainly can origin from differences between the individual wind turbines and the prototype (Ref. 1). As a consequence it is recommended to verify the wind turbine power curve on the basis of measurements in order to optimise the wind turbine operation and to prove the power curve guaranteed by the manufacturer. The power performance of wind turbines can also be affected due to ageing of the turbines (wear-off of material) or by environmental impact (rotor blade acridition, dirt on rotor blades).

### 5.4 Lower than expected technical wind turbine availability.

The predicted energy production of a wind farm usually relies on a certain level of technical availability of the wind turbines. Most wind turbine manufactures also guarantee the level of technical availability to their clients (e.g. wind turbine during 98% of the year available). The problem of this kind of warranty is, that the periods of non-availability can fall into periods with strong winds and hence the loss of energy production can be much larger than expressed by the percentage of non-availability. For instance a technical availability of 98% can lead to a loss of energy production of 8% if the 2% periods of non-availability always happen at wind speeds above rated wind speed. Therefore, a proper warranty of the wind turbine availability should also incorporate the possible energy production during a certain period. A long term monitoring of the wind conditions at the wind farm site specially designed to the requirements of the performance verification can serve to prove the technical availability. It must

be pointed out clearly, that the monitoring device usually offered by the wind turbine manufacturers for supervision of the wind farm operation and fault detection is not suited for this purpose (Ref. 1).

## 6 Discussion

In this study the wind resource is estimated by meteorological model calculations based on wind data from Hambantota met station and Kajuwatta wind data. Hambantota met station wind mast was located in 3.25km distance from the wind farm and Kajuwatta station is located inside the wind farm. By using the Hambantota met station wind data, predicted annual energy production is 3660.013 MWh and by using the Kajuwatta station wind data, that value is 3366.162 MWh, while actual measured value is 3362.602 MWh. Non-availability of wind turbines has being considered for these calculations. According to these WAsP calculations, prediction by using Kajuwatta wind data is more accurate. This difference may be occurred due to seasonal variation of wind climate and variation of wind climate in the terrain. However, WAsP is facilitating enough to verify the performance of 3MW Hambantota wind farm by using Hambantota met station data.

Wind pattern in Sri Lanka is seasonal, and then monthly bases prediction gives more accurate values rather than considering yearly bases prediction. In the WAsP metrological model, wind speed distribution is always fit with the Wiebul distribution. Then WAsP prediction by using yearly wind speed distribution is lees accurate as seasonal monsoon wind pattern in Sri Lanka is not tally with the Wiebul distribution.

## 7 Acknowledgement

We would like to express our sincere gratitude to the pre-electrification unit of Ceylon electricity board to supply wind data for this study. Our thanks are extended to the DGM Thermal power plant Ceylon electricity board to grant permission to visit 3MW Hambantota wind farm and our thanks are also extended to the staff of wind farm for their kind assistance to take required observations.

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