Wind potential assessment in urban area of Surakarta city

Cite as: AIP Conference Proceedings **1931**, 030070 (2018); https://doi.org/10.1063/1.5024129
Published Online: 09 February 2018

Dominicus Danardono Dwi Prija Tjahjana, Arnold Thamrin Halomoan, Andreas Wibowo, et al.

Wind Potential Assessment in Urban Area of Surakarta City

Dominicus Danardono Dwi Prija Tjahjana[1*], Arnold Thamrin Halomoan[1], Andreas Wibowo[1], Dwi Aries Himawanto[1], Yoga Arob Wicaksono[1]

[1]*Mechanical Engineering Department, Faculty of Engineering, Sebelas Maret University, Surakarta 57126, Indonesia*

*Corresponding author Email: ddanardono@staff.uns.ac.id

Abstract. Wind energy is one of the promising energy resource in urban area that has not been deeply explored in Indonesia. Generally the wind velocity in Indonesia is relatively low, however on the roof top of the high rise building in urban area the wind velocity is high enough to be converted for supporting the energy needs of the building. In this research a feasibility study of wind energy in urban area of Surakarta was done. The analysis of the wind energy potential on the height of 50 m was done by using Weibull distribution. The wind data based on the daily wind speed taken from 2011-2015. From the result of the wind speed analysis, a wind map in Surakarta was developed for helping to determine the places that have good potential in wind energy. The result showed that in five years the city of Surakarta had mean energy density (E_D) of 139.43 W/m^2, yearly energy available (E_I) of 1221.4 kWh/m^2/year, the most frequent wind velocity (V_{Fmax}) of 4.79 m/s, and the velocity contributing the maximum energy (V_{Emax}) of 6.97 m/s. The direction of the wind was mostly from south, with frequency of 38%. The south and west area of the city had higher wind velocity than the other parts of the city. Also in those areas there are many high rise buildings, which are appropriate for installation of small wind turbine on the roof top (building mounted wind turbine/ BMWT).

INTRODUCTION

Rising fuel price and environmental concern have driven many country to utilize the renewable and green energy as the main energy source. Indonesia planned to use renewable energy as one of the main source of national energy production in 2025 with value 23% of total national energy production. Among renewable energy resources, wind power is an important source of environmental-friendly energy and has become more important in the recent years. Based on the renewable energy mapping done by Indonesia national energy council in 2016, Indonesia has wind and hybrid energy potential about 60 GW for average wind speed 3-6 m/s and only 3.1 MW is in used [1].

Wind energy has a large potential to be explored in the urban area, whether through the installation of small wind turbines in the building rooftops or integrated in the building [2]. Surakarta as a rapid growing urban city have many high rise building on its region which consume high amount of electrical energy with value 27.55% of total Surakarta electricity consumption for 2016 [3]. With high electrical energy consumption, the utilization of wind energy in Surakarta city becomes more relevant to be developed. However, until recently there is no report about wind energy assessment over Surakarta city region.

Most common method use to assessing the wind energy potential of a particular site is to use Weibull distribution methods [4]. Previous study conducted by Danardono *et al* analyze the wind speed characteristics and calculated the wind power generation potential using Weibull distribution function at several coastal region [5, 6, 7]. Weibull distribution method also used by Solyali *et a*l and Keyhani *et al* to analyze wind power potential in Northern Cyprus and Iran [8, 9].

Although several studies have been done to assess the characteristics of wind potential energy across Indonesia, no attention has been given to the urban region. The aim of this study is to evaluate the wind energy potential in

The 3rd International Conference on Industrial, Mechanical, Electrical, and Chemical Engineering
AIP Conf. Proc. 1931, 030070-1–030070-7; https://doi.org/10.1063/1.5024129
Published by AIP Publishing. 978-0-7354-1623-9/$30.00

Surakarta city. The result of the assessment will be very useful in determining the proper wind energy harvesting technology in urban area. In this study, wind energy potential assessment in Surakarta city was done using Weibull distribution method. The wind data based on daily wind speed taken from 2011-2015. The wind rose diagram of Surakarta city also developed to determine the dominant wind direction.

METHODOLOGY

Wind Speed Profile

The location of wind potential assessment in this study located in the city of Surakarta, Central Java Province, Indonesia. Daily wind speed data used in this study taken from the Indonesian Air Force Meteorological station which located in the Adi Soemarmo Air Force Base. The wind speed data is taken from recorded wind speed at height of 10 m for over 5 years period from January 2011 to December 2015. In assessing the wind potential energy, the first step was extrapolating the available wind data from the nearest weather station or airport to the intended location and height. The next step was calculating the average wind velocity and the standard deviation of the extrapolating result of the wind data. Two-parameter Weibull probability density function was used in this study. The wind velocity is characterized by two parameter functions: the probability density function and the cumulative distribution. Based on the wind direction from the available wind data, a wind rose diagram was generated using WRPlot View software.

To analyze the wind speed at different height form the measurement height, the available wind speed data at the measurement site height can be extrapolated to other heights on the basis of the roughness height of the terrain [10, 11]. Due to the boundary layer effect, wind speed increases with the height in a logarithmic pattern which is defined as:

$$v = v_Z \left(\frac{z}{z_G}\right)^{\alpha} \qquad (1)$$

The typical value of α and Z derived from the Atmospheric Boundary Layer Parameters tables suggested by ASHRAE which categorized into four categories based on the terrain condition as shown in the Table 1. The value and the terrain categories suggested by ASHRAE also consistent with those adopted in other engineering applications such as ASCE Standard 7 [12].

Table 1. Suggested values of Z_G and α for various terrain conditions [12]

Terrain Category	**Description**	**Exponent α**	**Layer Thickness δ, m**
1	Large city centers, in which at least 50% of buildings are higher than 21.3 m, over a distance of at least 0.8 km or 10 times the height of the structure upwind, whichever is greater	0.33	460
2	Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger, over a distance of at least 460 m or 10 times the height of the structure upwind, whichever is greater	0.22	370
3	Open terrain with scattered obstructions having heights generally less than 9.1 m, including flat open country typical of meterological station surroundings	0.14	270
4	Flat, unobstructed areas exposed to wind flowing over a distance of 460 m or 10 times the height of the structure inland, whichever is greater	0.10	210

Because of the different of the terrain roughness between measurement location and the urban area, the equation (1) will be modified to the following equation to estimated wind speed at the predicted height [11]:

$$\frac{v_m}{v_z} = \frac{\left[\frac{Z_m}{Z_{mG}}\right]^{\alpha m}}{\left[\frac{z}{z_G}\right]^{\alpha}} \tag{2}$$

For the case in this study, the value of the α_m, α, Z_{mG} and Z_G is taken as 0.14, 0.33, 270 and 460 according to Surakarta City and the measurement location terrain condition category as shown in ASCE Standard 7.

Weibull Distribution Function

The Weibull distribution model consists of two parameter functions: probability density function *f(V)* and cumulative distribution function *F(V)*. The probability density function *f(V)* indicates the probability of the wind at a given velocity *V*. Where *c* is the characteristic of the wind potential of the observed region (scale factor) and *k* is the non-dimensional Weibull shape parameter The probability density function *f(V)* is defined as [10]:

$$f(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{3}$$

The cumulative distribution *F(V)* is the integral of the probability density function which shows the probability of the wind velocity within a given wind speed range. The cumulative distribution *F(V)* is defined as:

$$fF(v) = \int_0^{\alpha} f(V)dV = 1 - \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{4}$$

One of the most important factors to determine the potential of wind energy in certain area is the value of the average wind speed *(V_m)* and the standard deviation *(δV)*. The average wind speed and standard deviation is expressed by using Eq. 5 and Eq. 6 respectively.

$$V_m = \left(\frac{1}{n}\sum_{i=1}^{n} V_i^{3}\right)^{\frac{1}{3}} \tag{5}$$

$$\sigma_v = \sqrt{\frac{\sum_{i=1}^{n}(V_i - V_m)^2}{n}} \tag{6}$$

Once the value of V_m and δV are calculated, the value of *k* and *c* can be estimated respectively as:

$$k = \left(\frac{\sigma_v}{v_m}\right)^{-1.090} \tag{7}$$

$$c = \frac{v_m k^{2.6674}}{0.184 + 0.816\, k^{2.73855}} \tag{8}$$

As the value of c and k already determined, the most probable wind speed (V_F) and the wind speed carrying maximum energy (V_E) can be determined. The most probable wind speed (V_F) shows the most frequent wind speed for wind probability distribution while the wind speed carrying maximum energy (V_E) represent the wind speed value which carries maximum wind energy [9]. The most probable wind speed (V_F) and the wind speed carrying maximum energy (V_E) can be calculated using the following equations:

$$V_F = c\left(1 - \frac{1}{k}\right)^{1/k} \tag{9}$$

$$V_E = c\left(1 + \frac{2}{k}\right)^{1/k} \tag{10}$$

Wind Power and Energy Density

The wind power density (WPD) calculates the distribution of the wind speed and the dependence of wind power on air density. WPD indicates the capability of wind resource at certain region while wind energy density is defined as the power density over a time period [9][10]. Wind power density and wind energy density is expressed as [10]:

$$WPD = \frac{\rho_a c^3}{2}\frac{3}{k}\Gamma\left(\frac{3}{k}\right) \quad (11)$$

$$WPD = \frac{\rho_a c^3}{2}\frac{3}{k}\Gamma\left(\frac{3}{k}\right)T \quad (12)$$

RESULT AND DISCUSSION

Weibull Distribution

In this study, wind speed data of Surakarta city for over 5 years, from January 2011 to December 2015 were analyzed to determine the average wind speed in Surakarta City. The calculations were then made to obtain the Weibull distribution parameters and predicted mean wind power. The monthly mean wind speed values v and standard deviations are presented in the Table 2 while the Weibull parameter are presented in Table 3.

Most of the average wind speed values are between 4 m/s and 5 m/s with total frequency 35.90%. during the 5 years period, the highest average wind speed occur in the September 2012 with wind speed of 7.366 m/s and the lowest wind speed occur in March 2015 with value of 3.080 m/s. From this data, it can be seen that the monthly wind speed in Surakarta has a significant difference between one month to the other with standard deviation of 2 m/s.

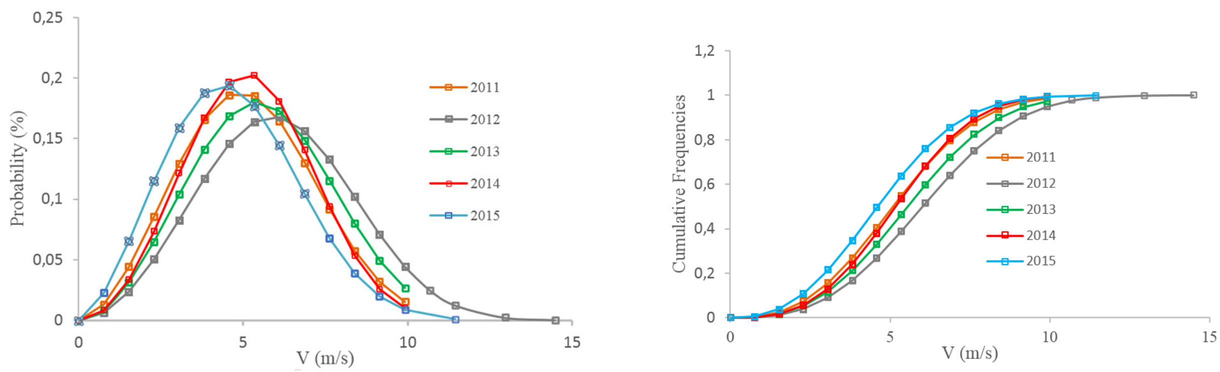
TABLE 2. The monthly mean wind speed values v and standard deviations

Month	Parameter	2011	2012	2013	2014	2015	5 Years
January	v	3,939	6,862	3,539	4,266	3,927	5,376
	σ	1,454	3,668	1,256	1,741	1,422	2,516
February	v	3,715	4,944	3,676	4,985	3,458	4,458
	σ	1,918	2,023	1,358	2,450	1,944	2,051
March	v	4,319	5,499	3,642	5,064	3,080	4,726
	σ	2,094	2,086	1,256	2,140	1,099	1,932
April	v	4,014	4,201	4,313	4,176	3,626	4,373
	σ	1,364	1,509	1,660	1,483	1,478	1,547
May	v	3,379	4,916	4,331	3,736	3,107	4,277
	σ	1,172	1,884	1,742	1,074	1,220	1,547
June	v	5,328	4,672	4,453	3,767	3,657	4,724
	σ	1,557	1,616	1,502	1,268	1,324	1,615
July	v	4,860	6,292	5,854	4,521	4,626	5,527
	σ	1,827	1,516	2,145	1,987	1,244	1,923
August	v	5,376	6,584	5,856	4,583	4,973	5,837
	σ	1,692	1,788	1,560	1,328	1,575	1,780
September	v	6,587	7,366	7,072	5,712	4,476	6,640
	σ	1,443	1,708	1,722	1,532	1,761	2,002
October	v	6,117	6,426	7,137	5,668	6,374	6,654
	σ	2,336	1,984	1,980	1,459	1,896	2,012
November	v	4,294	5,623	5,215	4,943	4,902	5,350
	σ	1,419	1,714	1,844	1,679	2,250	1,926
December	v	5,205	5,238	5,596	5,712	4,880	5,573
	σ	2,065	1,896	1,823	2,144	2,771	2,205
Yearly	v	5,163	6,077	5,607	5,204	4,714	5,048
	σ	2,036	2,274	2,130	1,881	1,982	2,029

As shown in the Table 2, the yearly value of k parameter was between 2.571 and 3.031 with average value for 5 years period was 2.701. The lowest and highest k value occured in 2015 and 2014. While the lowest and highest c parameter value was 5.312 and 6.819 which occured in year 2015 and 2012 respectively with average value of 5.680 for 5 years period. The Weibull distribution probability and cumulative distribution function curve are presented in the Fig. 2. The result of Weibull distribution calculation showed the most frequent wind speed for over 5 years period is in range of 5 m/s with probability 20% for wind speed range between 0 and 8 m/s for over 92% time period.

TABLE 3. The Weibull parameter

Years	k	c (m/s)	V_f	V_e	V_m
2011	2.757	5.805	4.930	7.075	5.166
2012	2.920	6.819	5.907	8.153	6.069
2013	2.871	6.295	5.423	7.568	5.611
2014	3.031	5.830	5.109	6.891	5.209
2015	2.571	5.312	4.385	6.644	4.716
5 Years	2.701	5.680	4.786	6.974	5.051



(A) (B)

FIGURE 2. Weibull distribution standard deviation method: (A) density probability function and (B) the cumulative distribution function

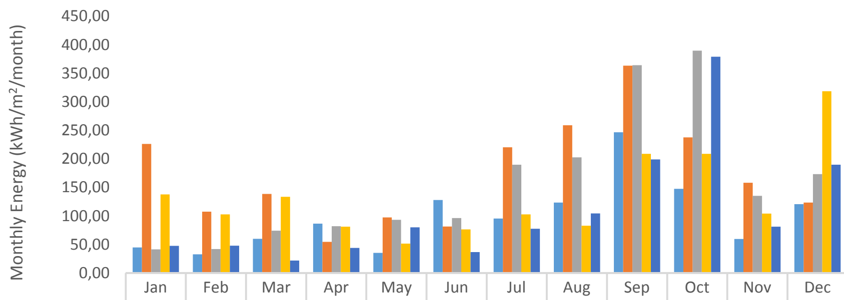
Wind Power Density and Energy

The wind power density and energy for over 5 years in Surakarta city area are presented in the Table 4 while the monthly wind power availability are presented in Fig. 6. The highest value of wind power density in Surakarta city area occured in 2012 with value of 200.3 W/m^2 and the lowest power density value occured in 2015 with value only 81.3 W/m^2. The annual energy in Surakarta city for over 5 years is 1160.473 kWh/m^2/year with the energy ranged between 712.476 to 1754.630 kWh/m^2/year and the average monthly wind power availability in Surakarta city was 200 W/m^2.

TABLE 4. The wind power density and energy for over 5 years in Surakarta city area

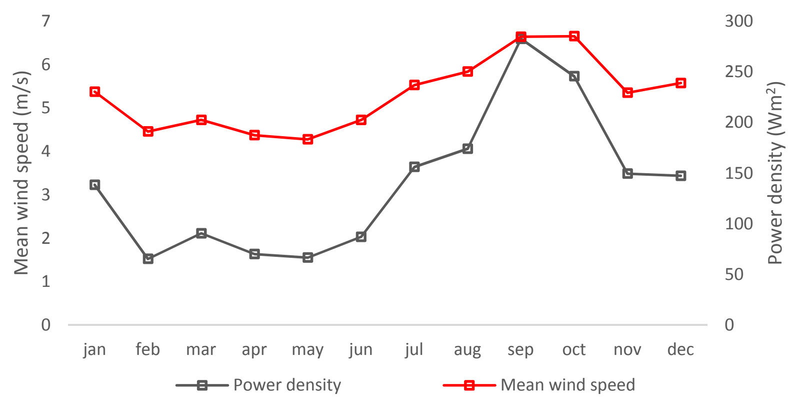
Year	V_m (m/s)	P/A (W/m^2)	E/A (kWh/m^2/year)
2011	5.16	118.4	1037.275
2012	6.08	200.3	1754.630
2013	5.61	150.6	1318.876
2014	5,20	126.4	1107.332
2015	4,71	81.3	712.476
5 years	5.05	132.5	1160.473

Based on this result, Surakarta city is classified in sufficient category as a wind energy producer for every year. Although the large-scale wind turbines is not suitable to use in Surakarta city, the wind energy converter technology still suitable to be implemented in Surakarta city by using small scale wind turbine. As shown in Fig. 6, the monthly power density for 5 years is very fluctuating, major change in wind power density with a maximum value (389.6 W/m^2 occurs in October 2013) with a value 17.76 times the minimum value (21.93 W/m^2 in March 2015).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2011	44,82	32,78	60,10	86,57	35,34	128,07	95,58	123,51	246,61	147,68	59,60	120,57
2012	226,07	107,47	138,65	54,78	97,58	81,40	220,21	258,80	363,27	237,61	158,08	123,55
2013	41,53	42,06	74,36	81,95	93,23	96,43	189,87	202,58	364,00	389,61	135,13	173,17
2014	137,90	102,70	133,57	81,12	51,45	76,47	102,73	82,97	208,88	208,88	104,09	318,51
2015	47,80	47,81	21,93	44,14	80,08	36,88	77,58	104,34	198,96	378,87	81,34	189,92

(A)



(B)

FIGURE 3. Surakarta city wind power: (A) Potential availability and (B) average monthly wind power density

In order to find the Surakarta overall wind direction for over 5 years, the wind rose diagram was generated using WRPlot View software. The wind direction frequency from 2011 to 2015 is presented in Fig. 6. As shown in Fig. 6, the highest wind direction frequencies was mostly from south, with total frequency of 38%. This total 38% frequencies consisted of, 8% of the total frequencies for wind speed 2.1-3.8 m/s, 12% of the total frequencies for wind speed 5.7-8.8 m/s, 2% of the total frequencies for wind speed 8.8-11.1 m/s and the highest frequencies value 16% of the total frequencies for wind speed 3.8-5.7 m/s. The wind rose diagram also indicated that the South and South-West area of the city had higher wind velocity than the other parts of the city.

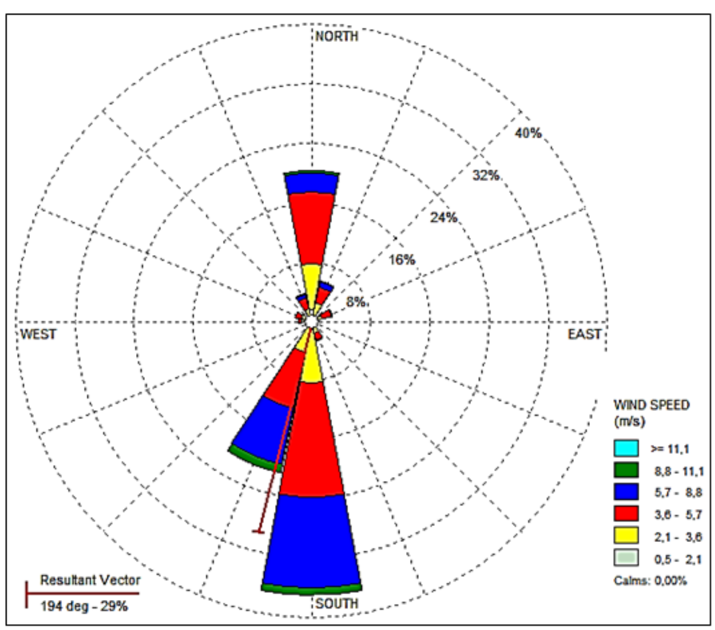


FIGURE 4. Surakarta city wind rose diagram

CONCLUSION

In this study, the assessment of the wind energy potential in Surakarta city was analyze using Weibull distribution for over 5 years period from 2011 to 2015 on the height of 50 m. The result indicated that the city of Surakarta had mean energy density (E_D) of 139.43 W/m^2 and yearly energy available (E_I) of 1221.4 kWh/m^2/year with the most frequent wind velocity (V_{Fmax}) is 4.79 m/s, and the velocity contributing the maximum energy (V_{Emax}) is 6.97 m/s. The result also indicated that the South and South-West area of the city had higher wind velocity than the other parts of the city with wind direction mostly from the southern region of the city. The study shows that energy from the wind can be harvested on the roof top of the high rise building at the height of at least 50 m. An appropriate type and design of wind turbine should be applied according to the V_{Emax}.

ACKNOWLEDGMENT

This research is supported by Universitas Sebelas Maret Surakarta through PNBP research grant (PU UNS), T.A. 2017, No: 623/UN27.21/PP/2017.

REFERENCE

[1] E. Prasojo, *Outlook Energi Indonesia 2016*, Sekretariat Jendral Dewan Energi Nasional (2016)
[2] Stankovich, Sinisa., Campbell, Neil., Harries, and Alan. Urban Wind Energy: Earthscan, BDSP Partnership Ltd. (2009)
[3] BPS Kota Surakart, Kota Surakarta Dalam Angka 2017, Badan Pusat Statistik Kota Surakarta (2017)
[4] J. M. Stevens, M., T. Smulders, P., *Wind Engineering*. **3**, 132-145 (1979)
[5] D. D. D. P. Tjahjana, I.K. Al-Masuun, A. Gustiantono, 2016, "Wind Potential Assessment to Estimate Performance of Selected Wind Turbines in Pandansimo Beach-Yogyakarta", AIP Confrence Proceedings 1717, 030018.
[6] D. D. D. P. Tjahjana, Salem, Abdelkarim. A., Himawanto, Dwi Aries., 2016, "Wind energy potential analysis in Al-Fattaih-Darnah", AIP Conference Proceedings 1717, 030015.
[7] D. D. D. P., Tjahjana, Premono, B. S., Hadi, Samsul, 2017, "Wind energy potential assessment to estimate performance of selected wind turbine in northern coastal region of Semarang-Indonesia", AIP Conference Proceedings 1788, 030026.
[8] Solyali, Davut., Altunç, Mustafa., Tolun ,Süleyman., Aslan, Zafer., Wind resource assessment of Northern Cyprus, Renewable and Sustainable Energy Reviews, **55,** pp.180–187 (2016)
[9] Keyhani, A., Ghasemi-Varnamkhasti, M., Khanali, M., and Abbaszadeh, R., 2010, *An Assessment of Wind Energy Potential as a Power Generation Source in the Capital of Iran, Tehran*, Renewable and Sustainable Energy Reviews*,* Vol. 35, pp.188-201.
[10] Mathew, S., 2006, *Wind Energy: Fundamentals, Resource Analysis, and Economics (Vol. 1)*, Berlin: Springer.
[11] Tahbaz, Mansoureh., 2009, Estimation of the Wind Speed in Urban Areas-Height less than 10 Metres, International Journal of Ventilation, **8:1**, 75-84 (2009)
[12] ASHRAE, 2005, Handbook-Fundamentals (SI):Chapter 16: Air Flow around Buildings, American Society of Heating Refrigerating and Air Conditioning Engineers.