SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2811-3950

Wind Resource Assessment by Analyzation and Simulation in WAsP for Electricity Generation in Chiang Mai, Thailand

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ARTICLE INFO

Article history:
Received 11 September 2021
Received in revised form 20 December 2021
Accepted 23 December 2021
Available online 26 January 2022

Keywords:
Wind energy assessment; Weibull distribution; WAsP; Chiang Mai

ABSTRACT

The purpose of this study is to assess and analyse the potential wind energy in Chiang Mai, the northern province of Thailand. The calculation in this paper is based on ten-minutes interval data at 10m height recorded for three years data from 2017 to 2019 at Thai meteorological station, Thailand. Weibull model is applied to evaluate the wind distribution by utilizing wind atlas analysis and application program (WAsP). Meanwhile, the average wind speed and the average power density was recorded at 1.48 m/s and 15 W/m2. The prominent wind direction is from the south west to north east. The two potential sites showed the maximum annual energy production 1401.419 MWh and 1913.410 MWh by using Bonus 300kW Mk III wind turbine with LCOE $382.64 / MWh and $274.63 / MWh respectively. This paper suggests the suitable sites for the electricity generation in Chiang Mai. Hence, it will not only reduce the stress on conventional methods but also create awareness regarding the potential of wind energy.

1. Introduction

Energy utilization has been increased in recent years. To meet this, need unfriendly energy sources are being used that are causing detrimental effects on the environment like greenhouse gas emission. In different countries, advanced renewable resources are making headway to deal with such problem. International energy agency or IEA that calculated by 2035 exceeding to $38 Trillian [1]. IEA is going into overdrive for sustaining the energy supply predicament by promoting new energy resources [2].

It is observed in the recent years due to increasing population in cities, there are more energy crises [3]. The need of hour is to understand the exigency of this issue and to increase the utilization of wind and solar as a main source of producing electricity and they cause no harm to environment. Furthermore, they are favourable in terms of substitute as clean energy and abundant in nature [4]. Manufacturing of wind turbine has cut off high cost and technological issues emerging from distant

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https://doi.org/10.37934/arfmts.91.2.8395

energy transportation project and help to make most of wind resource in local city areas [5]. This has riveted attention of researchers to assess wind resource in a definite manner.

It is necessarily important to assess the initials of wind resource to manage to come by the usage and benefit of wind energy. Two methods are being operated to gather data to estimate the resource of the wind. In the first method, output data is derived from numerical models, for instance, Weather Research and Forecasting and fifth generation Mesoscale [6]. Second method is used to take data from weather bureau. Wind characteristics are recorded and studied by using anemometer and the observed wind speeds and direction is used to analyse the data [7].

The drawbacks of both conventional approaches are seen. The first approach, which relies on high-resolution information from mesoscale computational methods, is not only inadequate for dealing with smaller-scale phenomena, nevertheless it likewise causes operating complications in the wind energy industry because of the vast quantity of computation time and resources needed [8]. Keeping aforesaid problem, many software is created by companies for wind assessment with quality resolution by means of weather towers in larger areas. WAsP is the one of the most used software created by the Danish Riso National Laboratory (DRNL) in wind energy industry for wind assessment [9] and has given good results [10]. WAsP generates errors generally less than 10% from one weather tower or station which tends to consider the fact that Wasp gives accurate results [11]. There are some other obstacles in a way of accurate wind resource assessment that is continue to be of major concern in wind industry. On the account of the fact that the location of meteorological posts is scattered, WAsP is not able to deliver wind resource evaluation with high resolution with the usage of records from those stations [12]. Furthermore, those wind observations specifically consciousness on the 10 m top and loss of wind records happens at high degrees, it restricts use of wind aid on greater points [8]. Shortage of wind facts at in height bounds the approximation and expertise of wind shear or wind strain on higher ranges, it impacts the wellbeing of wind mills substantially.

Moreover, some areas might have high safety chance of turbine with robust wind shear or wind pressure, the peak or area having strong wind is mistaken for exploitation. Consequently, the multi-layer wind observation statistics ought to offer a decent prospect to examine the vertical variations of wind shear and decrease the wind resource evaluation errors precipitated through way of the vertical outburst grounded at the records as of meteorological stations [13].

On the whole, it may be said that the accurateness of wind facts and the study of wind pressure are critical aspects for wind resource evaluation. Those countries which are located near equator are labelled as low wind speed area [14]. Several researches are conducted to assess the potential wind power as well as wind characteristic in different regions of Thailand [15, 16]. Wind energy harnessing has begun in the Northern region of Thailand, to be more specific elevation of Chiang Mai by the energy departments of Thailand [17, 18]. It is required to examine step by step characteristics of the wind in the region. It can provide assistance to the researchers and relevant bodies. The aim of this paper is to dig in the study the mean wind speed, mean wind direction, Weibull distribution and potential energy production.

2. Meteorological Data Analysis

Figure 1 shows the stagewise depiction of the process involved in this study. First of all, the data is collected 3 years data has been collected from the Chiang Mai meteorological stations. The data was recorded with 10 minutes interval for every day [19]. Furthermore, the collected data was categorized and segregated in MS excel. The processed data was entered in WAsP software for further process.

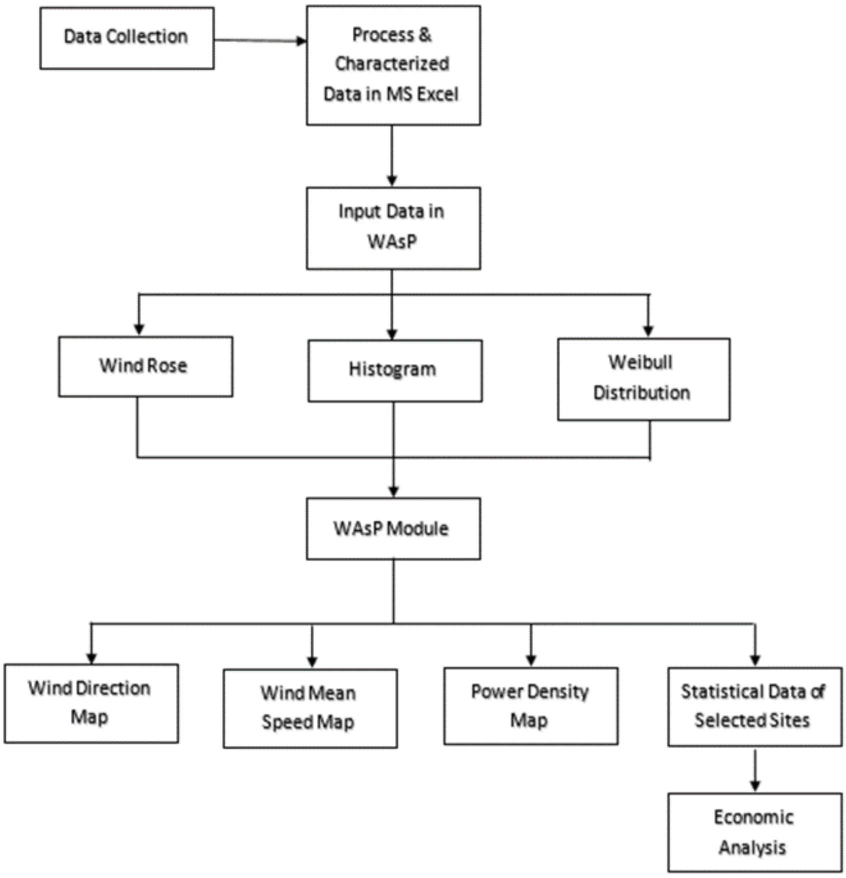


Fig. 1. Theoretical framework

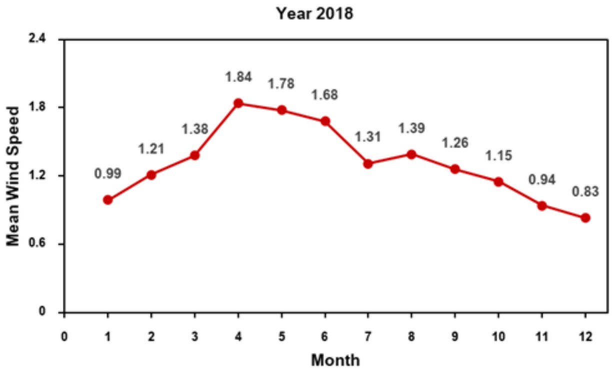
2.1 Wind Speed Distribution

The data collected from Chiang Mai meteorological station with 10 minutes interval is observed at 10m height. Table 1 shows the mean wind speed of every month from the year 2017 to 2019.

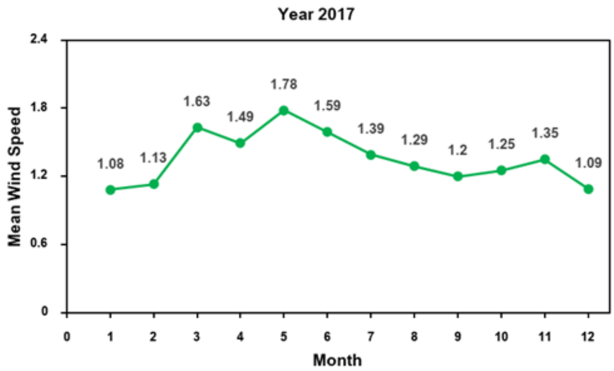
Table 1
Monthly and yearly mean wind speed of Chiang Mai

Mean wind speed													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2017	1.08	1.13	1.63	1.49	1.78	1.59	1.39	1.29	1.20	1.25	1.35	1.09	1.36
2018	0.99	1.21	1.38	1.84	1.78	1.68	1.31	1.39	1.26	1.15	0.94	0.83	1.31
2019	0.80	0.91	1.26	1.44	1.97	1.90	1.58	1.28	1.29	1.20	0.99	0.76	1.28
Average	0.72	1.08	1.43	1.59	1.85	1.72	1.43	1.32	1.25	1.20	1.09	0.89	0.99

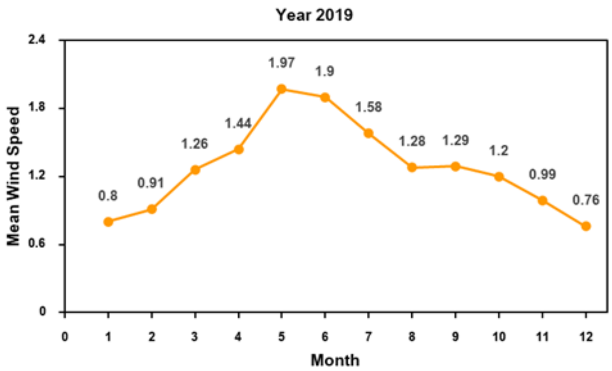
Figure 2(a), shows that in year 2017 the mean wind speed showed highest in the month of May at 1.78 m/s and in January it shows the lowest mean speed at 1.08 m/s. Moving further to Figure 2(b) shows the year 2018, the highest mean wind speed was also in the month of May at 1.78 m/s and the lowest mean wind speed was in December at 0.83 m/s. Finally, the Figure 2(c) shows the year 2019, the highest wind speed was in the month of May as well, it showed 1.97 m/s and the lowest was in the month of December at 0.76 m/s. The annual wind speed of the year 2017, 2018 and 2019 was 1.36 m/s, 1.31 m/s and 1.28 m/s respectively.



(a) Mean wind speed in year 2017



(b) Mean wind speed in year 2018



(c) Mean wind speed in year 2019

Fig. 2. Wind line graph of Chiangmai

The average of three years is shown in Figure 3. The month of May shows the highest average wind speed at 1.85 m/s and in January the mean wind speed shows the lowest at 0.72 m/s.

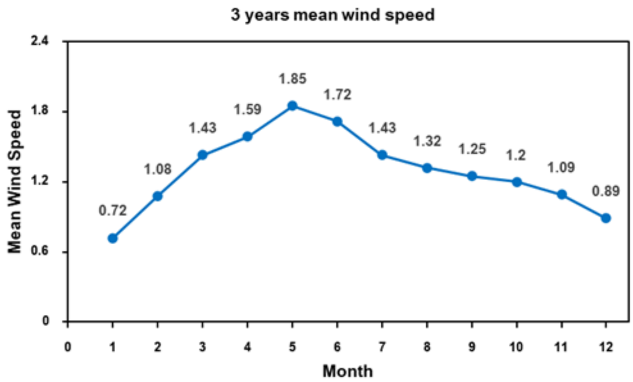


Fig. 3. Three years average line graph of Chiang Mai

2.2 Frequency Distribution

In this study, Weibull probability distribution function (PDF) is used to study the actual wind speed and wind direction. To study the wind characteristics the two parameter Weibull distribution is considered as the utmost feasible distribution function. The two parameters in Weibull distribution are known as shape and scale parameter. “k” represents the shape parameter and “c” represents the scale parameter. Weibull distribution function is expressed as [20]

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

$P_{(v)}$ represents the frequency wind speed, v. The scale factor c (m/s) represents the mean wind speed and the dimensionless shape factor k indicates the shape and width of the distribution. Hence, the parameters c and k determine the Weibull distribution. The cumulative Weibull distribution, $P_{(v)}$, which gives the probability of the wind speed greater than the value, v, is expressed as [20]:

$$P_{(v)} = exp\left\{-\left(\frac{v}{c}\right)^{k}\right\} \quad (2)$$

Figure 4 shows the shape parameter k 1.18 and the scale parameter c 1.6m/s and mean speed 1.48 m/s of Chiang Mai.

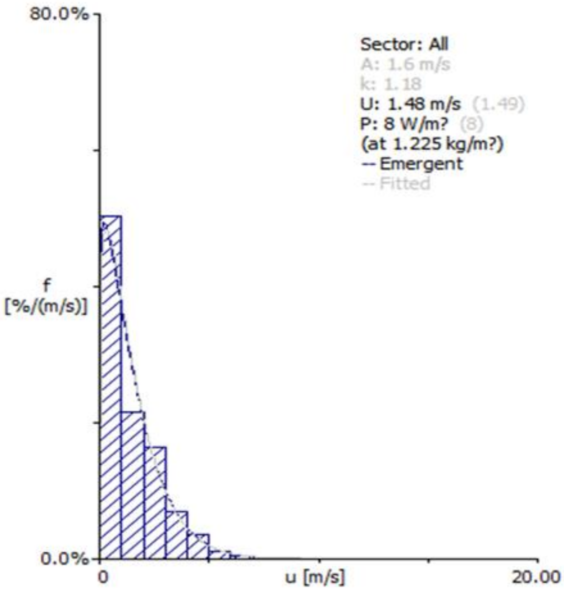


Fig. 4. Histogram of Chiang Mai

2.3 Wind Direction

Additional important aspect to be measured with the wind speed is wind direction. Figure 5 shows the wind frequency rose depicting the prominent wind direction which wind blows from the south-west direction to north-east direction

Wind data was recorded at the Chiang Mai meteorological station located at the airport, which is quite unsuitable for the wind turbine step up due to surface roughness. Although, the data collected from this location facilitates to evaluate the expected potential wind power in a site with better surface condition.

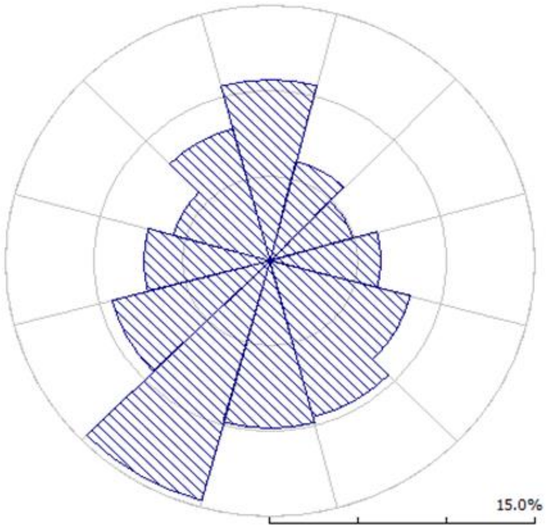
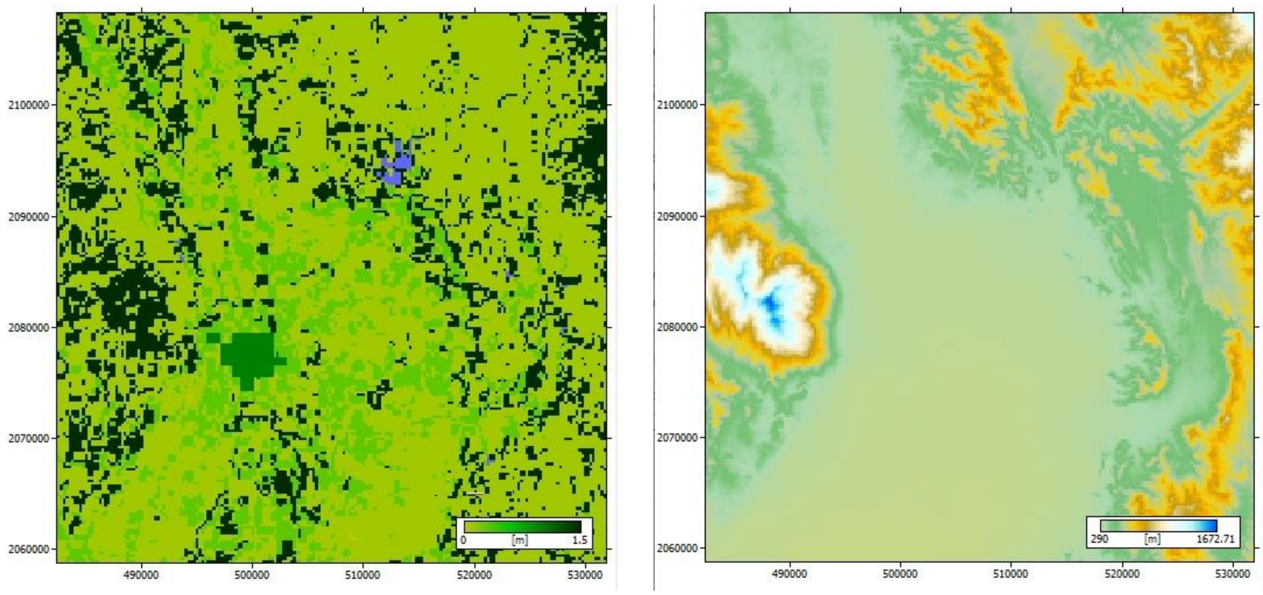


Fig. 5. Wind Rose of wind direction

3. Topographic Data Analysis

The wind and the kinetic energy available in the wind is also influenced due to terrain characteristics of the region. Thus, analysis of the terrain data and its effects on the wind become the important factors while studying about the potential wind energy of certain area. Escarpments, ridges and hill effect the wind speed. Henceforth, to study the wind resource assessment topographic data is inevitable.

Spatial image of the specific region is created by using WAsP obtained from Shuttle Radar Topography Mission (SRTM). Map extension is sized 50 km*50 km depending on the landscape of the station. Two maps area created to analyse the elevation and roughness of the region. Figure 6(a) shows the roughness map and Figure 6(b) shows the elevation map. These two maps are merged together and the wind valued are applied to them to create mean wind speed map, wind direction map, wind density map and the annual energy production is simulated.



(a) (b)

Fig. 6. (a) Surface roughness and (b) elevation map of Chiang Mai

3.1 Power Density

The maximum output per unit can be equated as [21]

$$P = \frac{1}{2}\rho V^3 \tag{3}$$

Furthermore, the mean wind power density is also extracted by calculated the observed data by the following equation [22]

$$\bar{P} = \frac{1}{2N}\bar{\rho}\sum_{i=1}^{N_{obs}} n_i \; V_i^3 \tag{4}$$

After merging the statistical data with the topographical data, the results produced showed the power density in Chiang Mai ranging from 3 W/m2 to 87 W/m2 and the total mean power density was 15 W/m2. The Figure 7 elaborates the section with different power density values.

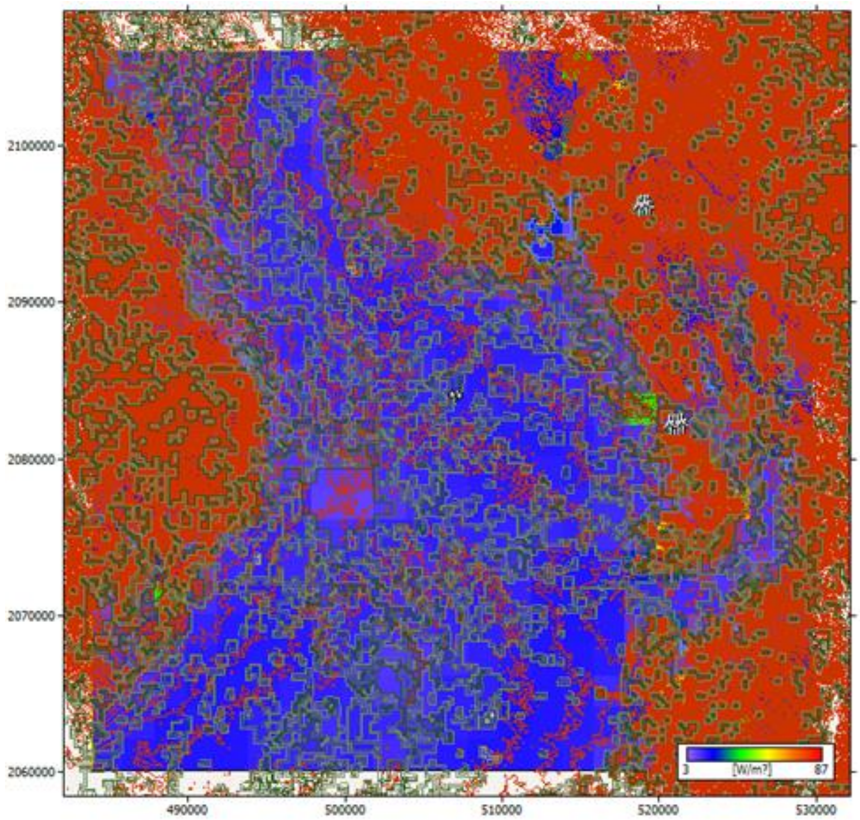


Fig. 7. Power density map of Chiang Mai

3.2 Mean Wind Speed

Meanwhile, for the mean wind speed map, the statistical data of mean wind speed and topographic data is merged to created mean wind speed map (Figure 8). The calculated mean wind speed for the area was 1.48 m/s. The recorded minimum wind speed at Chiang Mai station was 1.02 m/s and the maximum wind speed was 3.48 m/s.

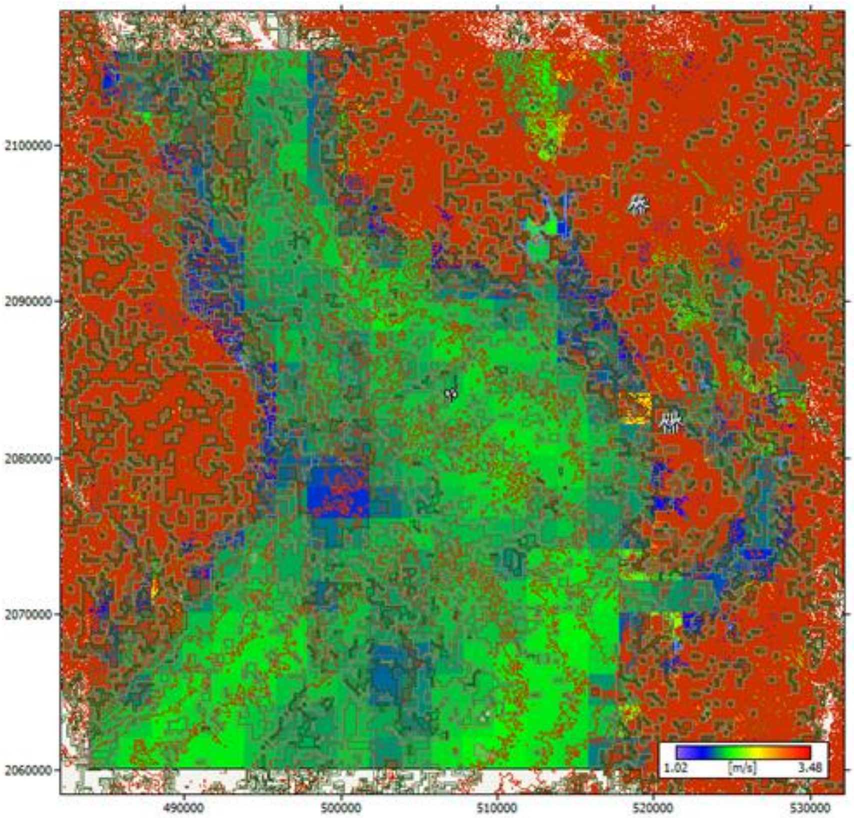


Fig. 8. Mean wind speed map of Chiang Mai

4. Wind Farm and Turbine

Chiang Mai station showed two potential sites for the farm. These two sites showed the maximum energy production in the area. Turbines are used to extract kinetic energy from water, steam or wind [23]. Eight wind turbines were used for the similation of each site at the height of 30 m. Bonus 300kW Mk-III wind turbine generator mangufactured by LM Glasfieber/Bonus is used in this study for the similation purpose. The power curve of Bonus 300kW Mk-III is 305 kW at speed of 14 m/s, power curve indicates the expected electrical power out as displayed in Figure 9.

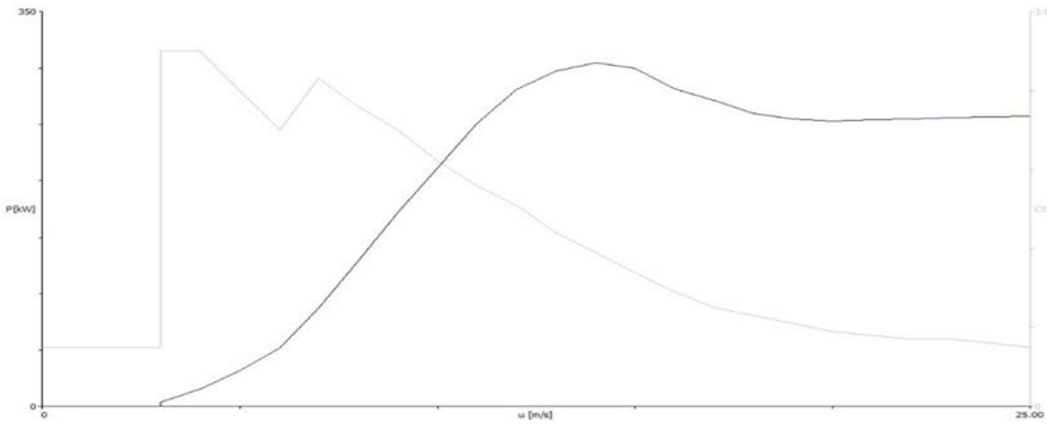


Fig. 9. Power curve of Bonus MK III (300 kW) wind turbine

The difference in the results of two different wind farm sites is due to the roughness and elevation of the selected sites. Figure 10 shows the selected site location for the wind farm created by merging data from WAsP with Google Earth software.

Fig. 10. Selected sites for wind farm simulation in Chiang Mai

5. Net Annual Energy Production

The net annual energy production (AEP) is calculated after deduction of losses. Table 2 shows the statistical data of site number 1 after the simulation of wind turbine. The total AEP and mean power density of this site is 1401.419 MWh and 68 W/m respectively. Furthermore, Table 3 shows the statistical data of site number 2, the total AEP and mean power density of site number 2 is 1913.410 MWh and 103 W/m respectively.

Table 2
Site No 1. Statistics

Variable	Total	Mean	Min	Max
Total gross AEP [MWh]	1499.079	187.385	169.661	215.074
Total net AEP [MWh]	1401.419	175.177	162.629	205.316
Proportional wake loss [%]	6.51	-	1.79	10.87
Capacity factor [%]	7.0	-	6.3	8.0
Mean speed [m/s]	-	3.06	2.90	3.30
Mean speed (wake-reduced) [m/s]	-	2.94	2.83	3.23
Variable	Total	Mean	Min	Max
Air density [kg/m^3]	-	1.094	1.091	1.096
Power density [W/m^3]	-	68	61	79
RIX [%]	-	-	10.6	13.6

Table 3
Site No 2. Statistics

Variable	Total	Mean	Min	Max
Total gross AEP [MWh]	2127.196	265.899	251.909	275.734
Total net AEP [MWh]	1913.410	239.176	215.651	261.932
Proportional wake loss [%]	10.05	-	3.61	14.39
Capacity factor [%]	9.9	-	9.4	10.3
Mean speed [m/s]	-	3.67	3.59	3.72
Mean speed (wake-reduced) [m/s]	-	3.48	3.34	3.62
Air density [kg/m^3]	-	1.076	1.076	1.076
Power density [W/m^3]	-	103	95	110
RIX [%]	-	-	24.9	25.6

Figure 11 depicts the location of two sites as well the wind direction of the sites. The wind direction map clearly depicts the prevailing wind direction in Chiang Mai station, which is southwest.

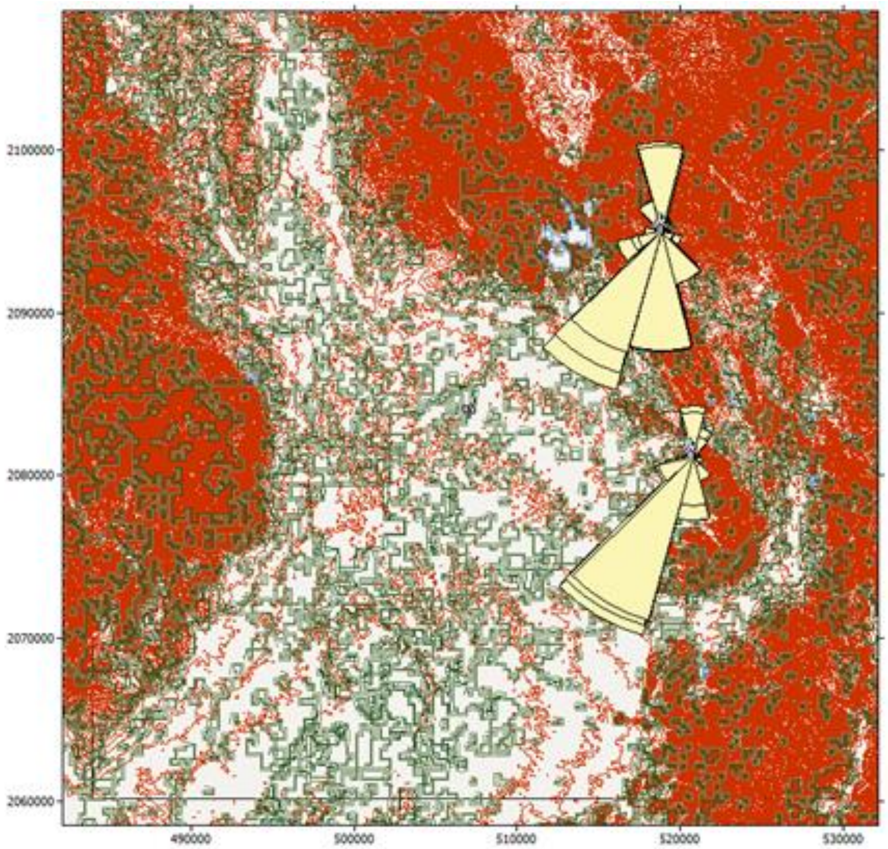


Fig. 11. Wind direction and wind speed map of the selected sites

6. Economic Analysis of Two Sites

Another aspect after the determination of the feasible site for wind farm, it is crucial to calculate the cost of the project to support the economical possibility. Over the time the project experiences several expenses, these expenses are classified as Capital Expenditures (CAPEX), and Operating Expenditures (OPEX). CAPEX includes the initial cost used for purchasing land, transportation and setting up of the equipment and other expenses throughout the building stage. Contrarily, OPEX includes the expenses which occur in the course of operation and maintenance of the wind farm during the power plant lifespan. OPEX is further classified as fixed OPEX and variable OPEX [24]. The economic assessment of electricity can be defined as levelized cost of energy or LCOE [25].

$$LCOE = \frac{\text{Average total cost to build and operate a power plant}}{Total\ power\ generated\ by\ the\ power\ plant}$$

or

$$LCOE = \frac{(CAPEX) + (Fixed\ OPEX + Variable\ OPEX)}{(Power\ Production)}$$

The estimated summary of LCOE is defined in the table 4 by calculating the CAPEX value and average OPEX derived from the research conducted in Thailand [24].

Table 4
Estimated LCOE calculation

Parameters	AEP	CAPEX Million $	OPEX Fixed	OPEX Variable	LCOE /MWh
Site 1	1401.419	2.52	0.03514	13.91	$382.64 / MWh
Site 2	1913.410	2.52	0.03514	13.91	$274.63 / MWh

7. Conclusions

This research is based on a precision survey of wind characteristics by means of the observed wind data in the year 2017, 2018, and 2019 in Chiang Mai, Thailand. The data was collected at the height of 10 m in 10 minutes interval.

In Chiang Mai the windiest month is May and the recorded mean wind speed for each year was 1.36 m/s, 1.31 m/s and 1.28 m/s for the year 2017, 2018 and 2019 respectively. In the month of December, the wind speed is lowest. Moreover, the calculated mean wind speed of Chiang Mai province is 1.48 m/s with the shape parameter k 1.18 and scale parameter c 1.6 m/s. The dominant wind direction is from south-west direction to north-east direction.

The power density in Chiang Mai ranges from 3 W/m^2 to 87 W/m^2. The minimum wind speed at the height of 10 m was 1.02 m/s and the maximum wind speed was 3.48 m/s. The net AEP of site 1 and site 2 were 1401.419 MWh and 1913.410 MWh respectively by using Bonus 300kW Mk-III wind turbine generator. Finally, LCOE of site 1 is $382.64 / MWh and site 2 is $274.63 / MWh.

The outcome of this research can be utilized as a significant material while designing a wind power generation system in Chiang Mai. It can provide the guideline for the further research in the area. Moreover, a hybrid system in the can be created in Chiang Mai to maximized the power generation and reduce CO_2 emission.

Acknowledgement

This work was supported by the grants from Graduate School, Prince of Songkla University and Energy Conservation and Promotion Fund Office (Project number: RE-2-0037). The authors acknowledge the help of the Thai Meteorological Department (TMD) for sharing valuable wind data.

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