Determination of feasible sites for wind farm using WAsP in Uttaradit, Thailand.

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Abstract. Electricity production from the wind plays the potential role to reduce conventional way of electricity generation to reduce the negative impacts on the environment. In this study the data is collected from Uttaradit, the northern province of Thailand. The calculation in this study is based on ten-minutes interval data at 10m observed during the year 2017-2019 by Thai meteorological department. Weibull distribution is applied to extract the monthly and yearly wind in the selected area by using wind atlas analysis and application program (WAsP). Moreover, in WAsP a stimulation was created to observe the comparison of potential of wind energy between three windiest sites located in the study area. The results generated show that the mean wind speed is 2.35m/s and the gradient wind direction from north and south are quite distinct. The annual energy production calculation of three sites in Uttaradit by WAsP estimates about 2125.815MWh, 3379.621MWh and 3369.235MWh respectively by using Bonus 300kW Mk III wind turbine. This paper suggests and supports the suitable sites and wind turbine for the electricity generation in Uttaradit. Hence, it will not only reduce the stress on conventional methods but also create awareness regarding the potential of wind energy.

1. Introduction

Rapidly growing economy, expanding urbanization, new infrastructure demands such as mass rapid transit systems and campaigns for the thriving automobile sector to invest in electric vehicles have raised energy demand [1]. On the other hand, consumption of energy at the current level would deplete the reserves of oil and natural gas gradually [2]. Thailand is turning to alternative and indigenous energy sources because of high energy dependency ratios and exposure to commodity market price volatility [3]. By the rising unpopularity of coal-fired plants that made this pivot hardened with remarkable social opposition to coal projects in the south. Over the last decade the installed capacity of renewable energy doubled, mainly driven by biomass and hydropower. Since 2018, renewables shared 15% of the total consumed power in Thailand. The installed capacity of wind energy is still one-fifth of the 3,002MW target set by Alternative Energy Development Plan-2036 [4]. In Thailand approximated
754MW is the overall capacity of wind power installed in Thailand, gained from the northern, north-eastern and southern parts of Thailand [5].

The annual energy production and how the value of the energy produced compares to other sources of energy are the crucial factors in siting a wind farm or wind turbine also known as wind plant or wind park [6]. The data available at meteorological stations throughout the world is of little use during prediction of wind power potential and estimation of energy production from wind farms. In order to build the full potential wind farm, there must be an accurate and precise study on the data for the regarding area [6].

Northern Thailand is geographically characterized by several mountain ranges, which continue from the Shan Hills in bordering Myanmar to Laos, and the river valleys which cut through them [7]. Though like most of Thailand, it has a tropical savanna climate, its relatively high elevation and latitude contribute to more pronounced seasonal temperature variation, with cooler winters than the other regions of Thailand.

The Uttaradit province is selected in this study for certain reasons, firstly the huge inhabited region which is required for the suitable wind farm site as shown in figure 1. Secondly a study has been done by Maejo University, Thailand to find the wind potential in Uttaradit province in the year 2011 [8]. Moreover, Energy Department of Thailand is planning to decrease the use of conventional ways of energy production and increase the clean and sustainable methods of electricity generation in Uttaradit province [9].

According to official statement the total annual consumption of electricity in Uttaradit is 482,900,653kWh which is allocated to three sectors, residential (204,396,557kWh), industrial (201,361,347kWh), government sector (72,301,132kWh) and others (4,841,618kWh) [10].

In this study, the wind resource map and evaluation of the suitable site in Uttaradit region is created by WASP software. This software is developed by the Riso National Laboratory, Denmark to forecast the climate and study the power generation by wind farms [11]. WASP is used in several countries by the researchers to develop wind atlas and wind resource maps including Lithuania, Bangladesh, Fiji, Portugal and South Korea [12].

This research will help to allocate the most suitable site for the wind farm by using WASP software. Potential energy generation by turbine will provide sufficient power in Uttaradit, thus this will help to achieve the target set by the AEDP-2036.
2 Methodology

Wind data of 3 years, which includes wind speed and wind direction is processed and analysed to get the information on monthly and annually basis. The wind data is obtained from the meteorological stations of Uttaradit provinces. Two significant Weibull parameters, shape parameters $k$ and scale parameter $c$ will be measured by using wind speed and wind direction data, obtained from Thai meteorological department. Wind Atlas Analysis and Application Program (WAsP software) is used to make monthly and yearly wind profile and to calculate average speed ($\text{m/s}$) and power density $P$ ($\text{W/m}^2$) for the selected site. Moreover, determination of the most suitable kind of wind turbine for the selected area to study the efficiency of wind energy in terms of mean wind speed and annual energy production.

2.1 Location

Uttaradit is located in the upper northern part of Thailand bordered with Laos. It is about 488km north of the capital city, Bangkok. The wind data including wind speed and wind direction is obtained from Uttaradit Weather observing station site positioned: 17°37’00.0” N 100°06’00.0” E; at 10m above the ground level anemometer height. The mean wind speed per hour in Uttaradit has little variation throughout the year. Normally the windier months are from February to August and calmer are from September to January. However, the mean wind direction per hour changes over the course of the year. Figure 2 depicts the mean wind speed of Thailand (left side) and study area (right side)\cite{13}. 

![Figure 1. Land division of Uttaradit province.](image-url)
2.2. Wind Data

The Wind data of 3 years starting from 01.01.2017 to 31.12.2019 recorded at Uttaradit weather observing station which includes wind speed and wind direction. The data is recorded repeatedly every 10 minutes at the height of 10m [14]. Firstly, this data is checked properly, then the combined data is separated into two excel sheets categorically as wind speed, wind direction for each year. Figure 3 represents the the wind rose and histogram. Wind rose shows that the mostly wind direction is from south and north. Moreover, in histogram it can been seen that the mean speed represented as $U$ is 2.35 m/s and power destiny represented as $P$ is 20 W/m$^2$.

Estimated calculation is based on Weibull probability distribution function (PDF) by finding the values of k-shape and scale parameters [15]. To characterise wind behaviours the two parameter Weibull distribution is regularly connected because it appears a great representation of wind data. The Weibull distribution function is expressed as [16].

$$P(v) = \frac{k}{c} \left(\frac{v}{c}\right)^{k-1} e^{\exp{-\left(\frac{v}{c}\right)^{k}}}$$  \hspace{1cm} (1)

Where $P(v)$ represents the frequency of incidence of wind speed, $v$. The scale factor $c$ (m/s) shows the average 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:
5 \[ P(v) = \exp\left\{-\left(\frac{v}{c}\right)^k\right\} \]  

The values after the calculation for the shape and scale parameters are 1.60 and 2.6m/s represented as `-k` and `-A` respectively. The value of shape parameter shows the regular winds focus around an average value. Scale parameter value shows the possibility for selection of the site for the windfarm.

The exponential contour map is extracted from Shuttle Radar Topographic Mission (SRTM) data linked with WAsP Map Editor. The extracted map is 90 km from west to east and 60 km from north to south while the station is in the center point. Furthermore details are also derived such as the roughness and, highest and lowest point of the selected area. The surface terrain generated by WAsP software obtained from SRTM and Global Wind Atlas (GWA) of the selected area are classified into 5 roughness

![Figure 3. Histogram and wind rose of Uttaradit station.](image)
parametters showed in table 1. Surface roughness indicates the concrete picture of the desiered area for the wind study.

Table 1. Land cover division along with surface roughness lengths (Source: WAsP Map Editor)

| Land Cover Class Name                      | Roughness Length (m) |
|--------------------------------------------|-----------------------|
| Water Surface                              | 0.0000                |
| Grassland, savannas or lichens/mosses      | 0.0300                |
| Croplands and Shrubland                    | 0.1000                |
| Mosaic natural vegetation / cropland       | 0.3000                |
| Forests                                    | 1.5000                |

Processed wind data and the countour map were infused together to create the wind resource map with the total area of about 4400km² and 2000m resolution. Wind resource map of the selected area can be seen in figure 4. The range of the wind speed value from 1.36m/s to 5.82m/s is also mentioned in the figure produced by WAsP.

Figure 4. Mean Wind Speed of Uttaradit.

Following the creation of wind resource map of the specific area, three suitable sites for the wind farm were selected for the simulation to aquire the maximum annual energy production (AEP) in accordance with the most feasible sites as shown in figure 5.
2.3 Wind Farm and Turbine
In this study, three sites for the wind farm were selected while considering annual energy production. Each wind farm consists of 8 wind turbines at the 30m hub height. Bonus 300kW Mk-III wind turbine generator is used in this wind farm simulation manufactured by LM Glasfieber-Bonus. The power curve of this wind turbine indicates the expected electrical power output which is 305kW at speed of 14m/s as displayed in figure 6.

![Power curve of Bonus MK III (300 kW) wind turbine.](image)

The turbines installed in each site showed the different results due to the roughness of the area, as the selected sites are in mountainous region. Wake losses generated by WAsP also differs in each
turbine as they are not positioned at the same height. Three different sites including 8 turbines each, suitable for the wind farm are marked in figure 7.

![Sites selection for the wind farm](image)

**Figure 7.** Sites selection for the wind farm.

### 3 Results and discussion

The net annual energy production (AEP) is calculated after deduction of losses. Table 2 shows least AEP and capacity factor which is 2125.815MWh and 10.8% respectively in site number 1, among other selected sites. The maximum mean speed and power density of the site 1 are 4.17m/s and 92W/m². RIX represents ruggedness index in the WAsP that helps as an objective measure of the extent of steep slopes in an area.

#### Table 2. Statistical analysis of site 1.

| Variable                        | Total   | Mean   | Minimum | Maximum |
|---------------------------------|---------|--------|---------|---------|
| Total gross AEP [MWh]           | 2312.601| 289.075| 174.019 | 378.568 |
| Total net AEP [MWh]             | 2125.815| 265.727| 165.346 | 344.828 |
| Proportional wake loss [%]      | 8.08    | -      | 4.46    | 10.87   |
| Capacity factor [%]             | 10.8    | -      | 6.5     | 14.2    |
| Mean speed [m/s]                | -       | 4.17   | 3.47    | 4.69    |
| Mean speed (wake-reduced) [m/s] | -       | 4.03   | 3.39    | 4.54    |
| Air density [kg/m²]             | -       | 1.107  | 1.102   | 1.114   |
| Power density [W/m²]            | -       | 93     | 53      | 125     |
| RIX [%]                         | -       | -      | 13.0    | 15.4    |

Table 3 depicts site number 2 having more potential as compared to site number 1. Site number 2 shows the increase in AEP and capacity factor which is 3379.621MWh and 16.4% respectively. The maximum mean wind speed and power density of site 2 are 4.86m/s and 166W/m².
Finally, the region has three suitable sites for the windfarm configuration. The assessment of the wind resource map spotted three suitable sites for the windfarm installation such as Uttaradit province of Thailand. The promising result at 10m height are used for the calculation in WAsP in other studies as well such as Venezuela and Algeria. In Alegria the annual mean speed shifts from 1.2 to 6.3 m/s at 10m above the ground level.

Moreover, the wind resource map spotted three suitable sites for the windfarm. Among three sites, the site number 2 showed the maximum AEP, while equipped with 8 Bonus 300kW Mk-III wind turbine generators. The net AEP calculated for the site number 2 is 3379.621 MWh and capacity factor is 16.4%.

Finally, table 4 illustrates site number 3 with AEP and capacity factor which is 3369.235 MWh and 16.1%, respectively. The maximum mean speed and power density of the site 3 are 4.93 m/s and 153 W/m².

### Table 3. Statistical analysis of site 2.

| Variable                     | Total   | Mean     | Min      | Max      |
|------------------------------|---------|----------|----------|----------|
| Total gross AEP [MWh]        | 3515.660| 439.458  | 245.262  | 557.527  |
| Total net AEP [MWh]          | 3379.621| 422.453  | 233.830  | 534.725  |
| Proportional wake loss [%]   | 3.87    | -        | 1.86     | 4.66     |
| Capacity factor [%]          | 16.4    | -        | 9.2      | 20.9     |
| Mean speed [m/s]             | -       | 4.86     | 3.80     | 5.50     |
| Mean speed (wake-reduced) [m/s] | - | 4.77     | 3.70     | 5.39     |
| Air density [kg/m²]          | -       | 1.127    | 1.123    | 1.135    |
| Power density [W/m²]         | -       | 166      | 77       | 231      |
| RIX [%]                      | -       | -        | 16.5     | 19.1     |

The results show the sites number 2 and 3 are suitable for the maximum AEP among the selected region of Uttaradit province.

### Table 4. Statistical analysis of site 3.

| Variable                     | Total   | Mean     | Min      | Max      |
|------------------------------|---------|----------|----------|----------|
| Total gross AEP [MWh]        | 3447.385| 430.923  | 191.964  | 596.542  |
| Total net AEP [MWh]          | 3369.235| 421.154  | 187.480  | 585.537  |
| Proportional wake loss [%]   | 2.27    | -        | 1.84     | 2.78     |
| Capacity factor [%]          | 16.1    | -        | 7.2      | 22.3     |
| Mean speed [m/s]             | -       | 4.93     | 3.61     | 5.78     |
| Mean speed (wake-reduced) [m/s] | - | 4.88     | 3.56     | 5.73     |
| Air density [kg/m²]          | -       | 1.103    | 1.097    | 1.114    |
| Power density [W/m²]         | -       | 153      | 59       | 233      |
| RIX [%]                      | -       | -        | 12.9     | 19.2     |

4. Conclusion

The assessment of the wind energy potential in the selected region of Uttaradit province, northern Thailand is studied by utilizing WAsP software. The mean wind speed of the region is 2.35 m/s at the height of 10m above the ground level. The promising result at 10m height are used for the calculation in WAsP in other studies as well such as Venezuela and Algeria. In Alegria the annual mean speed shifts from 1.2 to 6.3 m/s at 10m above the ground level.

Moreover, the wind resource map spotted three suitable sites for the windfarm. Among three sites, the site number 2 showed the maximum AEP, while equipped with 8 Bonus 300kW Mk-III wind turbine generators. The net AEP calculated for the site number 2 is 3379.621 MWh and capacity factor is 16.4%.

Finally, the region has competent potential in the accommodation of a wind farm installation such as accessibility, low population density, vacant space, local government policies and zero protected zone. This will also reduce the consumption of conventional ways of power generation.
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