Assessment of wind energy potential of Hat Yai (Songkhla), Thailand

I Kamdar¹, J Taweekun²,³
¹ Energy Technology Program, Faculty of Engineering, Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand.
² Department of Mechanical and Mechatronics Engineering, Faculty of Engineering, Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand.

Abstract. Due to environmental problems associated with fossil fuels and rising need for energy, wind power renewable energy will play a vital role in transformation of future energy structure in Thailand. Exploitation of wind energy for sustainable development, wind resource assessment plays an important role in wind power utilization. This case study presents wind resource assessment using the wind atlas analysis and application program (WAsP), in order to assess the potential of wind energy in Hat Yai, Thailand. Ten-minutes interval wind data observed by the Thai Meteorological Department recorded during the period 2017-2019, have been used to harness adequate wind power density and wind energy potential. The annual mean wind speed is 3.5 m/s at 10 m height above the ground. The prevailing direction southwest, south and northeast of the wind rose are very pronounced. The WAsP analysis estimates about 2,731.28 MWh of the total net annual energy production for the specific sites using the Enercon E-18 (80 kW) wind turbine of 1.92 MW capacity. The findings of this study indicate the possibility of the small-scale wind farm project for electricity generation in future.

Keywords: Sustainability, Wind resource assessment, Wind turbine, WAsP, Hat Yai.

1. Introduction
Fossil fuels, including coal, oil and natural gas, have been the primary energy source for many years. However, concerns regarding climate change and CO₂ emissions have encouraged the search for alternative energy systems that can reduce the greenhouse gases emissions. Energy goals such as the 2020 Climate and Energy Package across the countries have targeted energy projects that are independent of fossil fuels. To fulfill these goals and regarding climate change, wind energy has been found as a promising and clean technology with large potential [1].

Wind turbines are becoming familiar in the world for electricity generation. The electrical energy produced by wind turbines are without liberating CO₂, radioactive pollutants, smog, or acid rain. The global cumulative installed capacity of wind energy reached 651 GW in 2019 and it is expected that a new capacity of over 355 GW will be added during 2020 2024 [2]. The capability of these projects was in MW range and most of them were onshore and offshore wind turbines. One of the significant issues for micro-wind farms is wind mapping. Hence, accurate assessment of the wind pattern of the selected places is essential for the wind farm output [3].
The energy scenario in terms of increasing demand annually in Thailand is not much different in comparison to other countries. The electricity generation of Thailand in 2012 was 32.6 GW which reached to 42.163 GW by 2017, with over 67% being produced from natural gas. It is expected by Thailand’s Ministry of Energy power development plan 2010 (PDP 2010) that the total installed capacity of electricity generation will reach 70.868 GW in Thailand by 2030. Nevertheless, the aim of the Alternative Energy Development Plan (AEDP) of Thailand under PDP (2015-2036) is to replace fossil fuels up to 30% by 2036. This objective clearly defines the road map of renewable energy in Thailand [4].

In this research, the raw wind data from Thai Meteorological Department (TMD), along with the terrain data from Shuttle Radar Topography Mission (SRTM) and the surface roughness length information from Global Wind Atlas (GWA) warehouse map is used to conduct this study using the Wind Atlas and Analysis Application Program (WAsP). The objective of this study is to do feasible measures for wind resource assessment.

2. Methodology

2.1. Overview of study area and meteorological data description

Hat Yai is a city in the southern Thailand with an area of about 852.7 km² and hosts many tourists each year. It is the largest city of Songkhla province and has a population of about 156,802. The topography of Hat Yai is generally a vast plain. The city is adjacent to Songkhla Lake in the north while Sankalakiri mountain range passes across border of the city in southwest. Figure 1 shows a map of Hat Yai.

![Figure 1. Study area. (adapted source: [5]).](image)

This study analyzes the meteorological data in selected Hat Yai area situated in the southern part of Thailand. Wind data measurement for Hat Yai met mast has been taken at a standard height of 10 m above the ground for the wind resource assessment. The altitude of measurement tower is 57 m above sea level with
geographical coordinates (6° 56’ 24.0”N, 100° 23’ 31.9”E, Figure 2). The quality of wind data is found above 95% in the covered 3-years but there have been some missing data during some periods. At least one-year observation data is recommended for wind resource assessment to avoid monthly and seasonal bias [6]. In consideration of monthly and seasonal bias, the data used in this study was measured each 10-min over a period of 3-years from January 2017 until the end of 2019.

Figure 2. Overview of the satellite imagery of Hat Yai.

2.2. Elevation and roughness maps
The map projection is the Universal Transverse Mercator (UTM) coordinate system, Zone 47 and the datum is WGS-1984. The elevation and roughness maps of Hat Yai were prepared using the WAsP Map Editor tool in WAsP program (Figures 3 and 4). In order to show elevation and roughness changes of the area, a map extension of about 50 km x 40 km in WAsP Map editor was used for both maps. Most of the study area is fairly smooth except mountain ridges in the southwest and northeast with the highest elevation of about 920 m above sea level. There is total 7558 elevation contours in Figure 3. The southwest mountain ridge axis is almost perpendicular to the wind direction coming from the northeast which make these ideal sites for wind farm projects [7].
Figure 3. Digital map of Hat Yai depicting elevation.

Global Wind Atlas (GWA) warehouse map server and Google Earth maps were used for different landcover categories to classify the roughness lengths. The study area is classified into 6 different roughness lengths which are given in table 1.
Figure 4. Digital map of Hat Yai depicting roughness.

Table 1. Values of surface roughness for different landcover.

| S/N | Land Cover Class Name                              | Roughness Length (m) |
|-----|---------------------------------------------------|-----------------------|
| 1   | Water surface                                     | 0.0000                |
| 2   | Croplands, Shrubland                              | 0.1000                |
| 3   | Mosaic natural vegetation / cropland              | 0.3000                |
| 4   | Flooded forest                                    | 0.5000                |
| 5   | Urban areas                                       | 1.0000                |
| 6   | Forests                                           | 1.5000                |
3. Results and discussion

3.1. Wind climate analysis

Table 2 shows the omni-directional and statistical inspection of wind characteristics of the processed data. The fitted parameters are used with respect to the observed wind climate and are representative of a Weibull distribution that fits to all-sector wind speed histogram. The fitted distribution is not further used for wind resource calculations. In WAsP program, the emergent distribution is used to calculate the wind resources [8]. The weighted sum of the Weibull distribution from all the direction sectors is represented by emergent distribution. Ultimately, the combined parameters are also representative of a Weibull distribution. This distribution is used to match the power density and mean wind speed with the weighted sum of the sector-wise power densities and mean wind speeds, respectively [8]. The discrepancy between the source and emergent mean power densities is 0% while the difference between the source and emergent mean wind speeds is 3.2%.

Table 2. Wind statistics of study area in all-sectors in the wind resource assessment.

| Wind statistics | Weibull-A (m/s) | Weibull-k | Mean speed (m/s) | Power density (W/m²) |
|-----------------|-----------------|-----------|------------------|---------------------|
| Source data     | -               | -         | 1.87             | 17                  |
| Fitted          | 2.1             | 1.22      | 1.93             | 17                  |
| Emergent        | -               | -         | 1.93             | 17                  |
| Combined        | 2.1             | 1.22      | 1.93             | 17                  |

Figure 5 shows the wind rose and the omni-directional Weibull distribution. The most prevailing wind direction in Hat Yai is from southwest, south and northeast. Table 3 shows the sector-wise Weibull parameters, mean power density and mean wind speed. From the table, 60 W/m², 50 W/m², respectively. The second windiest direction is 30 W/m². The least frequent wind directions are 120°, 150°, 270°, 300° and 330°.

Table 3. Sectors-wise wind statistics of the processed data.

| f   | A (m/s) | k  | U (m/s) | P (W/m²) | *ΔU |
|-----|---------|----|---------|----------|-----|
| f   | A (m/s) | k  | U (m/s) | P (W/m²) | *ΔU |

*a represents difference in observed and calculated wind speed using Weibull distribution (%).
3.2. Wind resource assessment by WAsP

WAsP analysis was carried out for the rapid population growth and increasing infrastructure in Hat Yai. Three locations for prospective wind farm were scrutinized by analyzing 3-years wind data for future investment in wind energy. Figures 6 and 7 show the extrapolative average wind speeds and power densities in resource maps of Hat Yai. Enercon E-18 wind turbine with a rating of 80 kW have been marked at 24 sites for power analysis. These sites were carefully chosen in terms of mean average wind speed, wind power density and access to roads and electrical transmission lines. The distance among all wind turbine sites have been kept at 10 m rotor diameter and a hub height of 30.1 m. The specifications of the Enercon E-18 wind turbine are given in table 4 while power curve is shown in Figure 8. The wind map indicates good potential of wind energy for the southwest mountain ridge in Hat Yai. The central part of the city shows a poor potential for wind farm development due to urban infrastructure.
Figure 6. High resolution average wind speed map of Hat Yai.

Figure 7. High resolution average power density map of Hat Yai.
Table 4. Enercon E-18 wind turbine specifications.

| Rotor diameter | Hub height | Cut-in speed | Cut-out speed | Survival wind speed | Rated power | Rated wind speed |
|----------------|------------|--------------|---------------|----------------------|-------------|------------------|
| 18 m           | 30.1 m     | 2.5 m/s      | 25.0 m/s      | 67.0 m/s             | 80 kW       | 12.0 m/s         |

The net annual energy production (AEP) for the prospective turbine cluster 1’ wind farm including 8 sites are given in Table 5. The mean wind speed and mean power density of the prospective turbine cluster 1’ wind farm are 5.1 m/s and 285 W/m², respectively. Turbine site 006 shows the maximum capacity factor of 24.9% in this prospective wind farm. The average net AEP for the prospective turbine cluster 1’ wind farm is around 145 MWh. Figure 9 displays the resource map of the prospective turbine cluster 1’ wind farm.

Table 5. Statistical analysis of prospective turbine cluster 1’ wind farm.

\[ b \] represents Ruggedness Index.
Figure 9. High resolution map of prospective turbine cluster 1’ wind farm.

The net annual energy production (AEP) for the prospective turbine cluster 2’ wind farm including 8 sites are given in table 6. The mean wind speed and mean power density of the prospective turbine cluster 2’ wind farm are 4.3 m/s and 178 W/m², respectively. Turbine site 011 shows the maximum capacity factor of 18.1% in this prospective wind farm. The average net AEP for the prospective turbine cluster 2’ wind farm is around 104 MWh. Figure 10 depicts the resource map of the prospective turbine cluster 2’ wind farm.

Table 6. Statistical analysis of prospective turbine cluster 2’ wind farm.
Figure 10. High resolution map of prospective turbine cluster 2' wind farm.

The net annual energy production (AEP) for the prospective turbine cluster 3' wind farm including 8 sites are given in table 7. The mean wind speed and mean power density of the prospective turbine cluster 1' wind farm are 3.9 m/s and 154 W/m², respectively. Turbine site 022 shows the maximum capacity factor of 14.3% in this prospective wind farm. The average net AEP for the prospective turbine cluster 3' wind farm is around 91 MWh. Figure 11 shows the resource map of the prospective turbine cluster 3' wind farm.
Table 7. Statistical analysis of prospective turbine cluster 3’ wind farm.

Figure 11. High resolution map of prospective turbine cluster 3’ wind farm.
4. Conclusions
The wind resource assessment in Hat Yai has been carried out in the three best locations for the future wind farms. The overall wind speed in the hilly and nearby surrounding areas is about 3.0 m/s to 5.8 m/s according to the data analysis. This range of wind speed regime falls in the low-medium class. The prevailing wind direction in the area is southwest, south and northeast. Due to availability of small and flat lands, southwest wind direction towards Sankalakiri mountain range is best for small-scale wind farm projects in future. In the past, some of the wind turbines installed in Thailand were unsuitable according to the weather conditions. Those wind turbines imported were constructed for windier conditions. They were steel structured that only rotated in storms. Subsequent technological developments have resulted in the creation of low-speed and decentralized wind turbine which can be installed anywhere from homes to offices. Hence, further investigation must be carried for the development of an integrated renewable energy system.

The wind resource assessment in this study provides a scientific basis for development of wind farm projects in future to reduce dependence of Thailand's urban cities such as Hat Yai on fossil fuel-based generation. The approach used in this research can also be reproduced for wind resource assessment in other regions of the world.

Acknowledgements
This work was supported by the grants of Interdisciplinary Graduate School (IGS) and Energy Conservation and Promotion Fund Office (Project number: RE-2-0037), Prince of Songkla University, Hat Yai, Songkhla 90112, Thailand. The authors acknowledge the help of the Thai Meteorological Department (TMD) for sharing valuable wind data.

References

[1] P. Hevia-Koch, J. Ladenburg, Where should wind energy be located? A review of preferences and visualisation approaches for wind turbine locations, Energy Research & Social Science (2019). doi:10.1016/j.erss.2019.02.010.

[2] Global Wind Report, 2019. Accessed: November 30, 2020. Available: https://gwec.net/global-wind-report-2019/

[3] Z. Tasneem, A. Al Noman, S.K. Das, D.K. Saha, M.R. Islam, M.F. Ali, M.F. R Badal, M.H. Ahamed, S.I. Moyeen, F. Alam, An analytical review on the evaluation of wind resource and wind turbine for urban application: Prospect and challenges, Developments in the Built Environment (2020). doi:10.1016/j.dibe.2020.100033.

[4] S. Ali, J. Taweekun, K.K. Techato, J. Waewsak, S. Gyawali, S. Ali, S., Taweekun, J., Techato, K., Waewsak, J., Gyawali, GIS based site suitability assessment for wind and solar farms in Songkhla, Thailand, Renewable Energy. 132 (2019) 1360–1372. doi:https://doi.org/10.1016/j.renene.2018.09.035.

[5] I. Kamdar, S. Ali, A. Bennui, K. Techato, W. Jutidamrongphan, Municipal solid waste landfill siting using an integrated GIS-AHP approach: A case study from Songkhla, Thailand, Resources, Conservation & Recycling 149 (2019) 220–235. doi:10.1016/j.resconrec.2019.05.027.

[6] D.H. Ko, S.T. Jeong, Y.C. Kim, Assessment of wind energy for small-scale wind power in Chuuk State, Micronesia, Renewable & Sustainable Energy Reviews (2015).
doi:10.1016/j.rser.2015.07.160.

[7] H.L. Wegley, J. V. Ramsdell, M.M. Orgill, R.L. Drake, A siting handbook for small wind energy conversion systems., (1980).

[8] N.G. Mortensen, Wind resource assessment using the WASP software (2018). DTU Wind Energy.