



A Comparative Study of Wind Characteristics Between South-Western and South-Eastern Thailand Using Different Wind Turbine Models

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ABSTRACT

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Globally, wind energy has proven to be one of the most sustainable sources of energy. Wind energy assessment plays a critical role on determining installation of wind turbines worldwide. This work presents the technical evaluation of wind energy potential using three available wind turbine models for prospective onshore wind farm in the southern Thailand at Krabi and Songkhla sites. Ten-minute interval wind data over a period of 3 to 4 years obtained from Weather Observing Station is utilized to observe the diurnal and monthly wind speed, as well as frequency distribution. WAsP program is applied for energy yield calculations and wind resource maps. Our results reveal that Krabi and Songkhla has the highest mean wind speed of 4.39 m/s in December and 3.91 m/s in February, respectively. The prevailing wind direction in Krabi and Songkhla are north-east and south-east, respectively. WAsP analyses show that the total net AEP for Krabi is 7163.782 MWh, 7762 MWh and 12731 MWh using 275 kW, 300 kW and 500 kW wind turbine models, respectively. Similarly, the total net AEP for Songkhla is 7116.63 MWh, 7775.245 MWh and 12390 MWh using 275 kW, 300 kW and 500 kW wind turbine models, respectively. The total capacity factor for Songkhla and Krabi is 29.1% and 28.3%, respectively. Our results indicate that Enercon E-40/5.40 500 kW wind turbine model produces the highest total gross AEP and total net AEP for Krabi and Songkhla sites. Besides, the Vergnet GEV MP-C 275 kW turbine model shows slightly higher capacity factor in case of both sites. The findings of this study reflect that small to medium size wind turbines can be utilized to generate electricity at the sites.

1. Introduction

In recent decades, the demand of energy has increased globally as a result of growing population and socio-economic progress. The overall energy consumption will rise up to 6% globally during 2010-2040 as reported by the International Energy Outlook (IEO). Negative impacts of greenhouse gas (GHG) on environment and security of energy supplies have made the government organizations to increase the exploitation of various sources of renewables. Wind energy is one of the clean and

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inexhaustible sources of renewables and it can be utilized for the generation of electricity by means of wind turbines [1,2].

It is significant to evaluate the wind energy potential technically by knowing characteristics of wind in order to estimate the annual electricity production at potential locations [3]. It provides a pathway for wind energy practitioners with the necessary confidence to study their options to confront the increasing energy demands and mitigating risks [4,5]. To study these wind characteristics, various researchers have used different approaches such as Weibull, Rayleigh and Wind Atlas Analysis and Application Program (WASP) [6].

Researchers in different countries scrutinized the wind energy potential at specific location using various scientific methods. For example, Adaramola *et al.*, [7] used Weibull parameters to investigate wind energy potential in the coastal parts of Ghana. Solyali *et al.*, [8] inspected wind resource assessment in Cyprus using the Weibull distribution and WASP. They examined WASP model more efficient compared to other methods. Wang *et al.*, [9] performed an inclusive study regarding wind statistics along with wind power potential at four localities in China. Promsen *et al.*, [10] and Nouri *et al.*, [11] identified optimal sites for wind turbine installation by using short term wind statistics and WASP model. Boudia and Guerri [12] used long term wind statistics along with WASP model to study wind energy potential. Mohammadi *et al.*, [13] used different approaches to measure the Weibull parameters and analyse daily power density in the south part of Alberta, Canada. Sharma and Ahmed [14] studied wind resource assessment using WASP in the southern island of Fiji.

Detrimental impacts of fossil fuels on climate and high demand of electricity in the southern Thailand which is from 5 to 6% yearly due to tourism industry and socio-economic development [15]. Krabi and Songkhla are located in the south Thailand. Krabi is a significant tourism area in Thailand and millions of tourists visit annually. Similarly, Songkhla hosts thousands of tourists each year due to its border with Malaysia [16,17]. Hence, wind energy is generally more favorable and often recommended for electricity generation.

Few studies on wind energy potential have been considered in the past using different models across Thailand, however, technical evaluation of wind energy potential using WASP program along with different wind turbine models at selected sites is unknown. Therefore, this study aims to conduct wind energy potential of selected sites using near surface wind data obtained from Weather Observing Stations. The diurnal, monthly and frequency distribution of wind speed and direction are studied. WASP program is used for energy yield calculations and wind resource maps using three different wind turbine models available in literature.

2. Methodology

2.1 Overview of the Method

The proposed methodology with a schematic diagram for the selected sites is presented in Figure 1. The first step involves the analysis of wind data acquired from Weather Observing Station. This data is further processed through WASP Climate Analyst tool to generate wind statistics. This study utilizes 10-minutes average interval of wind data from a period of 3 to 4 years recorded at height of 10 m above ground level (AGL). The description of measurement sites and their geographical coordinates can be seen in Table 1.

Table 1
 Geographical coordinates and measurement duration of Krabi and Songkhla sites

Station name	Latitude (°)	Longitude (°)	Height (m)	Measurement duration	Accepted recording (%)
Krabi	8.103	98.975	10	2017-2020	93.87 %
Songkhla	7.18	100.60	10	2017-2019	98.94 %

The second step includes the coordinates and topographical information of the selected sites which are used as an input for WASP Map Editor to generate elevation and roughness maps. The third step encompasses power curves of selected wind turbine models and site’s wind characteristics in WASP program to estimate energy yield calculations and resource maps of selected sites.

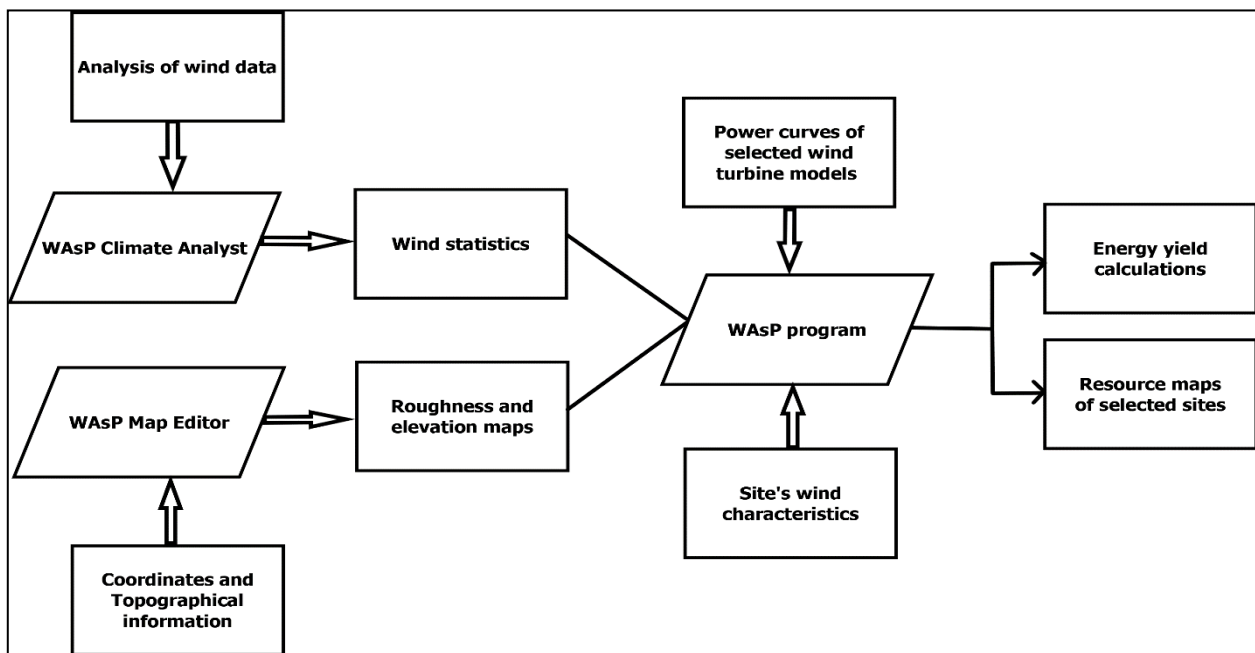


Fig. 1. Schematic diagram of methodology [4]

2.2 Simulation Model

WASP is a computer-based linear simulation model established by Denmark Technical University (DTU) at Danish Riso National Laboratory. The WASP model is computed for wind energy potential, site suitability analysis and calculations of energy yield for wind farms. It is used for vertical and horizontal extrapolation of wind data and shows errors less than 10% [4,18,19]. The basic input information that are required for the WASP program are the terrain height, surface roughness and obstacle effects. The WASP program can perform all the necessary energy production calculations for a single turbine site or for a wind park along with the wake losses, layout, capacity factor and various other factors [4]. The WASP model mainly belongs to the family of the Jackson–Hunt theory [20]. Inside WASP Module there are two important tools i.e., WASP Climate Analyst and WASP Map Editor which are explained below.

This study uses the observed wind climatology as a data recording tool for WASP Climate Analyst to estimate the wind conditions for the selected sites in terms of wind roses and Weibull distribution function. Furthermore, the wind rose is grouped into 12 sectors which signifies the relative frequency of wind direction. The Weibull distribution function is a two-parameter function which defines the

wind speed histogram. WASP utilizes this function for evaluation of wind characteristics in each direction by sector wise which can be expressed in mathematical form as [21]:

$$f(v) = \frac{k}{A} * \left(\frac{v}{A}\right)^{k-1} * e^{-\left(\frac{v}{A}\right)^k}, k > 0, v > 0, A > 1 \tag{1}$$

In Eq. (1), $f(v)$ denotes the Weibull distribution function, v means the observed wind speed, A and k signify the scale and shape parameter of the Weibull distribution function, respectively.

WASP Map Editor is a tool found inside WASP module which is used to generate elevation and surface roughness maps for the selected sites. The important information of topography and surface roughness have been entered to the servers of Global Wind Atlas (GWA) Map Warehouse-Elevation and Global Wind Atlas (GWA) Map Warehouse-Roughness to complete the elevation and surface roughness maps.

3. Results and Discussion

This section describes the diurnal and monthly wind speed pattern. Besides, a comparative and comprehensive study of wind characteristics of the selected sites has been discussed.

3.1 Diurnal Wind Speed

Figure 2 displays average of wind speed of each hour recorded at 10 m height to show the wind speed diurnal pattern of Krabi and Songkhla sites. It has been observed that both sites examine maximum average wind speed from 2 a.m. to 8 a.m. with minimum average wind speed between 12 p.m. and 10 p.m.

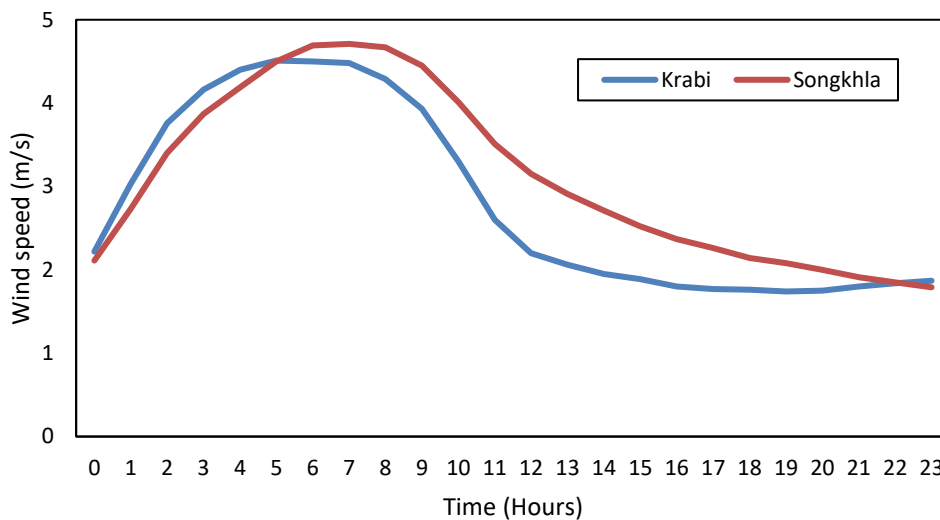


Fig. 2. Diurnal average wind speed for Krabi and Songkhla

3.2 Monthly Wind Speed

Figure 3 shows higher wind speed for Krabi site recorded at height of 10 m AGL which has been observed between October and February with the maximum average wind speed value 4.39 m/s in December. Similarly, the higher average wind speed for Songkhla site is experienced in January, February and August with the maximum average wind speed value 3.91 m/s in February. The lowest

average wind speed value of 2.02 m/s have been observed in June for Krabi site and 2.56 m/s in October for Songkhla site.

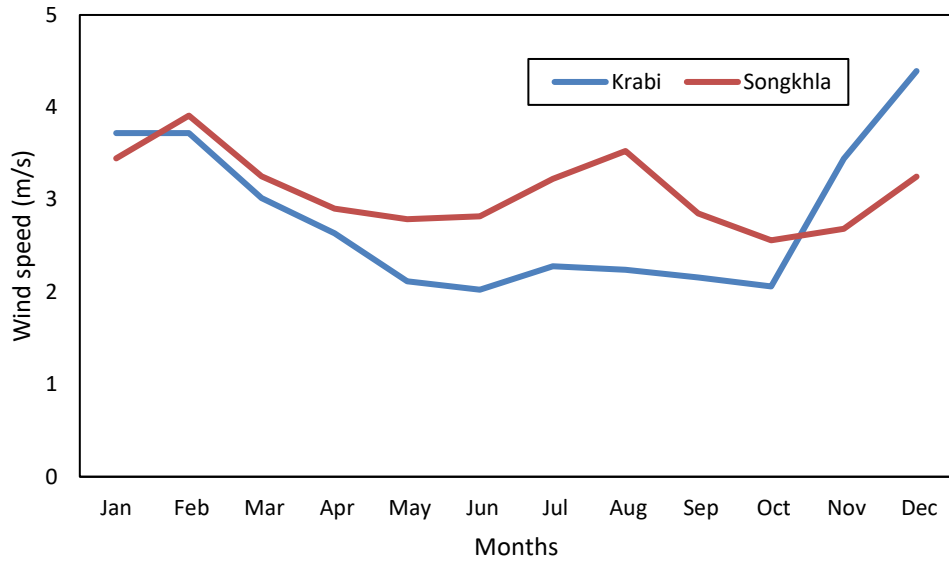


Fig. 3. Monthly average wind speed for Krabi and Songkhla

3.2.1 Frequency distribution of wind speed and wind direction

It is important to consider the frequency distribution of wind speed and wind direction during resource assessment as it gives site specific information.

Figure 4 shows the prevailing wind direction for Krabi which is north-east with a wind speed (3.73 m/s) frequency distribution 22.1%. The values of scale parameter A and shape parameter k are 3.1 m/s and 1.39, respectively.

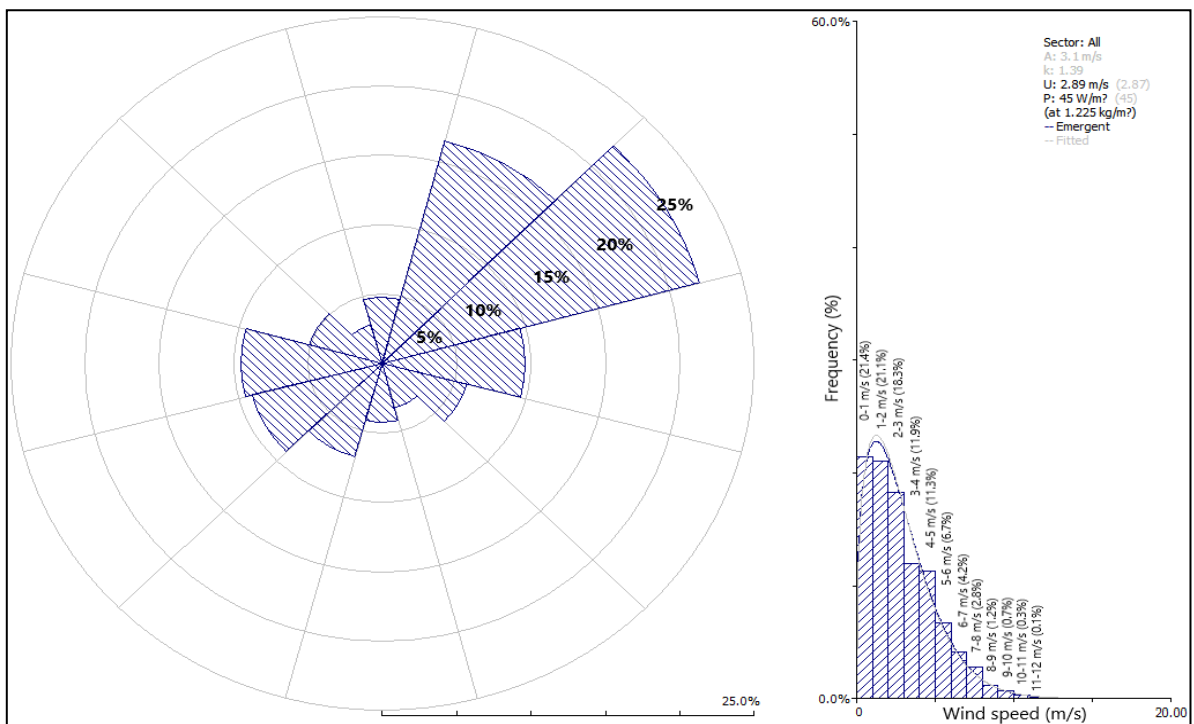


Fig. 4. Wind rose diagram and histogram of frequency distribution of wind speed for Krabi

Figure 5 presents the prevailing wind direction for Songkhla which is south-east with a wind speed (3.41 m/s) frequency distribution 31.3%. The values of scale parameter A and shape parameter k are 3.5 m/s and 1.60, respectively.

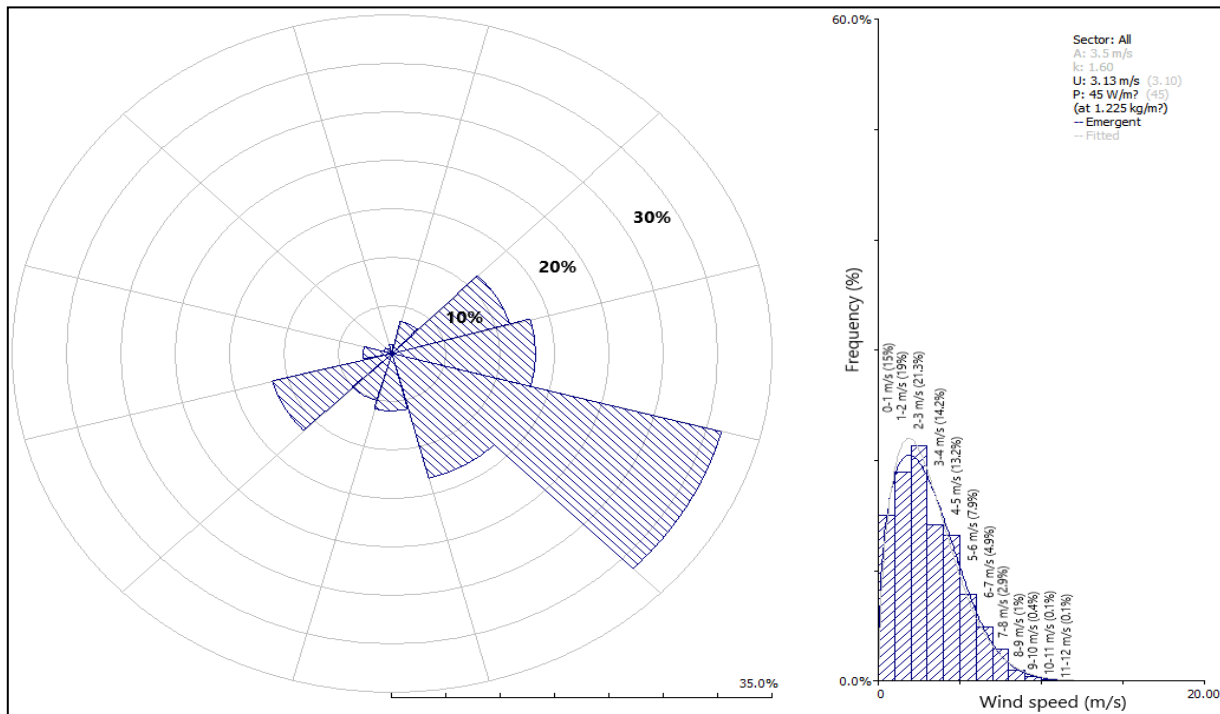


Fig. 5. Wind rose diagram and histogram of frequency distribution of wind speed for Songkhla

3.2.2 Evaluation of wind characteristics

WASP program is utilized for evaluation wind energy potential and wind characteristics at Krabi and Songkhla sites by using three available wind turbine models in the literature. Technical description and specification of the wind turbine models are given in Table 2.

Table 2

Specification of three wind turbines

Wind turbine model	Rated output (kW)	Rotor diameter (m)	Cut in speed (m/s)	Cut out speed (m/s)	Hub height (m)	Swept area (m ²)	Rated speed (m/s)
Vergnet GEV MP-C 275 kW	275	32	3.5	25	55	804	12
Bonus Mk III 300 kW	300	33.4	3	25	30	876	13
Enercon E-40/5.40 500 kW	500	40.3	2.5	25	42	1,275	12

The resource maps of Krabi and Songkhla using WASP program are displayed in Figure 6 to Figure 11. The AEP estimated for Krabi using 275 kW wind turbine ranges from 35.162 to 964.939 MWh, with 300 kW wind turbine ranges from 0.006 to 1023 MWh and with 500 kW wind turbine ranges from 0.038 to 1748 MWh. Similarly, the estimated AEP for Songkhla using 275 kW wind turbine ranges from 82.620 to 855.898 MWh, with 300 kW wind turbine ranges from 55.879 to 956.283 MWh and with 500 kW wind turbine ranges from 0.125 to 1540 MWh.

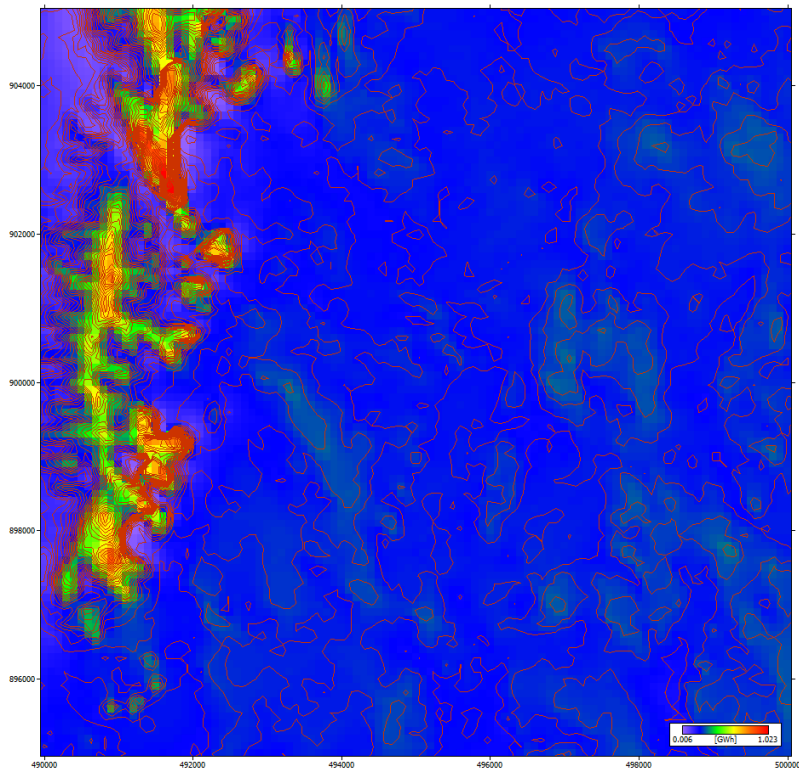


Fig. 6. Mean annual energy production of Krabi at 30 m hub height

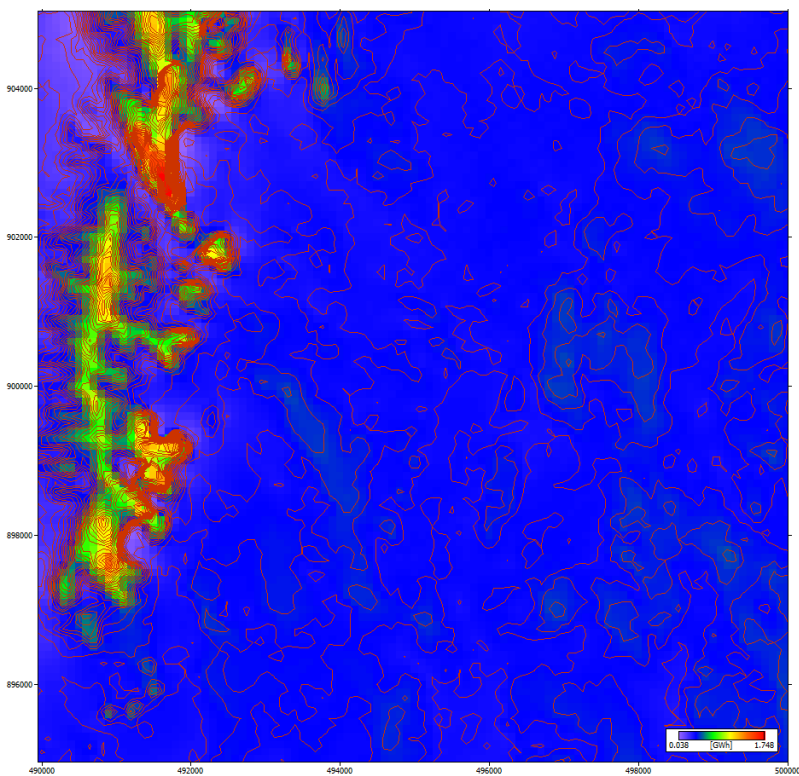


Fig. 7. Mean annual energy production of Krabi at 42 m hub height

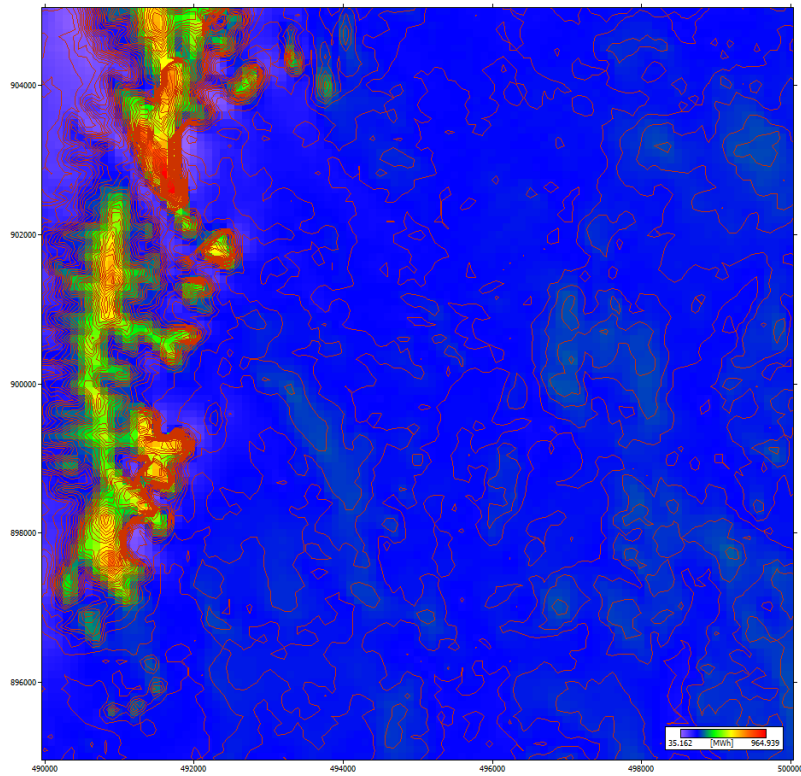


Fig. 8. Mean annual energy production of Krabi at 55 m hub height

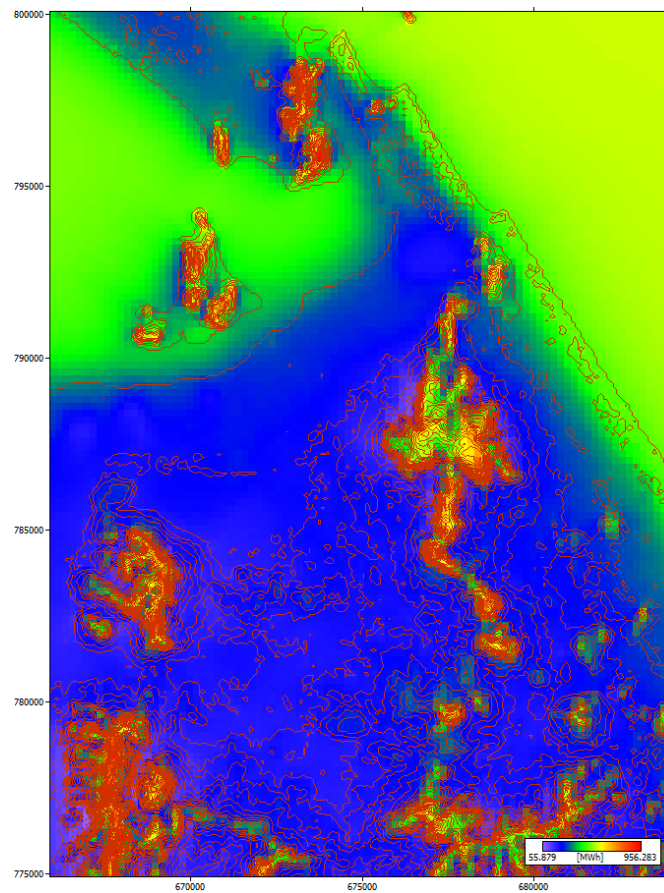


Fig. 9. Mean annual energy production of Songkhla at 30 m hub height

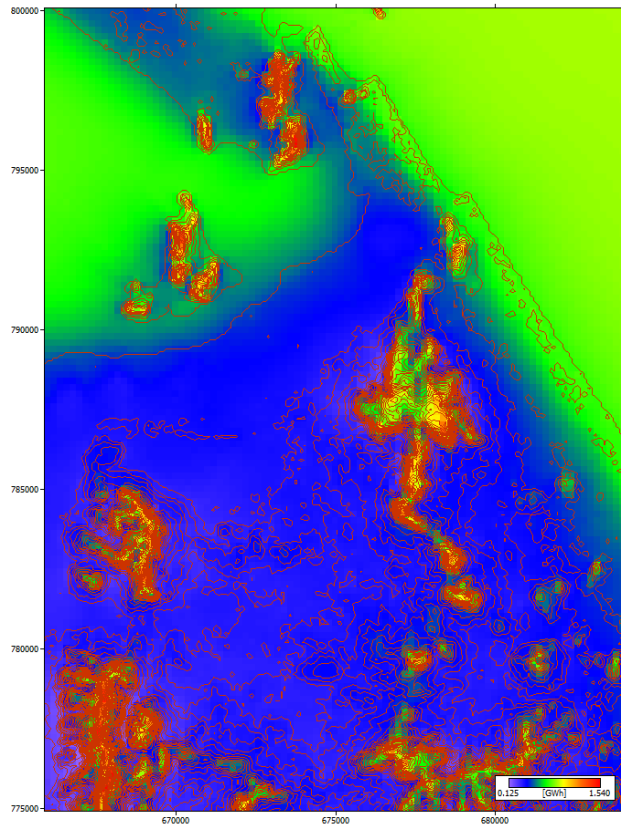


Fig. 10. Mean annual energy production of Songkhla at 42 m hub height

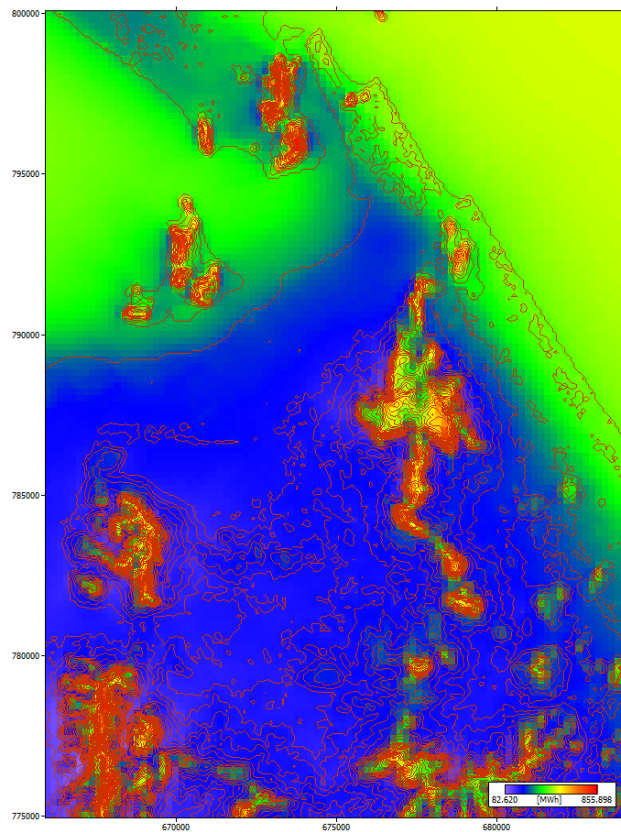


Fig. 11. Mean annual energy production of Songkhla at 55 m hub height

The statistical analysis of Krabi and Songkhla sites in terms of total gross AEP, total net AEP, proportional wake losses, annual mean wind speed, annual power density and total capacity factor have been evaluated in this study.

The total gross AEP estimated for Krabi and Songkhla using wind turbine with rated capacity of 275 kW at 55 m hub height are 7172.545 MWh and 7119.366 MWh, respectively. The mean speed and power density values are 6.85 m/s and 501 W/m² for Krabi and 6.75 m/s and 374 W/m² for Songkhla, respectively. The total capacity factor calculated for Songkhla and Krabi is 29.8% and 29.5%, respectively. Further details for both sites are given in Table 3.

Table 3

Summary for annual statistics using Vergnet GEV MP-C 275 kW at 55 m height

Variable	Total		Mean		Min		Max	
	Krabi	Songkhla	Krabi	Songkhla	Krabi	Songkhla	Krabi	Songkhla
Total gross AEP [MWh]	7172.545	7119.366	717.254	711.937	496.618	574.905	955.504	843.985
Total net AEP [MWh]	7163.782	7116.63	716.378	711.663	495.374	574.664	955.014	843.662
Proportional wake loss [%]	0.12	0.04	-	-	0.05	0.03	0.25	0.05
Capacity factor [%]	29.8	29.5	-	-	20.5	23.8	39.6	35
Average speed [m/s]	-	-	6.85	6.75	5.59	6.15	8.48	7.38
Wind power density [W/m ²]	-	-	501	374	260	278	972	477

The total gross AEP estimated for Krabi and Songkhla using wind turbine with rated capacity of 300 kW at 30 m hub height are 7768 MWh and 7775.964 MWh, respectively. The mean speed and power density values are 6.87 m/s and 590 W/m² for Krabi and 6.55 m/s and 378 W/m² for Songkhla, respectively. The total capacity factor calculated for Songkhla and Krabi is 29.1%. Further details for both sites are given in Table 4.

Table 4

Summary for annual statistics using Bonus Mk III 300 kW at 30 m height

Variable	Total		Mean		Min		Max	
	Krabi	Songkhla	Krabi	Songkhla	Krabi	Songkhla	Krabi	Songkhla
Total gross AEP [MWh]	7768	7775.964	777	777.596	539	644.544	1014	894.461
Total net AEP [MWh]	7762	7775.245	776	777.524	538	644.525	1013	894.316
Proportional wake loss [%]	0.07	0.01	-	-	0.02	0	0.16	0.02
Capacity factor [%]	29.1	29.1	-	-	20.1	24.1	37.9	33.4
Average speed [m/s]	-	-	6.87	6.55	5.28	5.92	9.19	7.13
Wind power density [W/m ²]	-	-	590	378	260	280	1400	488

The total gross AEP estimated for Krabi and Songkhla using wind turbine with rated capacity of 500 kW at 42 m hub height are 12738 MWh and 12391 MWh, respectively. The mean speed and power density values are 6.85 m/s and 533 W/m² for Krabi and 6.66 m/s and 372 W/m² for Songkhla, respectively. The total capacity factor calculated for Songkhla and Krabi is 29.1% and 28.3%, respectively. Further details for both sites are given in Table 5.

Table 5
 Summary for annual statistics using Enercon E-40/5.40 500 kW at 42 m height

Variable	Total		Mean		Min		Max	
	Krabi	Songkhla	Krabi	Songkhla	Krabi	Songkhla	Krabi	Songkhla
Total gross AEP [MWh]	12738	12391	1274	1239	863	998	1732	1468
Total net AEP [MWh]	12731	12390	1273	12390	861	998	1732	1468
Proportional wake loss [%]	0.06	0.01	-	-	0.01	0	0.13	0.02
Capacity factor [%]	29.1	28.3	-	-	19.7	22.8	39.5	33.5
Average speed [m/s]	-	-	6.85	6.66	5.44	6.03	8.76	7.29
Wind power density [W/m ²]	-	-	533	373	258	276	1131	475

The results reveal that Enercon E-40/5.40 500 kW wind turbine produces the highest total gross AEP and net AEP for Krabi and Songkhla sites. The annual capacity factor slightly varies for the selected wind turbines as it depends on turbine model and site. The Vergnet GEV MP-C 275 kW shows slightly higher capacity factor for both sites.

4. Conclusion

This study has used the recent meteorological wind data for Krabi and Songkhla sites to study the technical potential of wind energy by using three wind turbine models available in literature. The main points of wind resource analysis of both sites are:

- i. Both Krabi and Songkhla sites observe maximum diurnal average wind speed from 2 a.m. to 8 a.m. at height of 10 m AGL.
- ii. Krabi site shows maximum average wind speed of 4.39 m/s in December while Songkhla site indicates the maximum average wind speed of 3.91 m/s in February at height of 10 m AGL.
- iii. The prevailing wind direction in Krabi is north-east. The Weibull scale parameter A and shape parameter k values are 3.1 m/s and 1.39, respectively.
- iv. The prevailing wind direction in Songkhla is south-east with a wind speed. The Weibull scale parameter A and shape parameter k values are 3.5 m/s and 1.60, respectively.
- v. The total net AEP estimated for Krabi using 275 kW, 300 kW and 500 kW wind turbine models is 7163.782 MWh, 7762 MWh and 12731 MWh, respectively.
- vi. The total net AEP estimated for Songkhla using 275 kW, 300 kW and 500 kW wind turbine models is 7116.63 MWh, 7775.245 MWh and 12390 MWh, respectively.
- vii. The value of capacity factor for Songkhla and Krabi is 29.1% and 28.3%, respectively.
- viii. WAsP analysis shows that Enercon E-40/5.40 500 kW generates the highest total gross AEP and total net AEP for Krabi and Songkhla sites.

- ix. Regarding capacity factor, the Vergnet GEV MP-C 275 kW turbine model shows slightly higher capacity factor in case of both sites.

The results of the study at various hub heights confirm that both sites can be used to generate wind energy electricity in future. However, further investigation regarding cost analysis for each site would be required.

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