



Evaluation of Wind Energy Potential in Rayong Province, Thailand by WASP Program

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ARTICLE INFO

ABSTRACT

Article history:

Received 28 January 2021

Received in revised form 23 April 2021

Accepted 26 April 2021

Available online 1 June 2021

Keywords:

Wind power; wind speed; Rayong; wind direction

Over the past decades, wind energy is one of the alternative energy or renewable sources, which has been harvested to produce electricity. Our research aims to study the wind potential of the areas in the Rayong provinces of Thailand. Data from meteorological stations were collected every 10 minutes for of 3 years (2017-2019), with a measuring tower at 10-meter height above ground level (AGL). The annual average wind speeds were investigated in Rayong (2.02 m/s) with Weibull Probability Distribution Function (PDF). The annual average power density in Rayong regions was 13 W/m². In all locations, wind direction was detected mainly from Southwest (SSW) and the yearly maximum wind power capacity is 94.376 MWh. The capacity factor of 21.5 % was noticed. With relatively low wind speed was noticed in Rayong provinces of Thailand, a small wind turbine installed at 30 meters would be recommended as a cost-effective way to convert wind power to electricity.

1. Introduction

The exploitation of nonrenewable energy sources, especially coal and natural gas caused the threats to energy security and environmental impacts tremendously over the past decades [1]. The high demand of fossil fuel leads to the uncertainty of energy security which directly affects the global well-being and the economic competitiveness unavoidably [2]. Wind energy is one of the alternative energy or renewable sources, which has been harvested to produce electricity. Several advantages of wind energy have been emphasized including unlimited, clean and environmentally friendly [11].

Global Wind Energy Council reported the growth rate in wind-energy utilization increased dramatically by more than thirty percent (Figure 1) (GWEC, Global Cumulative Installed Capacity 2001–2016) [6]. As the Energy Statistics of Thailand reported that Thailand imported the electricity around 11% from neighboring countries, Thai government has strategically planned to increase the electricity production from renewable energy by 25% within the next ten years (2012-2021) according to the alternative energy development plan [7]. The organizations of both government and

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private sector showed interest toward wind electricity generation; moreover, those organizations support the establishment of sustainable ways to generate electricity production from wind power. With the clean and renewable wind energy, we would increase the energy security and attempt to comply with Thailand Twenty-year Efficiency Development Plan or EEDP (2011-2030).

Following the World Bank's reports of wind power potential in South East Asia including Cambodia, Laos, Thailand and Vietnam, the small wind turbines with a tower at 30 meters are more suitable for Thailand because the low wind speed (2-5 m/s) was detected in the most areas in Thailand [8]. The Western, Southern and Eastern Thailand have a good wind regime in the mountain areas [9]. To efficiently produce electricity from wind power using wind turbine generators, we need to scrutinize and select the location with the highest wind power potential for the long-term energy production. To achieve the most efficient electricity production, wind turbine micro-siting including wind speed, wind direction, wind rose, power density, roughness, elevation and environmental factors in each specific site were systematically evaluated [10]. The small wind power installation with a tower of less than 30 meters in Thailand shows the advantages of lowering the costs of installation and maintenance compared to the large wind turbines [12].

In this study, we aim to evaluate the wind energy potential quantitatively at Rayong, Thailand by using collected meteorological data over three year (2017-2019) at the height of 10 m. The simulation data from WAsP was mainly employed to locate the optimal location for the study sites of wind turbine installation.

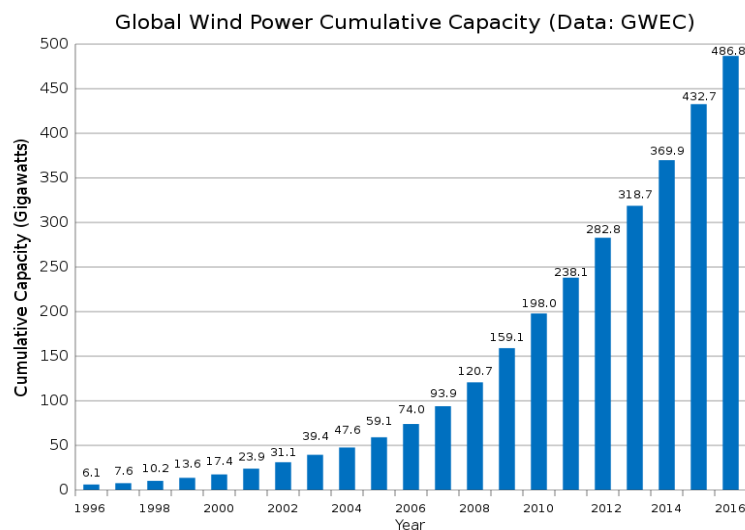


Fig. 1. The growth rate of global installed wind power capacity for electricity production [6]

2. Methodology

2.1 Meteorological Data Collection and Study Sites

All the meteorological data were obtained from the meteorological stations within the Rayong province and TMD Website. Rayong province is located on the Eastern Thailand and the administrative area in Rayong covers an area of 3,671.489 km² which was estimated by Geographic Information System (GIS). The geological features of Rayong (Figure 2) consisted of (i) a plain in the North and South of Rayong (ii) a coastal plain with small hills in the Southeast toward Southwest. (iii) The mountain region in the center of Rayong. The geographic location of the meteorological stations was located at 12° 38' 31.10" N and 101° 20' 37.0" E. Anemometers which monitored the wind speeds and wind direction were installed on the 10-meter towers above ground level (Figure 3). The wind

towers with mounted anemometers were used to collect all the meteorological measurements which are located at Rayong meteorological measurements (12°38'01.7"N 101°18'19.3"E) (Figure 4). In this study, wind data from the agrometeorological station which were collected every ten minutes over a three-year period (January 2017-December 2019) were employed as an input data for (i) calculating the wind speed and wind direction, (ii) generating the wind resource map and (iii) identifying the potential areas for wind energy generation.

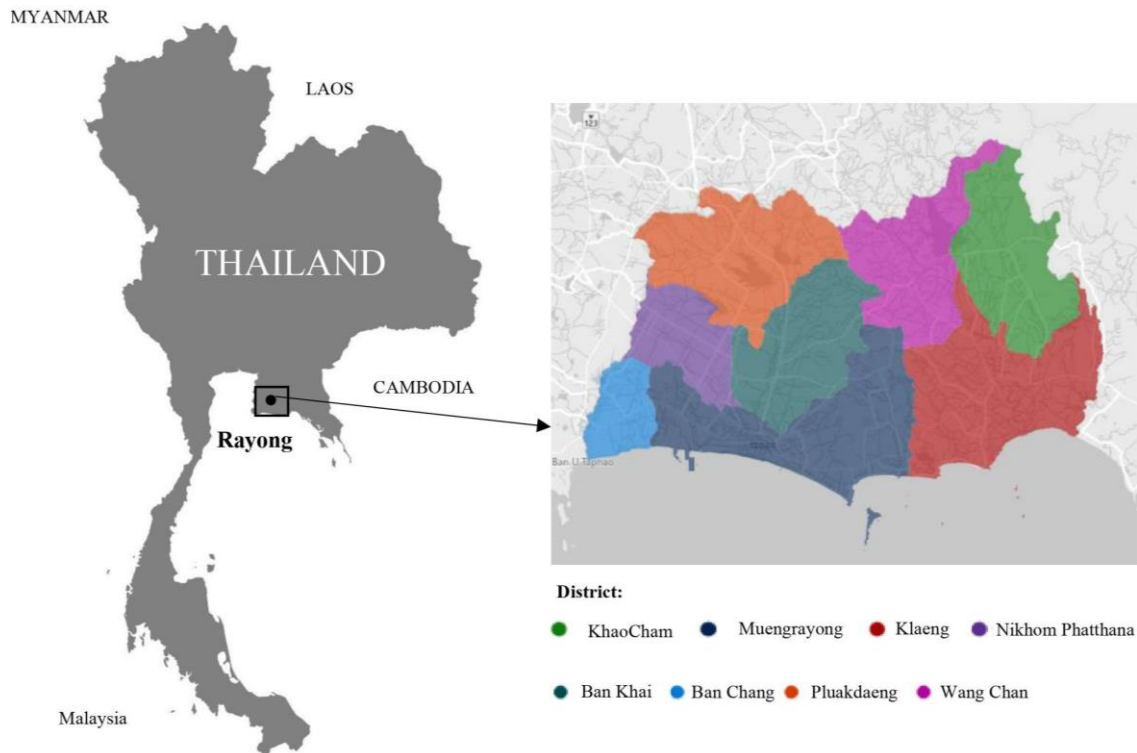


Fig. 2. A map of the geological features of Rayong province [3]



Fig. 3. The wind measuring device at the agrometeorological station [4]



Fig. 4. Rayong meteorological station [4]

2.2 Potential of Wind Energy and Wind Direction

By applying the wind data as the input into WASP program, we were able to generate the average wind velocity, Weibull distribution and wind rose. These parameters were derived from the equation of Weibull distribution. Weibull distribution is one of the most common method that has been used to calculate the wind speed. The Weibull distribution is not required the large size of samples, and it is very flexible. Only two parameters; shape (k) and scale (c) are required for processing the data [14]. We employed the WASP software which has a package of Weibull distribution. shown as in Eq. (1) which shows continuous probability distribution of any parameters.

$$f(V) = \frac{k}{c} \left(\frac{V}{c}\right)^{k-1} \exp \left[-\left(\frac{V}{c}\right)^k \right] \quad (1)$$

where

f(V): frequency of incidence of wind speed

k: shape parameter

c: scale parameter

v: wind speed(m/s)

2.3 Roughness and Elevation Maps

The roughness and elevation maps were generated by using the WASP Map Editor tool in WasP program. The geographic location of Rayong meteorological station (12° 38' 31.10" N and 101° 20' 37.0" E) with the grid size of 50x50 km² (Figure 5) were used to establish the roughness and elevation maps in Rayong.

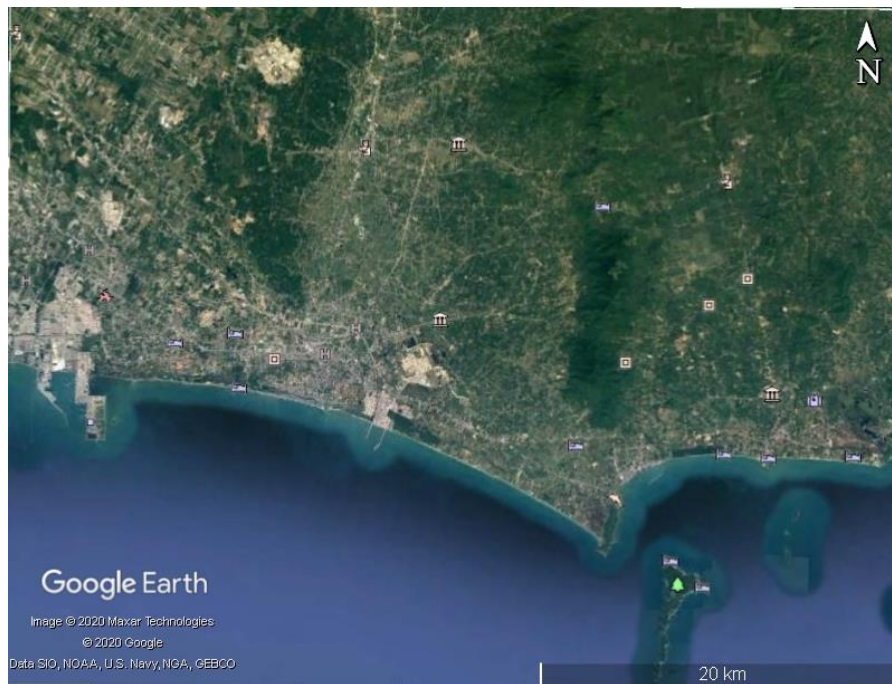


Fig. 5. The satellite image of Rayong Province [5]

2.4 Annual Average Wind Speed and Annual Average Wind Power Density

The input data were created from shape file by deriving the data from NASA’s Shuttle Radar Topography Mission (SRTM) and the input data were analyzed for (1) the annual average wind speed and (2) the annual average wind power density with WasP program [15].

2.5 Wind Turbine Power Performance

The specifications of Hummer 50kW H 17.0 wind turbine (Table 1) and power curve is shown in Figure 6 which is classified as a small-sized turbine was installed at 30 meter above the ground to determine the potential for wind energy application [13]. This type of wind turbine (Hummer 50kW H 17.0) was selected because it can perform at relatively low wind speed around 2.5 m/s and it will be stopped when the wind speed exceeds 20 m/s as shown in Table 1. To achieve the maximum wind energy potential, the wind turbine installation instruction has been followed to avoid the imbalance of wind turbine blades and inconsistency of capacity factor [16].

Table 1

Hummer H17.0 wind turbine specifications

Rotor diameter	Hub height	Cut-in speed	Cut-out speed	Area Swept	Number of blades	Rated power	Rated wind speed
17 m	30 m	2.5 m/s	20 m/s	227 m ²	3	50 kW	12.0 m/s

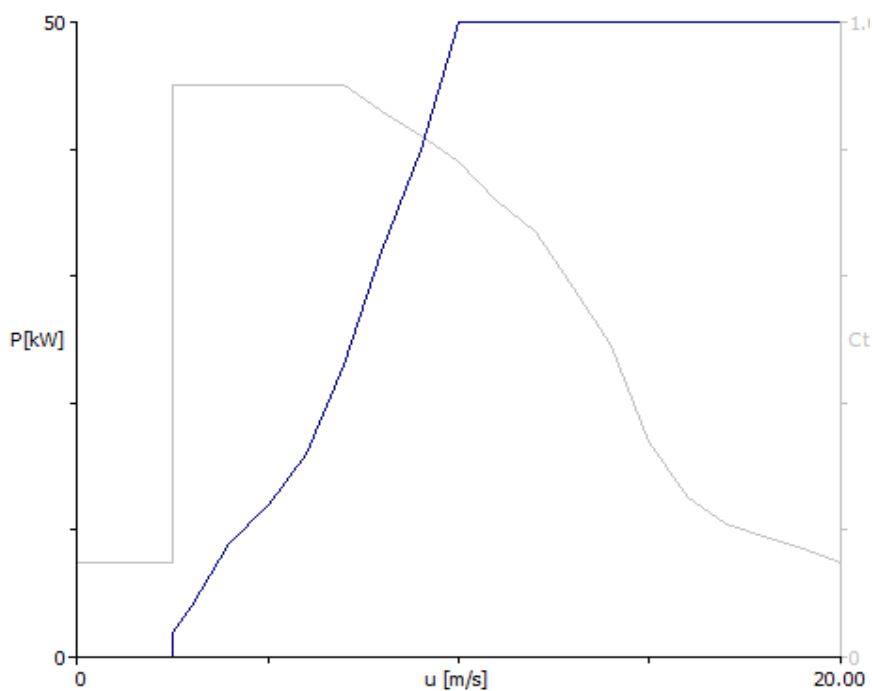


Fig. 6. Power curve of wind turbine generator: Hummer 50kW H 17.0

3. Results

3.1 Meteorological Data Collection and Study Sites

In this study, the wind speed measurement data from Rayong of Thailand for a period of 3 years (January 2017-December 2019) have been analyzed to generate mean wind speed (U), mean wind direction, mean power density (P), frequency of wind direction (f) and Weibull distribution parameters in terms of parameters of k and A . The main results obtained from the present study can be summarized as follows.

3.2 Potential of Wind Energy and Wind Direction

The wind data were obtained from Rayong meteorological station with Anemometers installed 10-meter above ground level from January 2017 to December 2019. Weibull distribution, which showed the cumulative frequency distribution of wind speed, was used as statistical models of wind data analysis. Together, the Weibull distribution and wind rose provided the annual maximum wind speed wind speed of 3.5 m/s and annual wind speed of 2.02 m/s in the South-southwest (SSW, 240 degree) (Figure 7). As shown in Table 2, the wind speed that is suitable for wind turbine installation should be greater than 2.5 m/s and geographical information of the study site needs to be considered. We were well-aware of the fact that the wind turbine have been installed at 30-meter height above ground level so that we are supposed to measure the wind characteristics at the same height according to the report from the World Bank Group; however, only wind data at 10-meter height above ground level are available from the local Rayong meteorological station.

Table 2
 Sectors-wise wind statistics of the processed data

	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
A [m/s]	1.4	1.4	1.6	1.5	1.5	1.6	1.9	2.4	3.5	3.2	1.8	1.3
k	1.95	1.81	1.55	1.58	1.69	1.75	1.79	2.12	2.55	2.46	1.57	1.84
U [m/s]	1.22	1.29	1.45	1.37	1.33	1.45	1.65	2.13	3.06	2.85	1.66	1.19
P [W/m ²]	2	3	5	4	3	4	6	11	27	23	7	2
f [%]	4.6	8.9	6.0	4.3	5.0	6.0	9.3	14.9	21.6	13.1	3.8	2.5

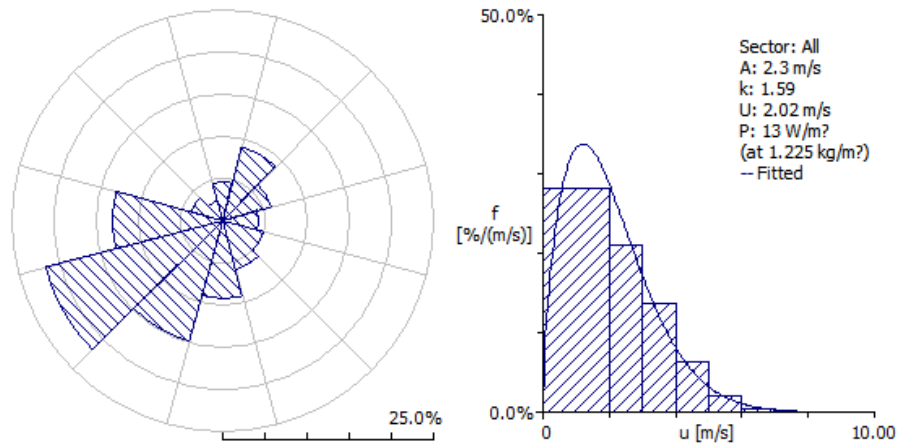


Fig. 7. The wind rose(left) and histogram of wind speed(right)

3.3 Elevation Map and Roughness Map

The roughness map and elevation map were created using the WAsP MAP Editor tool from the WAsP program with the grid size of 50x50 km² to cover the entire area of Rayong province. The analysis indicated that the geological areas of Rayong consisted of both hills and mountains. The maximum height of a mountain was 700 meter above sea level as shown in Figure 8. The roughness length is $Z_0 = 0.3$ m. The terrain showed the roughness class 7 (croplands and forests).

Global Wind Atlas (GWA) warehouse map server and Google Earth maps were used for different land cover categories to classify the roughness lengths. The study area is classified into 7 different roughness lengths Show in the Table 3 corresponding to the actual topographical area of Rayong that has two mountain ranges (Figure 9).

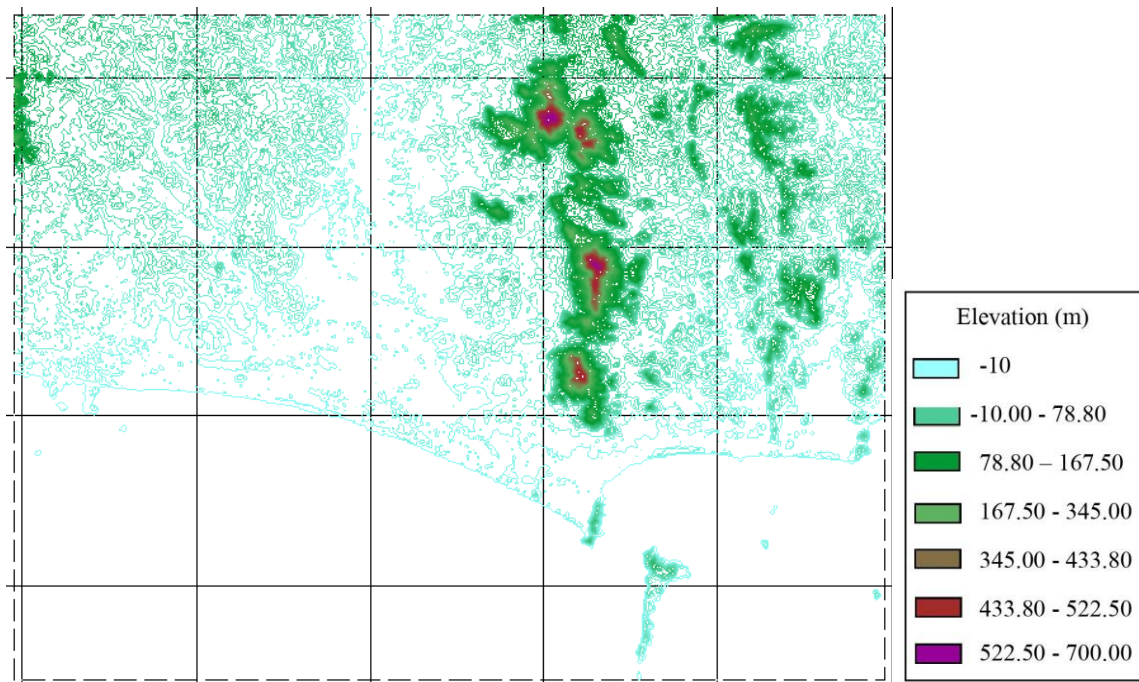


Fig. 8. Elevation around the metrological tower

Table 3
 Values of surface roughness for different landcover

No.	Land Cover Class Name	Roughness Length Z_0 (m)
1	Water surface	0.0
2	Bare areas	0.005
3	Grassland, savannas or lichens/mosses	0.03
4	Croplands	0.1
5	Mosaic natural vegetation / cropland	0.3
6	Flooded forest or shrubland	0.6
7	Forests	1.5

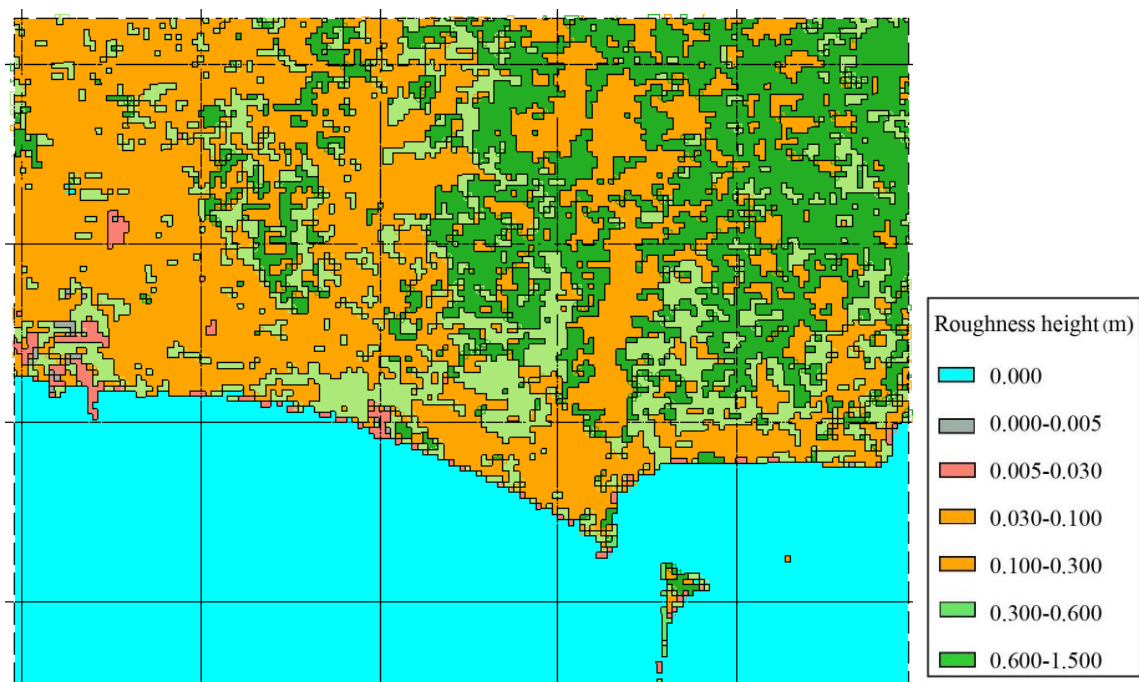


Fig. 9. Roughness height around the metrological tower

3.4 Wind Speed Mapping and Wind Power Density

We used WASP Map Editor and Shuttle Radar Topography Mission with the grid size of 50x50 km² and the resolution of 300 m to analyze the wind map and power density. The geographical distribution of mean yearly wind speed at the height of 10 m was detected in the range of 0.89–4.56 m/s. The wind direction was found mainly in the south-southwest direction with the average wind speed greater than 2.5 m/s. We showed that the wind turbine worked properly at the average wind speed of 2.5 m/s as displayed in Figure 10. The wind power density maps illustrated the mean yearly wind speed of 1–120 w/m² at the height of 10 m (Figure 11). Based on the evaluation from roughness, elevation maps, wind mapping and power density, the results showed that this area is qualified to install the wind turbine. The wind turbines were installed at six study sites which showed the high potential for wind energy generation.

Both annual average wind speed map and annual average wind power density showed the similar trend as the wind speed gets higher the wind power density is greater as well, or we can conclude that the wind power density varies directly as wind speed.

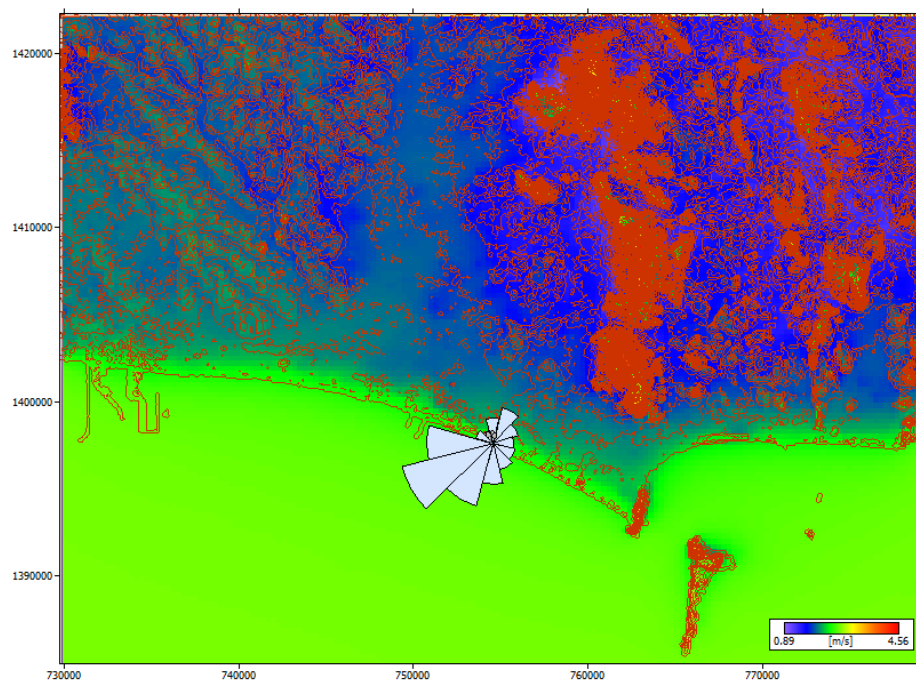


Fig. 10. Estimated Annual Mean Wind Speeds at 10 m

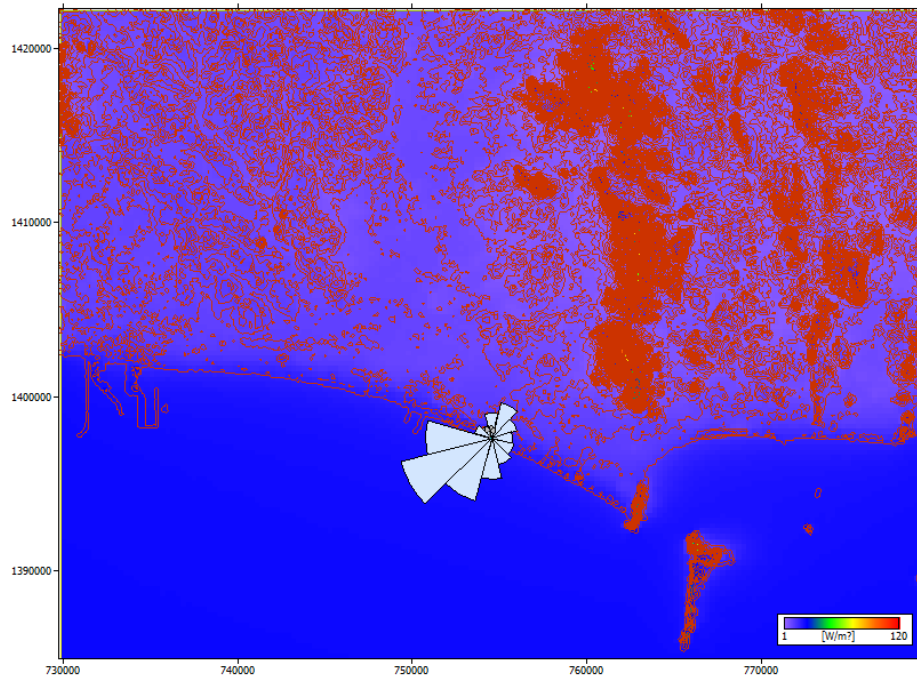


Fig. 11. Estimated Annual Mean Power Density at 10 m

3.5 Evaluation of Wind Turbine

As we considered all the key factors including average wind speed map, average wind power density map, the elevation and accessibility of the areas for wind turbine installation, we decided to use the power curve of 50kW Hummer H 17.0 wind turbine at the hub-height of 30 m. We chose this model of wind turbine because the 50kW Hummer H 17.0 wind turbine has a cut-in wind velocity of 2.5 m/s (Table 1) which was detected in our study sites. We chose the stand-alone wind energy system because it is more convenient for installation, especially at the coastal zone. We installed six wind turbines as shown in Figure 12. Our results of annual energy production (AEP) and the wind power capacity (Table 4) indicated that the third wind turbine showed the best performance of yearly wind power capacity (94.376 MWh) with the capacity factor of 21.5 %. The sum of annual energy production in each wind turbine was presented in Figure 13. We optimized some of the parameter including the length between wind turbine, wind speed and wind potential select the best location for turbine wind installation.

Table 4
 Statistical analysis of prospective turbine wind

Turbine Site	Location [m]	Hub height [m]	Mean speed [m/s]	Power Density [w/m ²]	Elevation [m]	Net AEP [MWh]	Wake loss [%]	Capacity factor [%]
site 1	(760564.7,1417562.0)	30.0	4.21	84	678.3	87.505	0.00	20.0
site 2	(762087, 1416841.0)	30.0	4.24	95	573.8	91.499	0.00	20.9
site 3	(762718.9,1409239.0)	30.0	4.26	104	579.2	94.376	0.00	21.5
site 4	(762974.4,1407738.0)	30.0	4.18	106	550.7	92.404	0.00	21.1
site 5	(761670.0,1403482.0)	30.0	4.05	89	425.5	85.812	0.00	19.6
site 6	(762194.8,1402373.0)	30.0	4.16	91	540.0	88.574	0.00	20.2

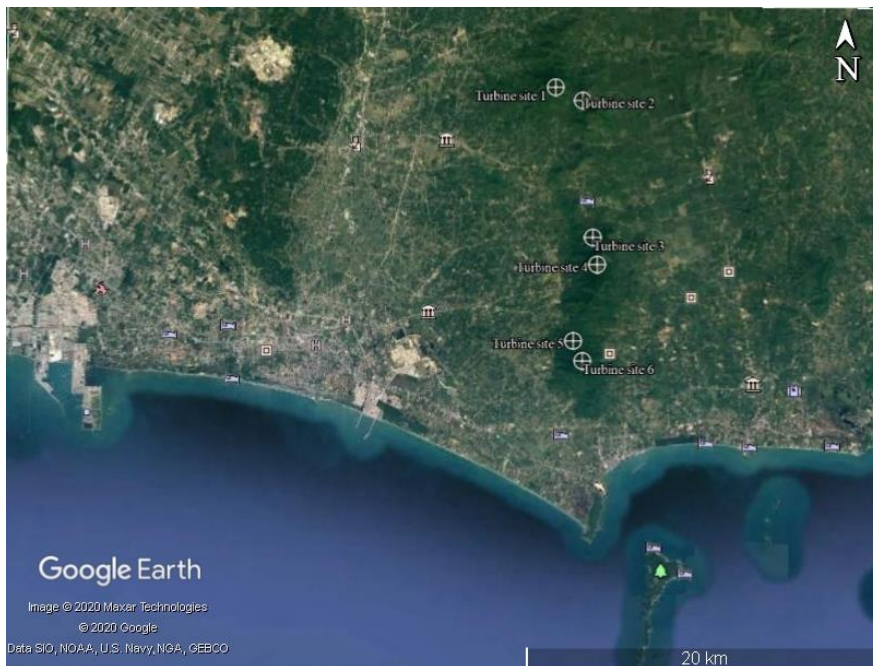


Fig. 12. The study sites with six wind turbines

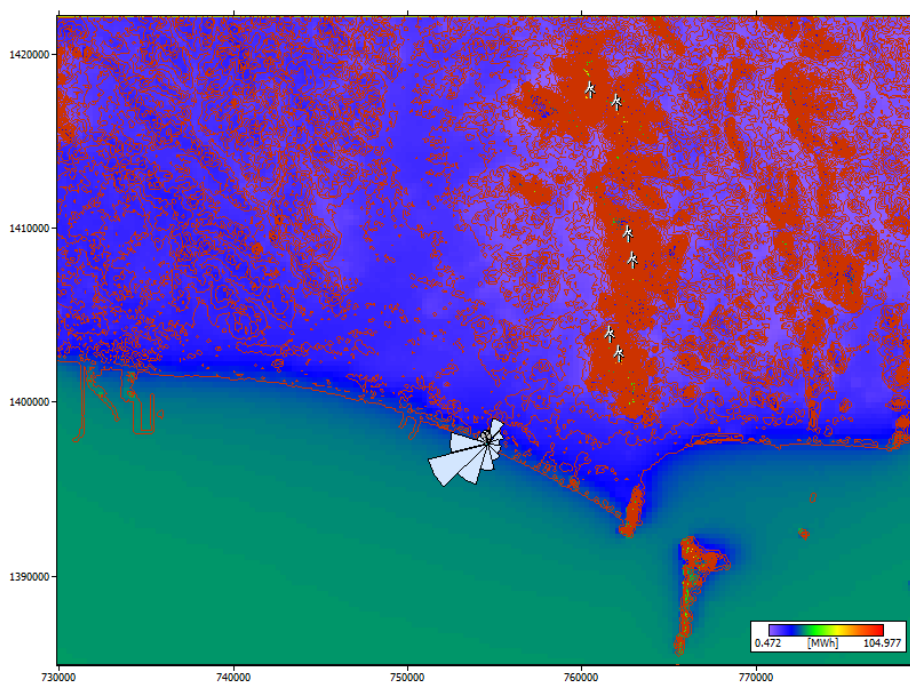


Fig. 13. Estimated Annual Energy Production

4. Discussion and Conclusions

In this study, detected the annual maximum wind speed of 3.5 m/s and annual wind speed of 2.02 m/s in the South-southwest (SSW, 240 degree). Additionally, one previous study in Ubonratchathani Province that measured the wind data at 10-meter height above ground level, which similars to this study, reports the average wind speed of 1.97 to 2.56 m/s [18]. Moreover, the researchers from Asian Institute of Technology (AIT) and Thai Meteorological Department investigated the surface wind speed in the Northern Thailand over the decades at the height of 10 m above ground level. The wind speed was detected from 2-4 m/s [19]. Both previous investigations

and together with our recent study strongly suggested installing the small wind turbines because the low average wind speed (2-5 m/s) was detected.

The wind speed was primarily influenced by the seasonal monsoon. This is likely caused by the southwest monsoon which occurs from May through October [17]. As we used the power curve of the 50kW Hummer H 17.0 wind turbine at the hub-height of 30 m, we determined the annual average of wind speed range of 0.89-4.56 m/s and annual average of wind power density of 1-120 W/m². The wind power capacity indicated that the third wind turbine showed the best performance of yearly maximum wind power capacity (94.376 MWh) with the capacity factor of 21.5 %. According to Thakur and Mithulanathan [20], 20-30% annual capacity factors was quite low but sufficient to produce the electricity in wind farm.

The previous study by Thongyai and Assawamartbunlue [21] illustrated that the greater AEP parameter is obtained with higher wind energy potential. However, some essential parameter might be inadequately optimized such as surface areas, type of the soil and the previous infrastructure of electricity [22-24]. As we previously stated that the wind data at the height of 10 m is one of our limitations, it is quite challenging to compare our study to others. Still our results of wind turbine evaluation agree with the World Bank's report that detected the low wind speed in Southeast Asia [8].

Our results may be applied as a reference to develop a wind turbine at 30 meters height above ground level in Rayong province of Thailand or the other location with similar wind characteristics in the future. Additionally, a thorough and careful economic analysis would be needed to estimate the specific capital expenditures.

Acknowledgement

This project would have been impossible without the financial and Facility supported by the Faculty of Engineering at Prince of Songkhla University (PSU). Moreover, we would like to thank Thai Meteorological Department (TMD) for providing information.

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