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Techno-Economic Analysis of Wind Energy Potential in North-Eastern of Thailand

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ABSTRACT

Thailand's alternative power development plan attempts to reduce the dependence of electrical power generation on fossil fuels by setting a goal of generating electricity from wind energy resources of 3,002MW within year 2,036. Moreover, the shortage of electricity in the North-eastern region of Thailand needs to be cared for to create stability of energy in Thailand. Therefore, the assessment of wind power resource potential in the north-eastern part of Thailand needs to be studied. This paper presents a technical and economic analysis of the wind power potential for five stations in the north-eastern part of Thailand: Buriram, Roi Et, Sri Sa Ket, Surin, and Ubon Ratchathani within 4 years (2017-2020) at a 10-minute interval. The data was collected from Thai Meteorological Department (TMD) at a 10m height above ground level. This paper focuses on the wind climate at 60m and 80m above ground level by using WAsP to simulate the mean wind speed and power density of each station. Moreover, this study uses Vestas V52-850kW and Vestas V90-2,000kW wind turbine generators to calculate the net annual energy production of each station. In addition to evaluating the economic analysis of investment, this study uses economic tools to evaluate the feasibility of investment. The result showed that Roi Et is the most suitable location for a wind farm. The mean wind speeds and power densities are 5.95 m/s and 265 W/m^2 at 60m and 6.15 m/s and 311 W/m^2 at 80m. The AEP can be generated at 18.932 GWh and 56.322 GWh at 60m and 80m heights respectively for Roi Et with a cost per unit of 0.09 $/kWh and 0.07 $/kWh. The other provinces have an AEP of 10.674 GWh for Buriram, 12.152 GWh for Sri Sa Ket, 12.969 GWh for Surin, and 8.508 GWh for Ubon Ratchathani at 60m height level, with a cost per unit of 0.15 $/kWh, 0.14 $/kWh, 0.13 $/kWh, and 0.2 $/kWh respectively. At 80m height, the AEP is 33.437 GWh with 0.11 $/kWh for Buriram, 45.737 GWh with 0.09 $/kWh for Sri Sa Kat, 41.189 GWh with 0.09 $/kWh for Surin, and 27.524 GWh with 0.14 $/kWh for Ubon Ratchathani.

Keywords:
Wind resource assessment; Sustainable energy; WAsP; North-eastern of Thailand; Wind energy

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1. Introduction

Energy is a key component of socio-economic development. At present, the largest proportion of generating electricity is fossil fuels, especially coal/lignite and natural gases. Fossil fuels are mainly caused by environmental issues due to the emission of greenhouse gases that lead to climate change. Thailand has a very high percentage of fossil fuel consumption. According to the Energy Policy and Planning Office 2020, Thailand uses natural gas and coal to generate electricity, 58 and 17 percent respectively. Besides, excessive dependence on any one resource affects the high risk of energy security for Thailand. Therefore, renewable energy has become an important resource that needs to be used to generate electricity to replace the excessive dependence on fossil fuel resources.

Renewable energy is a source of energy that is being used to replace the limited fossil fuels that are expected to be depleted in the near future. There are many forms of renewable energy, such as wind energy, hydro energy, solar energy, and biomass, etc. Besides, wind energy is one of the renewable energy sources that Thailand has continually been interested in. Because wind energy is clean and safe. Moreover, wind energy is considered an unlimited resource. In addition, the construction of wind power plants is easily achieved, but wind power electricity generation depends on sufficient wind speed [28]. According to the Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy 2019, Thailand has an installed alternative energy capacity of 11,852 MW. It could separate wind energy resources generation of 1,506.8 MW, or 12.7 percent of the total installed alternative energy in Thailand [1]. Furthermore, an alternative energy development plan [2] was created by the Energy Policy and Planning Office that sets the goal of installing electrical power capacity from wind energy resources of 3,002 MW by 2036.

Due to the study, the wind potential to generate electricity in Thailand does not cover the overall country. For example, studies in the central, southern and northern regions of Thailand, for example, studied; a study on the potential of wind energy for electricity generation in the central region of Thailand [3], a study on the potential of power generation from wind energy in the upper northern region [4], and an assessment of micrositing wind energy potential along the coasts of southern Thailand [5]. Therefore, to respond to the alternative energy development plan 2015 to increase the installed energy capacity of wind energy resources by 3,002 MW by 2036, the assessment of wind energy resource potential is crucial information for making an investment decision.

The north-eastern region of Thailand is the largest area in Thailand. The evaluation site is around 168,854 square kilometers. In 2017, northeastern had the capacity to generate 1,600 MW of electrical power but the demand for 3,600 MW. Therefore, the capacity of electricity is a shortage to the demand. Therefore, they needed to import electricity from a hydroelectric power plant in Lao PDR [6]. Wind energy is an important source of energy for producing electrical energy. The study of assessing the wind energy potential in Northeastern Thailand has the objective of assessing the wind energy potential in Khonkean, Mookdaharn, Kalasin, and Nogkhai at the level of hub-height of 60m and 90m above ground level to be the choice of decision for investment in the future by measuring the wind speed, power density, and Weibull parameters. The result of the study found Khonkean was the most suitable province for installing wind farms [8]. The study of wind speed and power characteristics of Kalasin province, Thailand has continued to assess the wind energy potential by using WAsP software to estimate energy yield output in the studied areas with VESTAS 2.0MW as the wind turbine generator. The result found in this area could generate 2,747 MWh/year [7]. However, the economic viability of wind power varies across locations, thereby influencing the benefits and costs associated with a particular wind project. Accurate wind resource assessment is therefore essential in the choice of a profitable location [26,27].

This study will assess wind energy resource potential in the northeastern of Thailand with 5 provinces by collecting 4 years of wind data from 1 January 2017 until 31 December 2020 at a 10minute interval. The data was collected by the Thai Meteorological Department (TMD) at an anemometer height of 10 meters above the ground level to predict mean wind speed, wind direction frequency, Weibull parameters, and power density at the heights of 60m and 80m above the ground level by using the Wind Atlas Analysis and Application Program (WAsP). In addition, the economic evaluation of wind energy production with Vestas 52-850kW and Vestas 90-2000 kW is a concern.

2. Methodology

2.1 WAsP Model

The WAsP model applies several models to generalize a set of wind observational data into regionally representative wind climatology by modeling wind flow across the landscape. The WAsP has been used for wind resource estimation, wind data analysis by using a set of long-term wind speed and wind direction data at a reference site, and also the relevant terrain effects such as height contour and roughness have been taken into account to simulate the turbulence effect. [18-19].

2.1.1 Observing wind climate

The observed wind climate represents the possible long-term wind climate at anemometer height at the position of the meteorological mast by using raw wind climate data as the initial data source [20]. The wind climatological input contains the wind direction distribution and the sector-wise distribution of the mean wind speed. WAsP uses the Weibull distribution to represent the sector-wise wind speed distribution [9].

2.1.2 Weibull distribution

The Weibull distribution is one of the statistical distributions that has been found to be accurate and adequate in analyzing and interpreting wind speed and predicting wind characteristics to determine wind energy potential, and it is also used as a reference distribution [21-23]. The WAsP climate analysis program references a Weibull distribution function that is fitted to the measured histograms to provide scale parameter (A-scale parameter) and shape parameter (k-shape) for each sector [24-25].

2.2 Elevation and Roughness Maps

The map projection is the Universal Transverse Mercator (UTM) coordinate system Zone 48 and the datum is WGS-1984 [15]. The elevation and roughness maps were created using the WAsP Map Editor tool in the WAsP Program (Figure 1-5) with a map extension of 30 km × 30 km. The elevation map of each station demonstrates the height contour lines of the area around the station; a) NANG RONG Hydrometeorological Station, b) ROI ET Weather Observing Station, c) SRI SA KET Agrometeorological Station, d) SURIN Weather Observing Station, and e) UBON Weather Observing Station. The GWA-Roughness-GlobCover is one of the roughness length products provided by the Global Wind Atlas warehouse map. It is used to classify the land cover classes with 12 different roughness lengths by using a conversion table as shown in table1.

Table1
The land cover specification in the GlabCover database to roughness lengths [17]

No.	Land Cover Class Name	Roughness Length (m)
1	Water bodies	0.0
2	Permanent snow and ice	0.0004
3	Bare areas	0.005
4	Grassland, savannas or lichens/mosses	0.03
5	Sparse vegetation	0.05
6	Cropland or Shrubland	0.1
7	Wetlands	0.2
8	Mosaic natural vegetation / cropland	0.3
9	Flooded forest or mosaic grassland / forest	0.5
10	Flooded forest or shrubland	0.6
11	Urban areas	1.0
12	Forests	1.5

a) NANG RONG Hydrometeorological Station

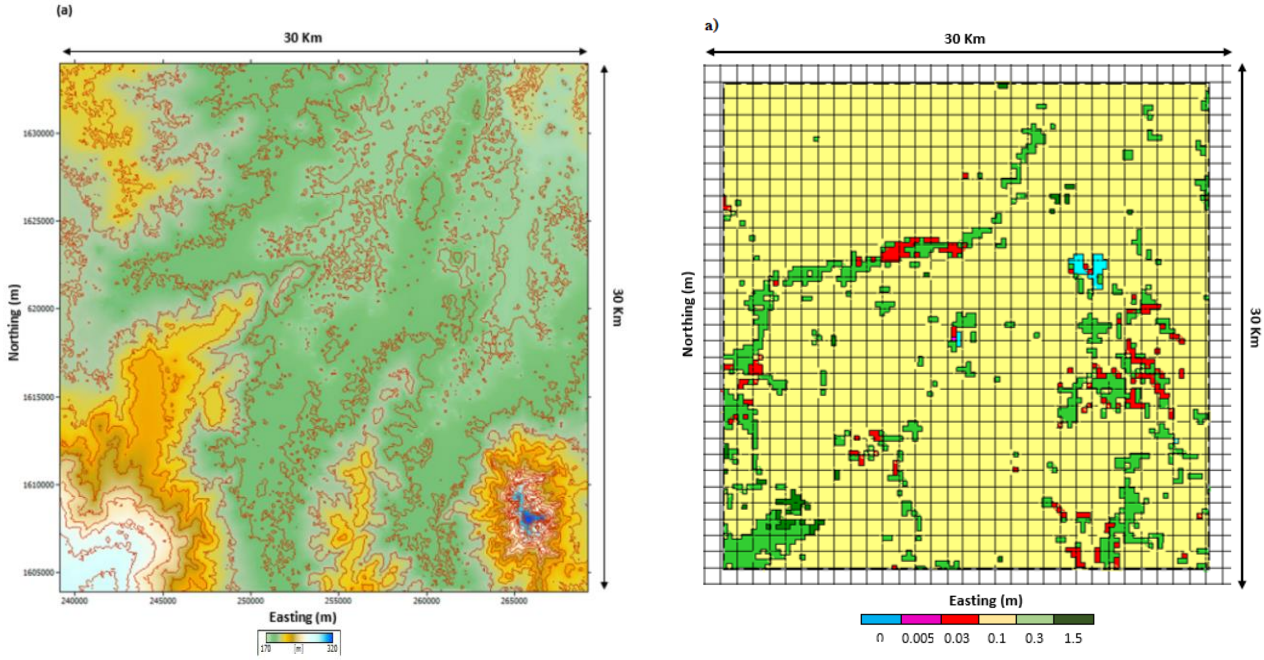

Fig. 1. Elevation and roughness map of NANG RONG Hydrometeorological Station

The elevation map of NANG RONG Hydrometeorological Station in Buri Ram province has a total of 1,681 height contours and 364 roughness change lines, with the highest elevation of about 320 meters above sea level. Whereas, most of the areas are the plain areas alternating with the plateau in the southeast, most areas are cropland or shrubland, according to the roughness map.

b) ROI ET Weather Observing Station

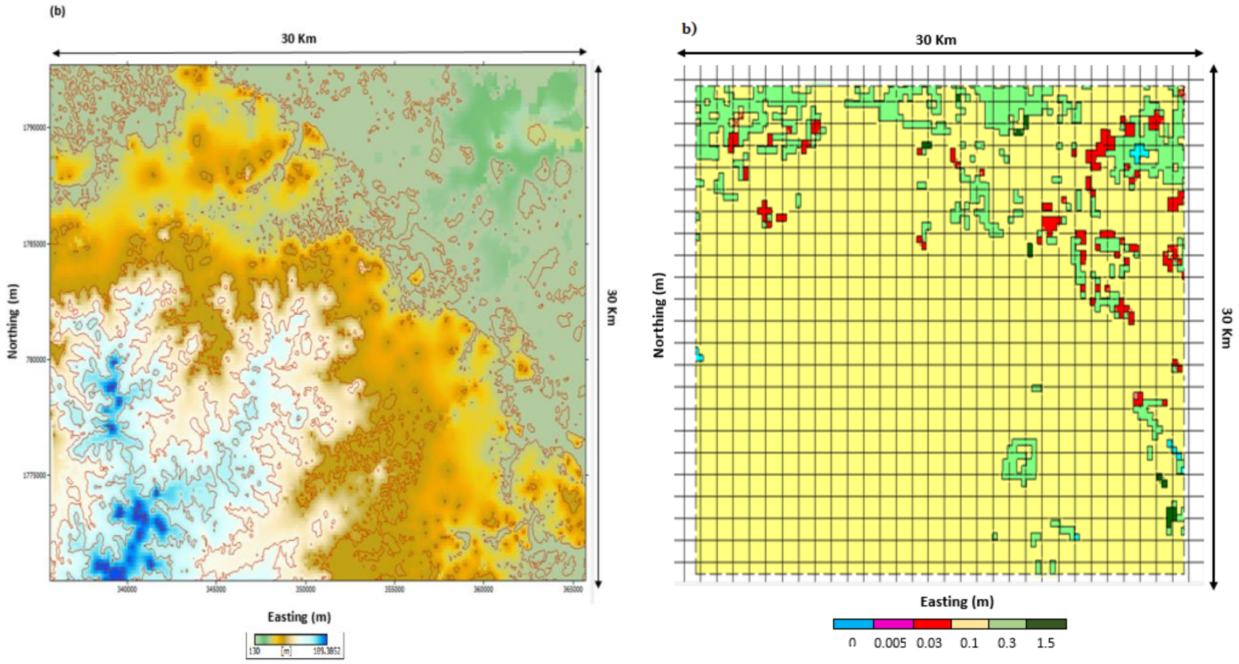

Fig. 2. Elevation and roughness map of ROI ET Weather Observing Station

The elevation map of ROI ET Weather Observing Station in Roi Et province has a total of 1,943 height contours and 255 roughness change lines. The southwest of the map area is the highest elevation, at about 190 meters above sea level. Whereas, most of the areas are plain areas with the specification of land cover is either cropland or shrubland, according to the roughness map.

c) SRI SA KET Agrometeorological Station

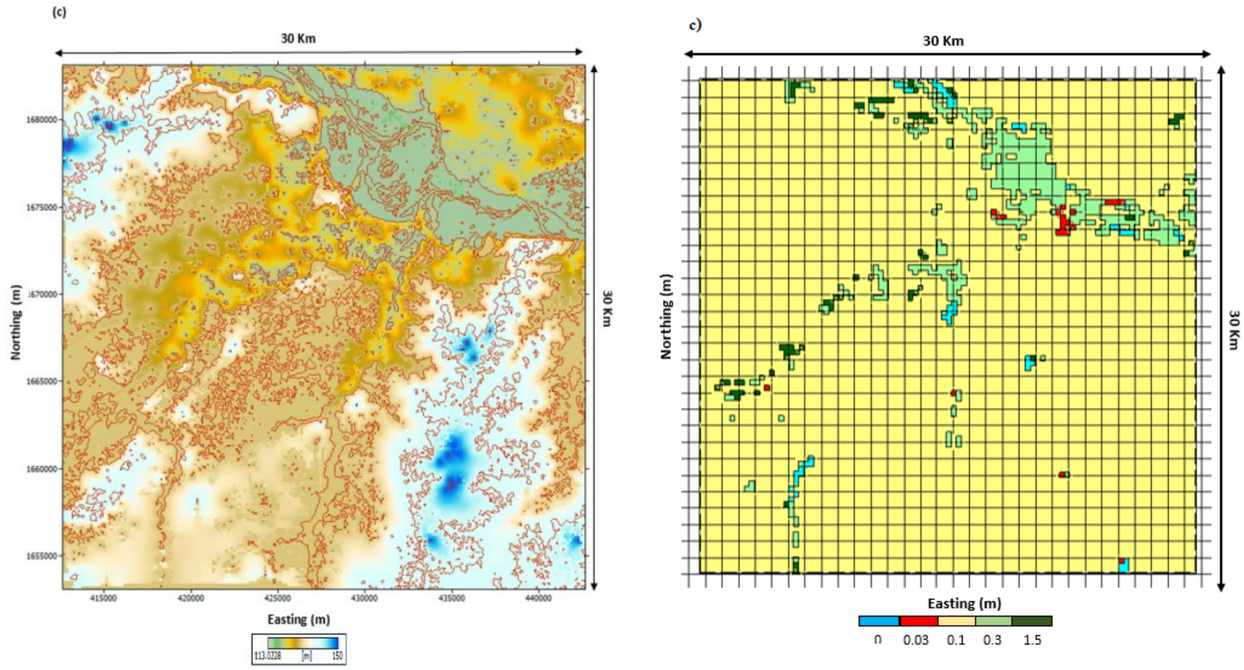

Fig. 3. Elevation and roughness map of SRI SA KET Agrometeorological Station

The elevation map of SRI SA KET Agrometeorological Station in Sri Sa Ket province has a total of 2,422 height contours and 179 roughness change lines. The highest elevation is about 150 meters above sea level. Most of the areas are plain areas with the specification of land cover is cropland or shrubland, according to the roughness map.

d) SURIN Weather Observing Station

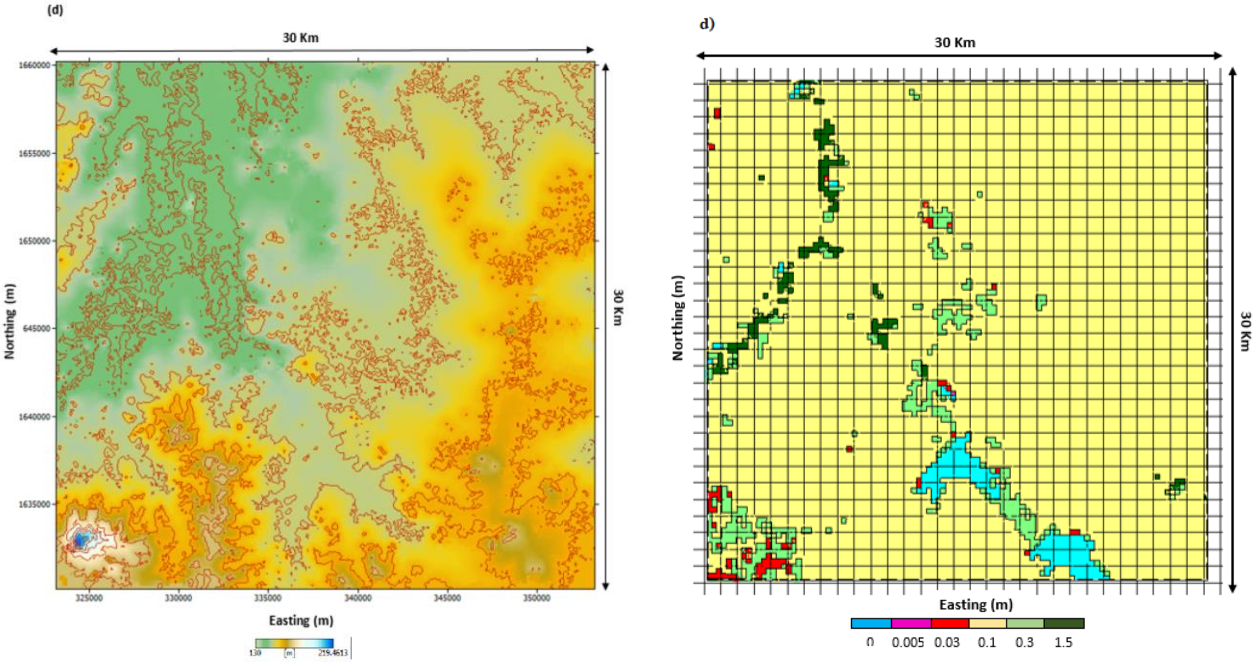

Fig. 4. Elevation and roughness map of SURIN Weather Observing Station

The elevation map of the SURIN Weather Observing Station in Surin province has a total of 1,921 height contours and 267 roughness change lines. The highest elevation is about 220 meters above sea level, whereas most of the areas are cropland or shrubland, according to the roughness map.

e) UBON Weather Observing Station

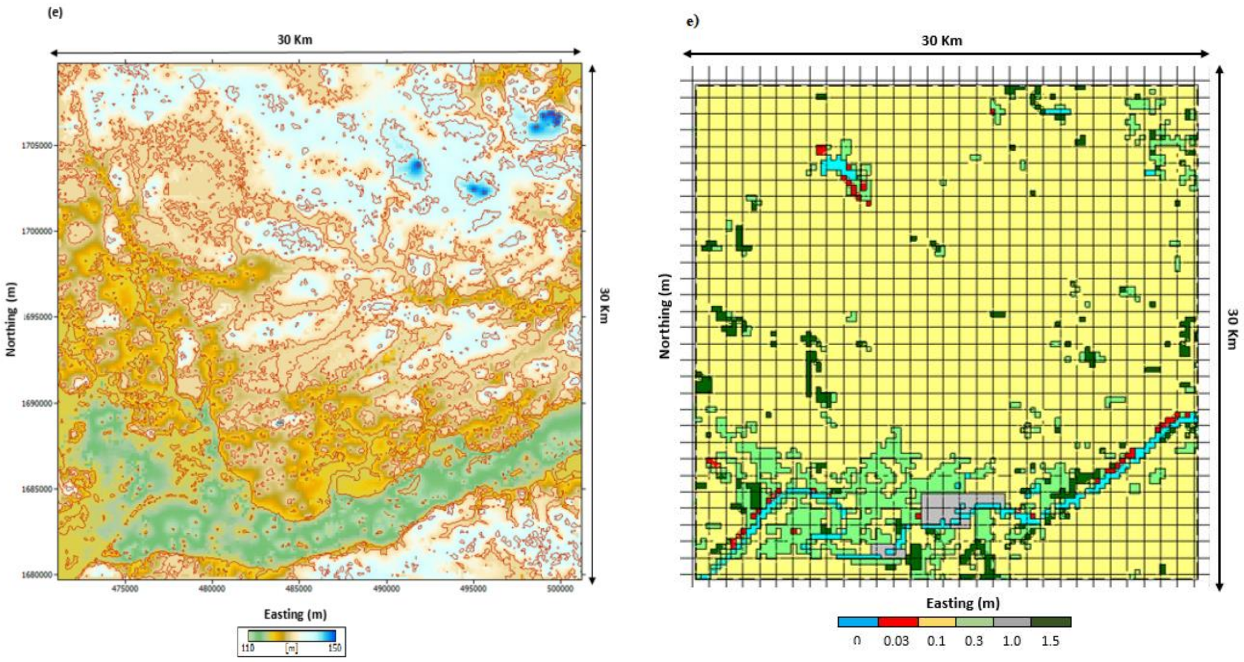

Fig. 5. Elevation and roughness map of UBON Weather Observing Station

The elevation map of the UBON Weather Observing Station at Ubon Ratchathani has a total of 2,341 height contours and 531 roughness change lines, with the highest elevation of about 150 meters above sea level. Whereas, most of the areas are either cropland or shrubland, according to the roughness map.

2.3 Economic Assessment

An economic valuation is used to support investment decisions, to demonstrate the return on investment and the cost per unit of electricity generation in the studied area. In which the study will be evaluated from 1.) Value of land use 2.) Cost of wind turbines 3.) Construction costs 4.) Grid connection costs 5.) Other capital costs, such as development and engineering costs, licensing procedures, and monitoring systems. The cost of the land use is estimated by the Treasury Department of Thailand in terms of the exchange rate of 30 Baht/USD. The land value is calculated from the estimation of the installation area of one wind turbine by using the height of the wind turbine (h) and the width of the specified rotor diameter. This study used 3 times the rotor diameter, so the value of land used would be 3h × 3h in terms of a square meter [10,12] and other costs would be estimated in terms of average price based on reference [11]. The evaluation of economic feasibility consists of Benefit-Cost Ratio (B/C ratio), Net Present Value (NPV), and Internal Rate of Return (IRR) [13] are concerned. In addition, the purchase of electricity per unit is in accordance with the Feed-in-Tariff (FiT) supported policy of the Thai government [16].

2.3.1 The indicator for economic evaluation
2.3.1.1 Net Present Value (NPV)

Net Present Value is the present value of net cash flow. That means the difference between the cash inflow value and cash outflow values over the time period of investment. NPV is used in capital budgeting and investment planning to analyze the profitability of a projected investment or project [14].

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t} \tag{1}$$

Where B_t = Cash inflows of investment over the time period
C_t = Cash outflows of investment over the time period
i = Loan rate of investment
t = Time period of investment

2.3.1.2 Benefit-Cost Ratio (B/C ratio)

A benefit-cost ratio (BCR) is one of the economic indicators that shows the relationship between the relative costs and benefits of a proposed project expressed in monetary or qualitative terms [14].

$$B/C = \frac{\sum_{t=1}^{n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{C_t}{(1+i)^t}} \tag{2}$$

2.3.1.3 Internal rate of Return (IRR)

The internal rate of return is a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis.

3. Results

3.1 Wind Climate Analysis

The wind statistics of each station as shown in Table 2 demonstrate the mean wind speed and power density of wind resources in the study area at 10meters above ground level. The mean wind speed and power density were 2.67 m/s and 35 W/m2 for Buri Ram, 3.96 m/s and 92 W/m^2 for Roi Et, 3.38 m/s and 66 W/m^2 for Sri Sa Ket, 3.05 m/s and 43 W/m^2 for Surin, and 2.93 m/s and 34 W/m^2 for Ubon Ratchathani. The typical cut-in wind speed is 3.5 m/s, but the mean wind speed of some stations was insufficient. Therefore, this study is dedicated to assessing the suitable hub height level of wind turbines.

Table 2
Wind statistics of 5 provinces where meteorological station is located at 10m height.

Station	Location		Universal Transverse Mercator (UTM) Zone	Elevation (m)	Mean Wind Speed (m/s) at 10 m	Power Density (W/m^2) at 10 m
	Latitude (m E)	Longitude (m N)				
Buri Ram	254175.94	1618916.76	48 P	181	2.67	35
Roi Et	350703.61	1777704.37	48 P	160	3.96	92
Sri Sa Ket	427663.50	1668083.80	48 P	130	3.38	66
Surin	338211.76	1645168.61	48 P	150	3.05	43
Ubon Ratchathani	486194.70	1694707.19	48 P	131	2.93	34

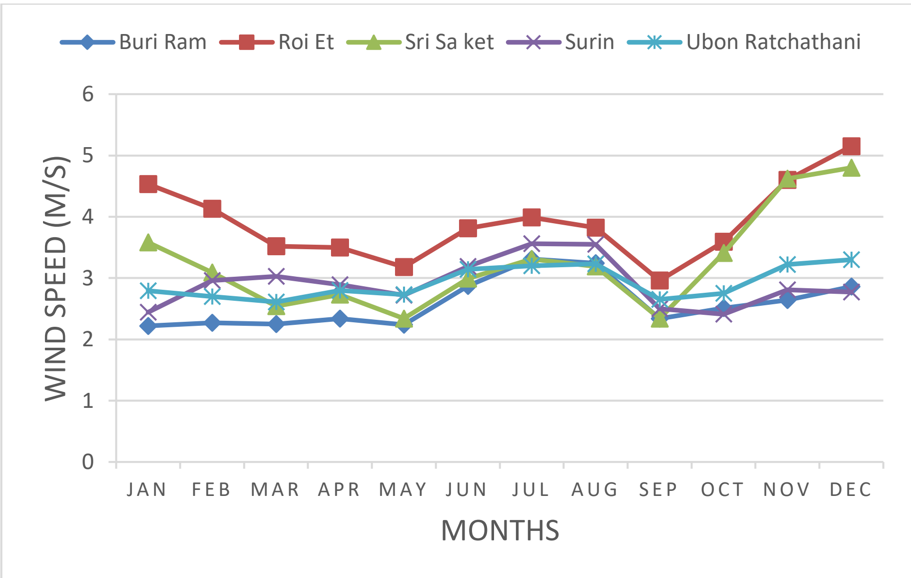

Fig. 6. Annual wind speed of 5 meteorological stations in North-eastern of Thailand at 10 m

Table 3 demonstrates the sector-wise Weibull parameters, mean wind speed, power density, and frequency of wind prevailing at Buri Ram meteorological station. The most frequent wind prevailing was from a 120° angle. The mean wind speed was 2.77 m/s, the power density was 34 W/m^2, while the strongest mean wind speed was from a 30° angle, where the mean wind speed and power density were 3.55 m/s and 60 W/m^2 respectively.

Table 3
Sector-wise wind statistics of Buri Ram at 10m

Angle[°]	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
f [%]	7.6	12.3	8.9	6.3	15.9	10.6	9.6	10.2	8.3	4	3.1	3.2
A [m/s]	3	4	3.2	2.5	3.1	2.2	2.2	3.2	3.5	2.8	2.2	1.9
K	1.54	1.75	1.61	1.4	1.53	1.38	1.34	1.45	1.42	1.17	1.16	1.31
U [m/s]	2.69	3.55	2.82	2.29	2.77	2.01	1.98	2.93	3.14	2.7	2.08	1.71
P [W/m^2]	31	60	34	22	34	15	15	44	56	51	24	10
$^a\Delta U$ [%]	2.58	2.51	2.90	3.39	0.62	-0.74	-0.02	0.46	0.96	0.11	1.39	2.20

where;
f = frequency
A = Weibull-A
k = Weibull-k
U = mean speed
P = power density
$^a\Delta U$ = Speed discrepancy

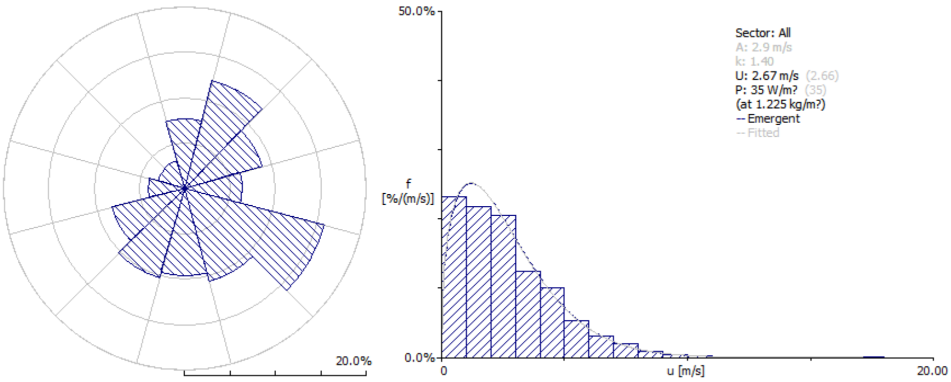

Fig. 7. Wind rose and Weibull distribution of Buri Ram at 10m

Table 4 demonstrates the sector-wise Weibull parameters, mean wind speed, power density, and frequency of wind prevailing at Roi Et meteorological station. The most frequent wind prevailing was from a 60° angle. This direction had the strongest mean wind speed and power density. The values were 5.6 m/s for the mean wind speed and 202 W/m^2 for the power density.

Table 4
Sector-wise wind statistics of Roi Et at 10m

Angle[°]	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
f [%]	3.8	8.3	19.2	12.1	4.7	6.2	13.5	13.7	8.6	3.9	2.7	3.1
A [m/s]	2.8	4.5	6.3	4.9	2.6	3.1	3.8	4.2	4.7	4.2	3.1	2.9
K	1.44	1.66	2.04	1.71	1.48	1.54	1.78	2.05	2.27	1.78	1.3	1.31
U [m/s]	2.57	4.05	5.6	4.4	2.34	2.75	3.4	3.69	4.17	3.71	2.9	2.7
P [W/m^2]	30	96	202	119	22	33	52	57	76	68	51	41
$^a\Delta U$ [%]	2.81	0.05	0.62	0.99	1.10	0.29	-0.21	1.37	3.67	4.78	0.93	1.18

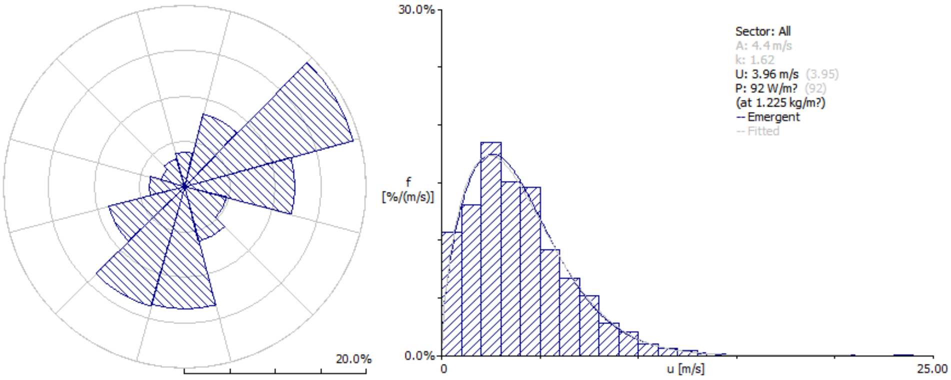

Fig. 8. Wind rose and Weibull distribution of Roi Et at 10m

Table 5 demonstrates the sector-wise Weibull parameters, mean wind speed, power density, and frequency of wind prevailing at Sri Sa Ket meteorological station. The most frequent winds prevailing were from 30° and 60° angles. Both of these directions had the strongest mean wind speeds of 5.15 m/s and 4.76 m/s, which had a power density of 143 W/m^2 and 127 W/m^2 respectively.

Table 5
Sector-wise wind statistics of Sri Sa Ket at 10m

Angle[°]	0°	30°	60°	90 °	120°	150°	180°	210°	240 °	270°	300°	330°
f [%]	4.1	15.6	15.2	5.5	4.7	8.5	8.5	11.7	12.3	6.3	4.3	3.3
A [m/s]	2.6	5.8	5.4	2.8	2	2.2	2.1	3.2	4.1	3.9	3.2	2.4
K	1.51	2.26	1.98	1.32	1.27	1.3	1.44	1.61	1.83	1.65	1.31	1.19
U [m/s]	2.37	5.15	4.76	2.58	1.82	2	1.89	2.84	3.6	3.45	2.97	2.26
P [W/m^2]	22	143	127	35	13	17	12	60	60	60	55	29
$^{a}\Delta U$ [%]	5.77	2.02	1.84	2.15	1.78	0.63	2.52	1.84	3.04	4.80	3.18	5.52

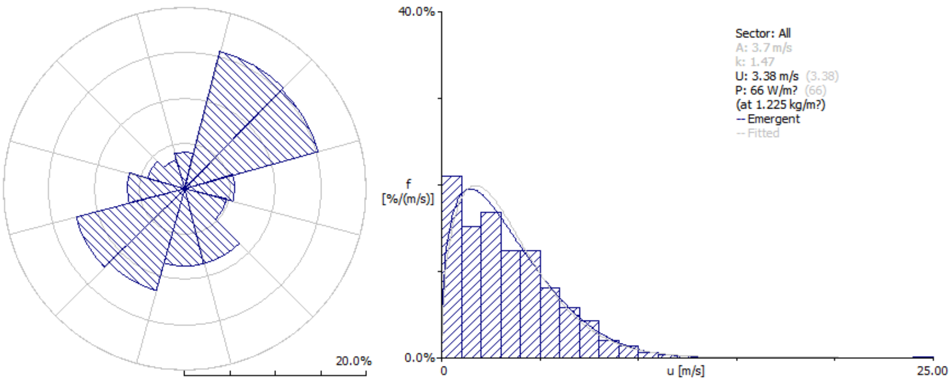

Fig. 9. Wind rose and Weibull distribution of Sri Sa Ket at 10m

Table 6 demonstrates the sector-wise Weibull parameters, mean wind speed, power density, and frequency of wind prevailing at Surin meteorological station. Most of the wind prevailing was from a 30° angle or northeast direction, which had a mean wind speed of 3.77 m/s and a power density of 71 W/m^2.

Table 6
Sector-wise wind statistics of Surin at 10m

Angle[°]	0°	30°	60°	90 °	120°	150°	180°	210°	240 °	270°	300°	330°
f [%]	6.5	13.8	8.7	5.9	8.1	19	10.1	10.8	5.8	4.3	3.3	3.7
A [m/s]	3.1	4.2	4.1	3	3	3.6	2.9	3.6	3.3	3	2.5	2.1
K	1.62	1.79	1.75	1.54	1.54	1.74	1.79	1.73	1.63	1.43	1.26	1.32
U [m/s]	2.77	3.77	3.68	2.71	2.73	3.18	2.59	3.22	2.98	2.73	2.29	1.92
P [W/m^2]	32	71	67	32	32	44	23	46	39	37	27	15
$^a\Delta$U [%]	3.93	2.05	4.24	4.33	2.81	0.35	3.23	5.08	5.08	5.23	4.59	4.31

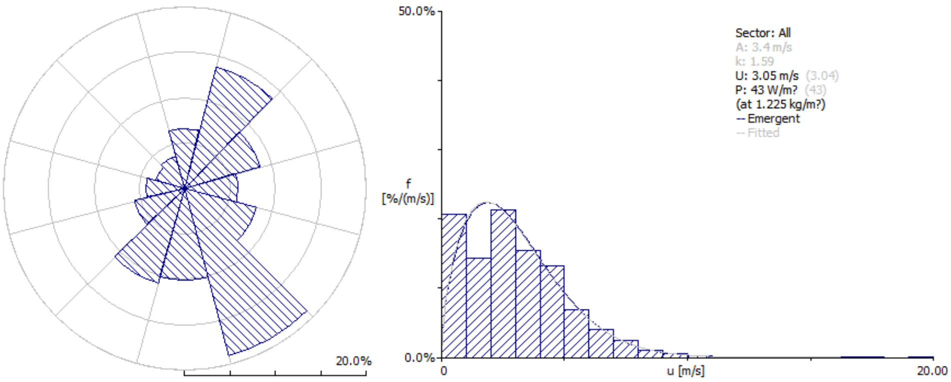

Fig. 10. Wind rose and Weibull distribution of Surin at 10m

Table 7 demonstrates the sector-wise Weibull parameters, mean wind speed, power density, and frequency of wind prevailing at the Ubon Ratchathani meteorological station. The most frequent wind prevailing was from a 30° angle, which had a mean wind speed of 3.1 m/s and a power density of 38 W/m^2, while the strongest mean wind speed was from a 300° angle, where the mean wind speed and power density were 3.48 m/s and 54 W/m^2 respectively.

Table 7
Sector-wise wind statistics of Ubon Ratchathani at 10m

Angle[°]	0°	30°	60°	90 °	120°	150°	180°	210°	240 °	270°	300°	330°
f [%]	11.5	16.6	7.6	5.6	7.3	12.7	9.6	8.5	8.2	5	4.3	3.2
A [m/s]	3.4	3.5	3.1	2.9	3	3.1	2.9	3.6	3.7	3.5	3.9	2.6
K	1.66	1.84	1.48	1.72	1.87	1.83	1.89	2.11	2.07	1.83	1.83	1.4
U [m/s]	2.99	3.1	2.84	2.57	2.62	2.79	2.61	3.18	3.3	3.11	3.48	2.35
P [W/m^2]	39	38	39	24	23	28	22	36	41	39	54	24
$^a\Delta$U [%]	-1.65	-0.78	-1.63	1.58	1.54	-0.63	-0.10	0.63	0.80	1.74	3.13	2.37

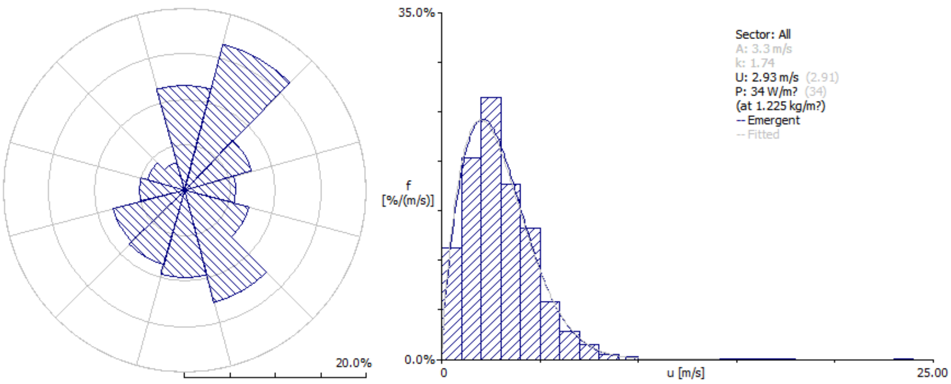

Fig. 11. Wind rose and Weibull distribution of Ubon Ratchathani at 10m

3.2 Wind Resource Assessment by WAsP

The WAsP software is used to perform wind climate prediction at the hub-height level above the ground level, where the data consists of wind speed, wind direction, and Weibull parameters at the selected wind farm sites. The results of simulating wind climate prediction are used to calculate the expected energy yield. The wind farm selected sites were carefully chosen by using elevation, roughness, mean wind speed, and power density maps for decision making. The elevation and roughness maps are shown in Figures 1-5. The mean wind speed and power density maps with high resolution are shown in Figures 12-13. The Vestas V52-850kW and Vestas V90-2MW wind turbine generators were used for power analysis at 60m height and 80m height above ground level respectively. The specifications of the wind turbine generators are shown in Table 8.

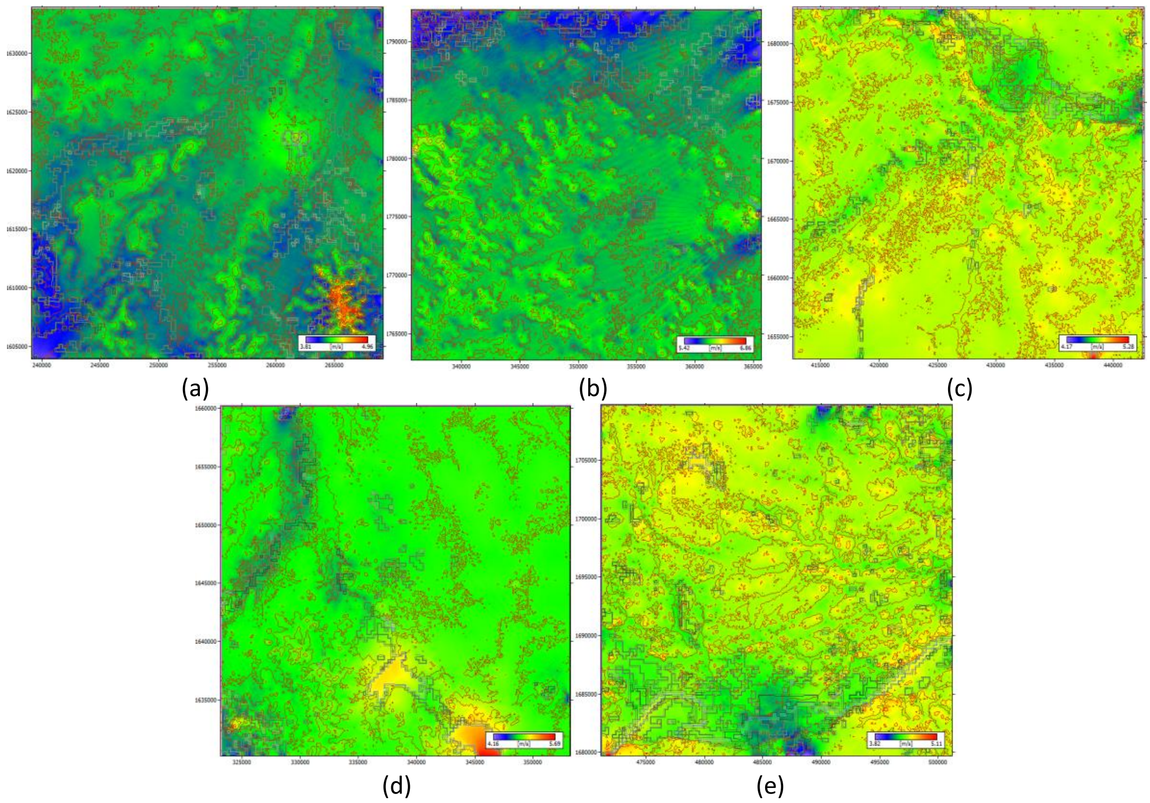

Fig. 12. High resolution map mean wind speed of 5 provinces a) Buri Ram, b) Roi Et, c) Sri Sa Ket d) Surin and e) Ubon Ratchathani

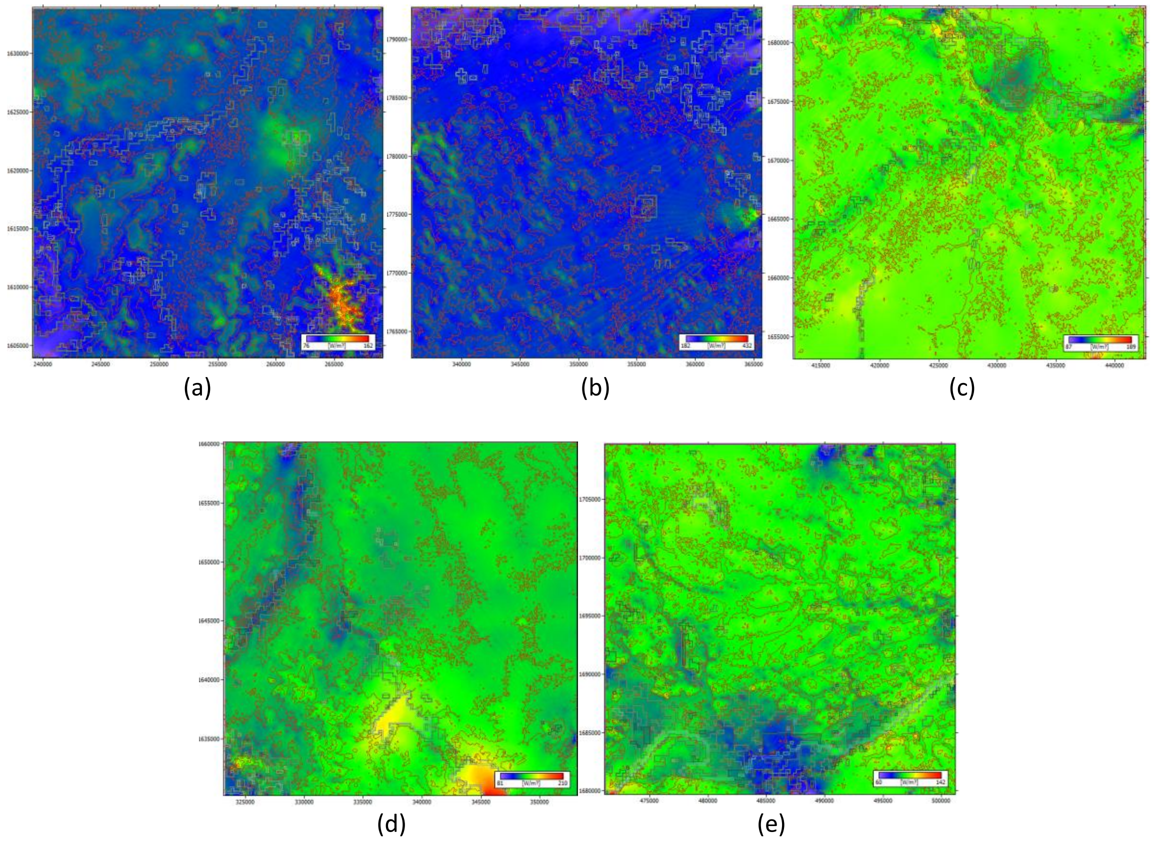

Fig. 13. High resolution map power density of 5 provinces a) Buri Ram, b) Roi Et, c) Sri Sa Ket d) Surin and e) Ubon Ratchathani

Table 8
Wind turbine generator specifications

Model	Rotor diameter	Hub height	Cut-in wind speed	Cut-out wind speed	Rated wind speed	Rated power	Power density
Vestas V52	52 m	60 m	4.0 m/s	25.0 m/s	14.0 m/s	850 kW	400.2 W/m^2
Vestas V90	90 m	80 m	4.0 m/s	25.0 m/s	13.0 m/s	2,000 kW	314.4 W/m^2

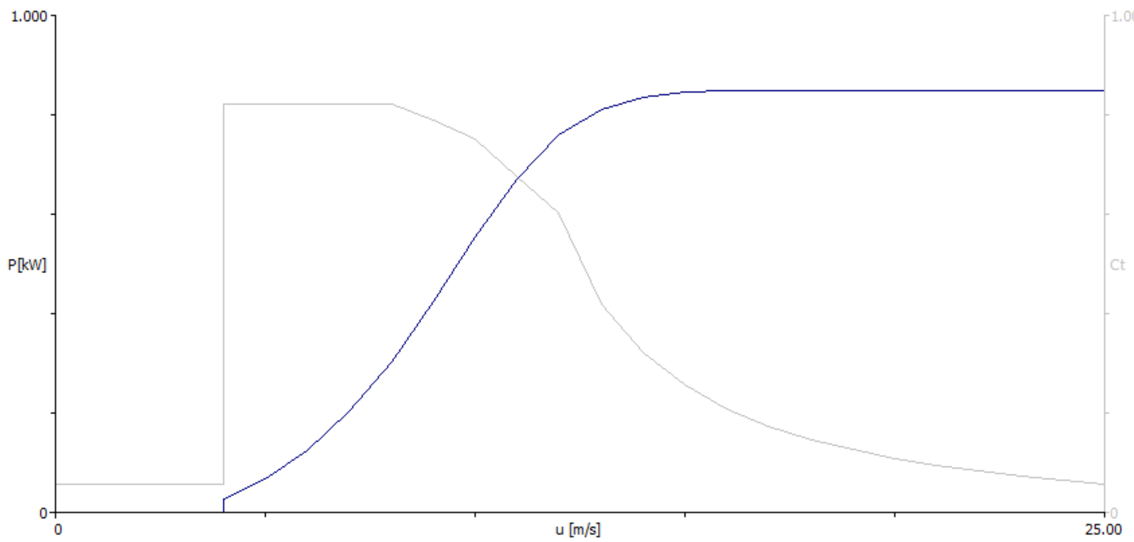

Fig. 14. Power curve of Vestas V52 turbine generator

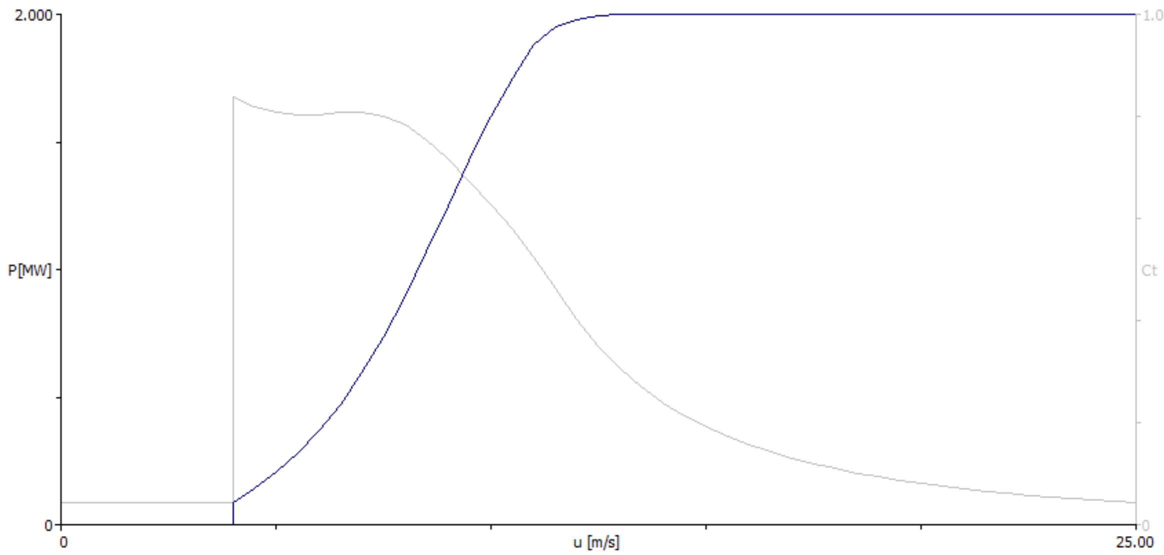

Fig. 15. Power curve of Vestas V90 turbine generator

Table 9 and 10 demonstrates the sector-wise Weibull parameters, mean wind speed, power density, and frequency of wind prevailing at 60 meters from Buri Ram. The most frequent wind prevailing was from 120° or the southeast (SE) side. The mean wind speed was 4.72 m/s and the power density was 128 W/m^2. Moreover, with the hub-height level at 80 meters, the most frequent wind prevailing was from the 120° or southeast (SE) side. The mean wind speed was 5.07 m/s and the power density was 151 W/m^2.

Table 9
Sector-wise wind statistics of wind farm site at Buri Ram at 60m

Angle[°]	0°	30°	60°	90 °	120°	150°	180°	210°	240 °	270°	300°	330°
f [%]	6.4	10.7	10.4	9.5	15.2	9.3	8.1	9.4	9.4	5	3.4	3.3
A [m/s]	4.8	7.2	6.6	5.2	5.3	3.5	3.5	4.8	6.2	5.7	4.1	3.7
K	1.85	2.04	1.94	1.75	1.78	1.66	1.61	1.7	1.69	1.43	1.39	1.58
U [m/s]	4.26	6.35	5.89	4.62	4.74	3.16	3.15	4.28	5.5	5.2	3.73	3.33
P [W/m^2]	89	268	224	122	128	42	43	100	214	230	88	52

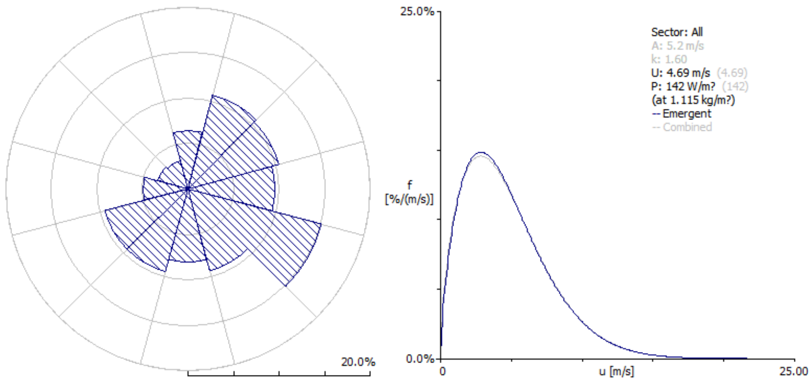

Fig. 16. Wind rose and Weibull distribution of wind farm site at Buri Ram at 60m

Table 10
Sector-wise wind statistics of wind farm site at Buri Ram at 80m

Angle[°]	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
f [%]	6.6	10.8	10.1	9.1	15.4	9.6	8.2	9.4	9.1	4.9	3.4	3.3
A [m/s]	5.2	7.6	7	5.5	5.7	3.8	3.8	5.1	6.5	6.1	4.4	4
K	1.91	2.12	2	1.8	1.85	1.71	1.66	1.76	1.75	1.47	1.44	1.63
U [m/s]	4.59	6.77	6.16	4.85	5.07	3.42	3.4	4.58	5.79	5.49	3.99	3.62
P [W/m^2]	108	312	249	136	151	51	52	117	239	256	102	64

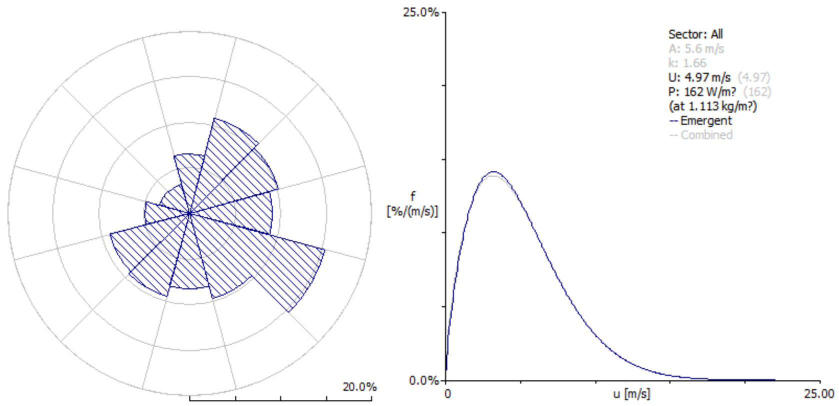

Fig. 17. Wind rose and Weibull distribution of wind farm site at Buri Ram at 80m

The net annual production (AEP) of a wind farm at Buri Ram, which consists of 12 wind turbine sites, is shown in Table 11 and 12. For the hub height level of the wind turbine at 60m, the mean wind speed (wake-reduced) and power density were 4.59 m/s and 138 W/m^2, respectively. The total capacity factor of the wind farm was 12.6%, which meant the total net AEP was 10.764 GWh. In addition, at the hub height level of the wind turbine at 80m, the mean wind speed (wake-reduced) and power density were 4.79 m/s and 159 W/m^2, respectively. The total capacity factor of the wind farm was 17.7%, which meant the total net AEP on average was 33.473 GWh.

Table 11
Statistical analysis at 60m of wind farm site at Buri Ram

Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	11.425	0.952	0.908	1.011
Total net AEP [GWh]	10.764	0.897	0.822	0.957
Proportional wake loss [%]	5.78	-	1.58	9.46
Capacity factor [%]	12.6	-	12	13.4
Mean speed [m/s]	-	4.69	4.61	4.8
Mean speed (wake-reduced) [m/s]	-	4.59	4.46	4.71
Air density [kg/m^3]	-	1.115	1.114	1.117
Power density [W/m^2]	-	138	130	148

Table 12
Statistical analysis at 80m of wind farm site at Buri Ram

Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	37.185	3.099	2.99	3.245
Total net AEP [GWh]	33.473	2.789	2.52	3.077
Proportional wake loss [%]	9.98	-	2.84	15.74
Capacity factor [%]	17.7	-	17.1	18.5
Mean speed [m/s]	-	4.98	4.91	5.08
Mean speed (wake-reduced) [m/s]	-	4.79	4.62	4.98
Air density [kg/m^3]	-	1.113	1.112	1.115
Power density [W/m^2]	-	159	151	169

Table 13 and 14 demonstrates the sector-wise Weibull parameters, mean wind speed, power density, and frequency of wind prevailing at 60 meters of Roi Et. The most frequent wind prevailing was from 60^o or northeast (NE) side. The mean wind speed was 8.25 m/s and the power density was 541 W/m^2. Moreover, the hub-height level at 80 meters, the most frequent wind prevailing was from 60^o or northeast (NE) side. The mean wind speed was 8.74 m/s and the power density was 624 W/m^2.

Table 13
Sector-wise wind statistics of wind farm site at Roi Et at 60m

Angle[^{o}]	0^o	30^o	60^o	90^o	120^o	150^o	180^o	210^o	240^o	270^o	300^o	330^o
f [%]	4	8.9	18.6	11.7	4.6	6.2	13.5	13.8	9.1	3.8	2.7	3.1
A [m/s]	4.6	7.4	9.3	7.4	4.1	4.8	6.1	6.7	8	6.3	5	4.7
K	1.72	1.98	2.26	2.01	1.75	1.87	2.15	2.48	2.65	2.17	1.57	1.58
U [m/s]	4.12	6.56	8.25	6.58	3.67	4.29	5.4	5.97	7.15	5.55	4.47	4.24
P [W/m^2]	89	308	541	307	62	92	158	191	313	171	128	108

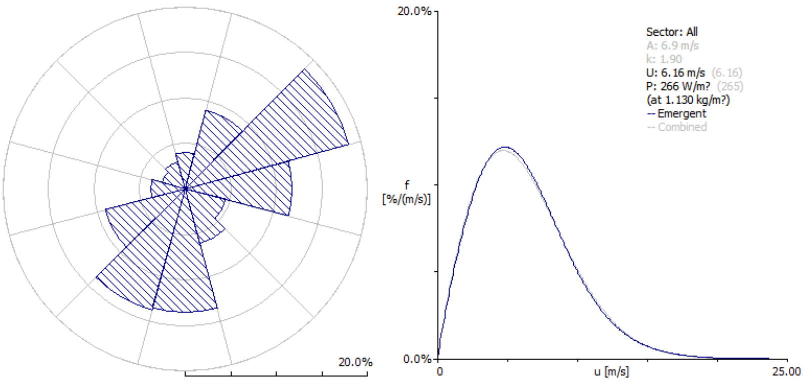

Fig. 18. Wind rose and Weibull distribution of wind farm site at Roi Et at 60m

Table 14
Sector-wise wind statistics of wind farm site at Roi Et at 80m

Angle[^{o}]	0^o	30^o	60^o	90^o	120^o	150^o	180^o	210^o	240^o	270^o	300^o	330^o
f [%]	4	8.8	18.7	11.7	4.6	6.2	13.5	13.8	9.1	3.8	2.7	3.1
A [m/s]	4.9	7.9	9.9	7.9	4.4	5.2	6.5	7.3	8.5	6.8	5.4	5.1
K	1.78	2.05	2.35	2.08	1.82	1.93	2.22	2.55	2.72	2.24	1.62	1.63
U [m/s]	4.4	6.97	8.74	7.04	3.93	4.6	5.77	6.52	7.59	5.98	4.8	4.54
P [W/m^2]	104	357	624	362	73	109	188	243	367	207	152	127

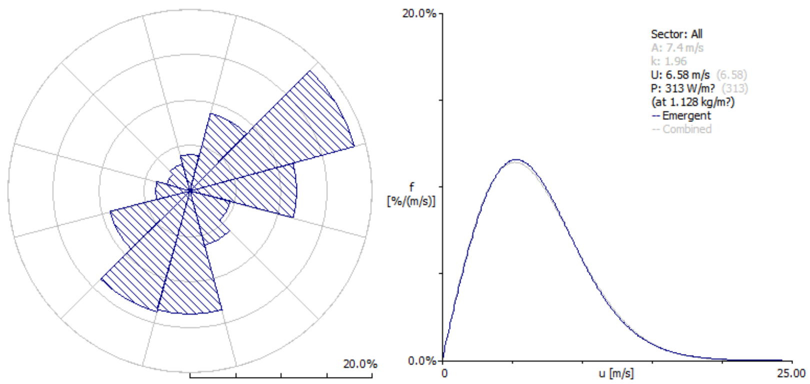

Fig. 19. Wind rose and Weibull distribution of wind farm site at Roi Et at 80m

The net annual production (AEP) of a wind farm at Roi Et, which consists of 12 wind turbine sites, is shown in Table 15 and 16. For the hub height level of the wind turbine at 60m, the mean wind speed (wake-reduced) and power density were 5.95 m/s and 265 W/m^2, respectively. The total capacity factor of the wind farm was 22.8%, which meant the total net AEP was 18.932 GWh. In addition, at the hub height level of the wind turbine at 80m, the mean wind speed (wake-reduced) and power density were 6.15 m/s and 311 W/m^2, respectively. The total capacity factor of the wind farm was 31.1%. The consequence of the total net AEP was 56.322 GWh.

Table 15
Statistical analysis at 60m of wind farm site at Roi Et

Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	20.662	1.722	1.634	1.84
Total net AEP [GWh]	18.932	1.578	1.414	1.702
Proportional wake loss [%]	8.37	-	0.99	17.41
Capacity factor [%]	22.8	-	21.7	24.4
Mean speed [m/s]	-	6.16	6.02	6.32
Mean speed (wake-reduced) [m/s]	-	5.95	5.72	6.13
Air density [kg/m^3]	-	1.131	1.13	1.131
Power density [W/m^2]	-	265	250	285

Table 16
Statistical analysis at 80m of wind farm site at Roi Et

Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	65.5	5.458	5.255	5.716
Total net AEP [GWh]	56.322	4.693	3.953	5.152
Proportional wake loss [%]	14.01	-	2	27.37
Capacity factor [%]	31.1	-	30	32.6
Mean speed [m/s]	-	6.56	6.45	6.7
Mean speed (wake-reduced) [m/s]	-	6.15	5.75	6.41
Air density [kg/m^3]	-	1.129	1.128	1.129
Power density [W/m^2]	-	311	296	329

Table 17 and 18 demonstrates the sector-wise Weibull parameters, mean wind speed, power density, and frequency of wind prevailing at 60 meters from Sri Sa Ket. The most frequent wind prevailing was from 30^o or north north-east (NNE) side. The mean wind speed was 6.63 m/s and the power density was 271 W/m^2. Moreover, with the hub-height level at 80 meters, the most frequent wind prevailing was from 30^o or north north-east (NNE) side. The mean wind speed was 7.48 m/s and the power density was 349 W/m^2.

Table 17
Sector-wise wind statistics of wind farm site at Sri Sa Ket at 60m

Angle[°]	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
f [%]	5.2	15.5	14.6	5.2	4.7	8.4	9	12.1	11.9	6	4.1	3.4
A [m/s]	4	7.8	7.5	4.1	3	3.4	3.4	5.1	6.3	5.8	5	3.6
K	1.65	2.69	2.38	1.59	1.52	1.57	1.71	1.96	2.22	2.01	1.58	1.44
U [m/s]	3.56	6.95	6.63	3.65	2.7	3.08	3.06	4.55	5.58	5.16	4.47	3.27
P [W/m^2]	61	286	271	69	30	42	37	104	170	148	128	57

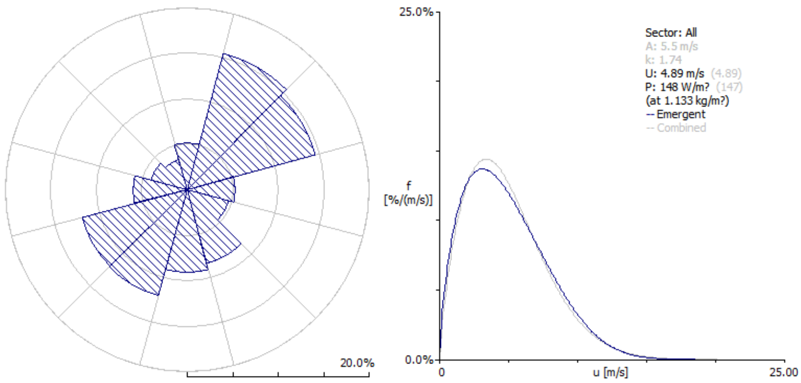

Fig. 20. Wind rose and Weibull distribution of wind farm site at Sri Sa Ket at 60m

Table 18
Sector-wise wind statistics of wind farm site at Sri Sa Ket at 80m

Angle[°]	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
f [%]	5.1	15.3	14.7	5.3	4.7	8.4	8.9	12	12	6	4.1	3.4
A [m/s]	4.2	8.4	8	4.5	3.2	3.7	3.7	5.5	6.8	6.3	5.4	3.8
K	1.7	2.77	2.46	1.64	1.57	1.62	1.77	2.02	2.3	2.07	1.63	1.48
U [m/s]	3.73	7.48	7.13	4.01	2.91	3.3	3.26	4.85	5.99	5.57	4.82	3.45
P [W/m^2]	67	349	328	88	35	50	43	122	205	180	153	65

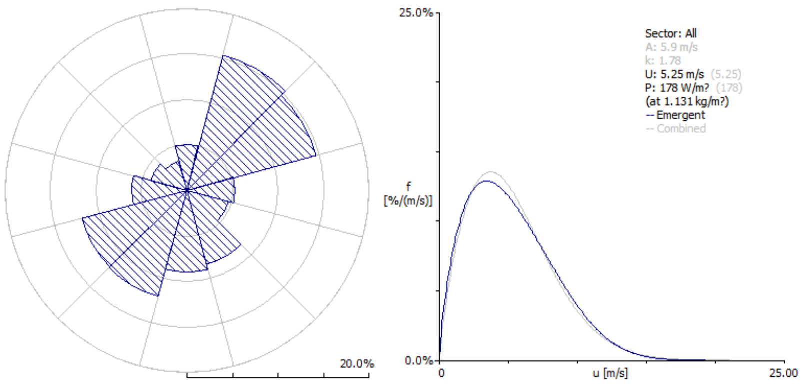

Fig. 21. Wind rose and Weibull distribution of wind farm site at Sri Sa Ket at 80m

The net annual production (AEP) of a wind farm at Sri Sa Ket, which consists of 12 wind turbine sites, is shown in Table 19 and 20. For the hub height level of the wind turbine at 60m, the mean wind speed (wake-reduced) and power density were 4.81 m/s and 147 W/m^2, respectively. The total capacity factor of the wind farm was 14.1%, which meant the total net AEP was 12.152 GWh. In addition, at the hub height level of the wind turbine at 80m, the mean wind speed (wake-reduced) and power density were 5.0 m/s and 176 W/m^2, respectively. The total capacity factor of the wind farm was 18.6%, which meant the total net AEP was 45.737 GWh.

Table 19
Statistical analysis at 60m of wind farm site at Sri Sa Ket

Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	12.784	1.065	1.02	1.108
Total net AEP [GWh]	12.152	1.013	0.931	1.058
Proportional wake loss [%]	4.94	-	0.55	11.46
Capacity factor [%]	14.1	-	13.5	14.7
Mean speed [m/s]	-	4.89	4.83	4.95
Mean speed (wake-reduced) [m/s]	-	4.81	4.69	4.86
Air density [kg/m^3]	-	1.133	1.133	1.134
Power density [W/m^2]	-	147	140	155

Table 20
Statistical analysis at 80m of wind farm site at Sri Sa Ket

Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	50.979	4.248	4.108	4.354
Total net AEP [GWh]	45.737	3.811	3.29	4.116
Proportional wake loss [%]	10.28	-	1.66	22.32
Capacity factor [%]	18.6	-	18	19.1
Mean speed [m/s]	-	5.24	5.19	5.29
Mean speed (wake-reduced) [m/s]	-	5	4.75	5.14
Air density [kg/m^3]	-	1.131	1.131	1.132
Power density [W/m^2]	-	176	169	182

Table 21 and 22 demonstrates the sector-wise Weibull parameters, mean wind speed, power density, and frequency of prevailing wind at 60 meters of Surin. The most frequent wind prevailing was from 150^o or south-south-east (SSE) side, which had the mean wind speed was 5.75 m/s and the power density was 198 W/m^2. Moreover, the hub-height level at 80 meters, the most frequent wind prevailing was from 150^o or south-south-east (SSE) side. The mean wind speed was 6.08 m/s and the power density was 230 W/m^2.

Table 21
Sector-wise wind statistics of wind farm site at Surin at 60m

Angle[^{o}]	0^o	30^o	60^o	90^o	120^o	150^o	180^o	210^o	240^o	270^o	300^o	330^o
f [%]	6.5	13.8	8.7	5.9	8.1	16.7	11.9	10.8	6.1	4.3	3.4	3.7
A [m/s]	5.2	7.2	6.4	4.6	4.8	6.5	5.6	6.2	5.8	4.8	4.1	3.5
K	1.96	2.15	2.12	1.86	1.87	2.08	2.06	2.05	1.98	1.72	1.53	1.58
U [m/s]	4.64	6.41	5.67	4.13	4.26	5.75	4.93	5.51	5.1	4.24	3.65	3.16
P [W/m^2]	110	266	187	82	90	198	126	176	144	98	73	45

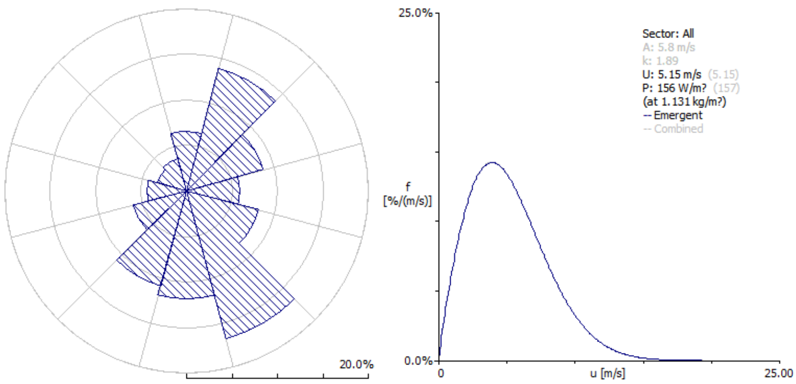

Fig. 22. Wind rose and Weibull distribution of wind farm site at Surin at 60m

Table 22
Sector-wise wind statistics of wind farm site at Surin at 80m

Angle[°]	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
f [%]	6.5	13.8	8.7	5.9	8.1	16.7	11.9	10.8	6.1	4.3	3.4	3.7
A [m/s]	5.6	7.8	6.9	5	5.1	6.9	5.9	6.5	6	5.1	4.4	3.8
K	2.02	2.22	2.19	1.92	1.93	2.11	2.1	2.11	2.04	1.77	1.58	1.63
U [m/s]	4.99	6.89	6.11	4.44	4.55	6.08	5.18	5.79	5.34	4.55	3.95	3.4
P [W/m^2]	133	321	225	99	106	230	143	198	161	116	88	54

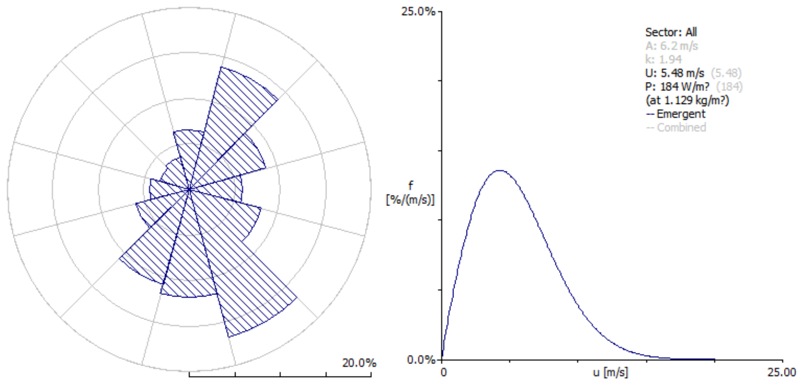

Fig. 23. Wind rose and Weibull distribution of wind farm site at Surin at 80m

The net annual production (AEP) of a wind farm at Surin, which consists of 12 wind turbine sites, is shown in Table 23 and 24. For the hub height level of the wind turbine at 60m, the mean wind speed (wake-reduced) and power density were 5.07 m/s and 156 W/m^2, respectively. The total capacity factor of the wind farm was 15%, which had a total net AEP of 12.969 GWh. In addition, at the hub height level of the wind turbine at 80m, the mean wind speed (wake-reduced) and power density were 5.32 m/s and 184 W/m^2, respectively. The total capacity factor of the wind farm was 21.3%, which had a total net AEP of 41.189 GWh.

Table 23
Statistical analysis at 60m of wind farm site at Surin

Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	13.535	1.128	1.11	1.142
Total net AEP [GWh]	12.969	1.081	1.058	1.105
Proportional wake loss [%]	4.18	-	0.75	5.6
Capacity factor [%]	15	-	14.7	15.1
Mean speed [m/s]	-	5.15	5.11	5.18
Mean speed (wake-reduced) [m/s]	-	5.07	5.03	5.12
Air density [kg/m^3]	-	1.131	1.131	1.131
Power density [W/m^2]	-	156	154	158

Table 24
Statistical analysis at 80m of wind farm site at Surin

Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	44.764	3.73	3.656	3.79
Total net AEP [GWh]	41.189	3.432	3.325	3.658
Proportional wake loss [%]	7.99	-	1.35	10.47
Capacity factor [%]	21.3	-	20.9	21.6
Mean speed [m/s]	-	5.49	5.44	5.52
Mean speed (wake-reduced) [m/s]	-	5.32	5.25	5.45
Air density [kg/m^3]	-	1.129	1.129	1.129
Power density [W/m^2]	-	184	180	187

Table 25 and 26 demonstrates the sector-wise Weibull parameters, mean wind speed, power density, and frequency of wind prevailing at 60 meters from Ubon Ratchathani. The most frequent wind prevailing was from 30^o or north-north-east (NNE) side. The mean wind speed was 5.04 m/s and the power density was 126 W/m^2. Moreover, with the hub-height level at 80 meters, the most frequent wind prevailing was from 30^o or north-north-east (NNE) side. The mean wind speed was 5.38 m/s and the power density was 149 W/m^2.

Table 25
Sector-wise wind statistics of wind farm site at Ubon Ratchathani at 60m

Angle[^{o}]	0^o	30^o	60^o	90^o	120^o	150^o	180^o	210^o	240^o	270^o	300^o	330^o
f [%]	11.3	15.9	7.6	5.7	7.6	12.7	9.4	8.2	8.1	5.2	4.5	3.7
A [m/s]	5.2	5.7	4.9	4.7	4.7	5	4.6	5.5	6.6	5.7	6.3	4.2
K	2.01	2.22	1.81	2.05	2.26	2.21	2.26	2.54	2.49	2.23	2.21	1.74
U [m/s]	4.58	5.04	4.33	4.13	4.16	4.39	4.09	4.86	5.87	5.07	5.55	3.71
P [W/m^2]	103	126	98	75	70	84	67	102	182	128	169	65

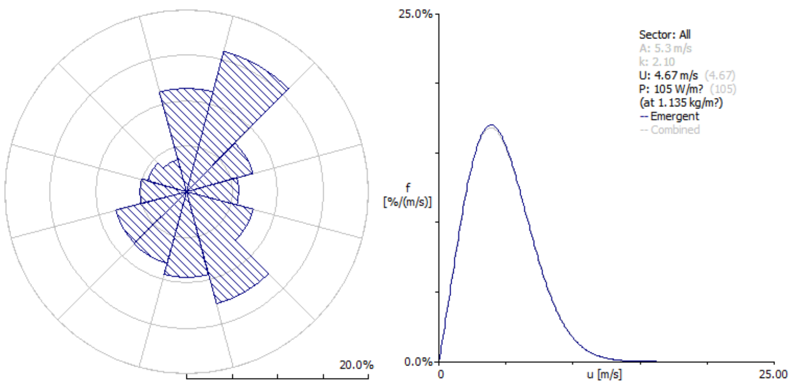

Fig. 24. Wind rose and Weilbull distribution of wind farm site at Ubon Ratchathani at 60m

Table 26
Sector-wise wind statistics of wind farm site at Ubon Ratchathani at 80m

Angle[^{o}]	0^o	30^o	60^o	90^o	120^o	150^o	180^o	210^o	240^o	270^o	300^o	330^o
f [%]	11.3	16	7.6	5.7	7.5	12.7	9.4	8.2	8.1	5.2	4.4	3.7
A [m/s]	5.6	6.1	5.2	5	5	5.3	5	5.9	7	6.1	6.7	4.5
K	2.08	2.28	1.87	2.12	2.33	2.28	2.33	2.62	2.55	2.3	2.28	1.79
U [m/s]	4.98	5.38	4.64	4.42	4.45	4.7	4.39	5.23	6.22	5.42	5.94	3.98
P [W/m^2]	129	149	116	89	83	100	80	124	212	152	201	77

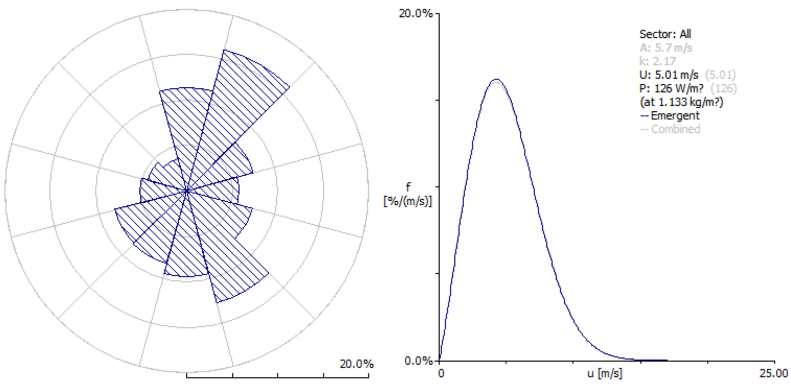

Fig. 25. Wind rose and Weilbull distribution of wind farm site at Ubon Ratchathani at 80m

The net annual production (AEP) of a wind farm at Ubon Ratchathani consists of 12 wind turbine sites, as shown in Table 27 and 28. For the hub height level of the wind turbine at 60m, the mean wind speed (wake-reduced) and power density were 4.53 m/s and 105 W/m^2, respectively. The total capacity factor of the wind farm was 10.5%, which had a total net AEP of 8.508 GWh. In addition, at the hub height level of the wind turbine at 80m, the mean wind speed (wake-reduced) and power density were 4.72 m/s and 125 W/m^2, respectively. The total capacity factor of the wind farm was 15.7%. The consequence of the total net AEP was 27.524 GWh.

Table 27
Statistical analysis at 60m of wind farm site at Ubon Ratchathani

Variable	Total	Mean	Min	Max
Total gross AEP [MWh]	9491.367	790.947	760.741	812.481
Total net AEP [MWh]	8508.426	709.036	669.745	737.046
Proportional wake loss [%]	10.36	-	4.33	15.65
Capacity factor [%]	10.5	-	10.1	10.8
Mean speed [m/s]	-	4.67	4.62	4.71
Mean speed (wake-reduced) [m/s]	-	4.53	4.47	4.57
Air density [kg/m^3]	-	1.135	1.134	1.135
Power density [W/m^2]	-	105	101	108

Table 28
Statistical analysis at 80m of wind farm site at Ubon Ratchathani

Variable	Total	Mean	Min	Max
Total gross AEP [GWh]	33.027	2.752	2.665	2.815
Total net AEP [GWh]	27.524	2.294	2.074	2.477
Proportional wake loss [%]	16.66	-	7.04	25.18
Capacity factor [%]	15.7	-	15.2	16.1
Mean speed [m/s]	-	5	4.95	5.03
Mean speed (wake-reduced) [m/s]	-	4.72	4.58	4.84
Air density [kg/m^3]	-	1.133	1.132	1.133
Power density [W/m^2]	-	125	120	128

3.3 Economic Analysis

An economic analysis will be performed to demonstrate the cost per unit of electricity generated to comply with consumer affordability and can demonstrate the benefits of investment to reduce the risk of investment. The value of land used, wind turbine costs, grid-connected costs, construction costs, and other capital costs were used in the study.

Table 29
The economic analysis of wind farm around the study station

	Wind farm at Buri Ram		Wind farm at Roi Et		Wind farm at Sri Sa Ket		Wind farm at Surin		Wind farm at Ubon Ratchathani	
	Vestas V52	Vestas V90	Vestas V52	Vestas V90	Vestas V52	Vestas V90	Vestas V52	Vestas V90	Vestas V52	Vestas V90
(1)	20	20	20	20	20	20	20	20	20	20
(2)	850	2,000	850	2,000	850	2,000	850	2,000	850	2,000
(3)	12	12	12	12	12	12	12	12	12	12
(4)	60	80	60	80	60	80	60	80	60	80
(5)	243,000	432,000	388,800	691,200	648,000	1,152,000	324,000	576,000	648,000	1,152,000
(6)	1,408,981.25	3,315,250	1,408,981.25	3,315,250	1,408,981.25	3,315,250	1,408,981.25	3,315,250	1,408,981.25	3,315,250
(7)	217,493.75	511,750	217,493.75	511,750	217,493.75	511,750	217,493.75	511,750	217,493.75	511,750
(8)	264,775	623,000	264,775	623,000	264,775	623,000	264,775	623,000	264,775	623,000
(9)	32,241,580	75,488,000	32,649,820	76,213,760	33,375,580	77,504,000	32,468,380	75,891,200	33,375,580	77,504,000
(10)	10.674	33.437	18.932	56.322	12.152	45.737	12.969	41.189	8.508	27.524
(11)	0.15	0.11	0.09	0.07	0.14	0.09	0.13	0.09	0.2	0.14

Note
(1) Wind farm life time (year)
(2) Wind turbine rated power (kW)
(3) Number of wind turbine (unit)
(4) Hub-height (meter)
(5) Land used value (USD)
(6) Wind turbine initial cost (USD)
(7) Grid connection cost (USD)
(8) O & M cost (USD)
(9) Total investment cost (USD)
(10) Annual electricity generated (GWh)
(11) Per unit electricity price (USD/kWh)

Economic analysis has indicated that the return of investment in each wind farm station under the condition of an interest rate of 4%, additional with feed-in-tariff at the price of 0.202 $/kWh. The economic possibility of investing in wind farms was possible, with a positive B/C ratio, NPV, and IRR at all stations except Ubon Ratchathani, at a height of 60 meters above ground level. In addition, Roi Et province had the highest mean wind speed, with a mean wind speed of 5.95 m/s at a height of 60 meters above the ground level and 6.15 m/s at a height of 80 meters above the ground level, resulting in electricity generation at a cost per unit of $0.09/kWh and $0.07/kWh respectively. For Buri Ram province, costs per unit for electricity generation were $0.15/kWh and $0.11/kWh at heights of 60 and 80 meters respectively. Si Sa ket province's costs per unit for electricity generation were $0.14/kWh and $0.09/kWh at heights of 60 and 80 meters respectively. Surin province's costs per unit for electricity generation were $0.13/kWh and $0.09/kWh at 60 and 80 meters respectively, and this province had a high economic value considered with the economic indicator. Therefore, Surin is one of the other provinces that had high economic feasibility after Roi Et. Finally, Ubon Ratchathani had been considered to be the province with the lowest economic feasibility. This province was unsuitable for wind farm investment due to low mean wind speed and high production costs, with costs of $0.2/kWh and $0.14/kWh at highs of 60 and 80 meters respectively.

4. Conclusions

The result of the study in 5 stations during 4 years of wind speed data collection at 10m above ground level has demonstrated that the mean speed value and power density of Buri Ram were 2.67 m/s and 35 W/m^2, Roi Et were 3.96 m/s and 92 W/m^2, Sri Sa Ket were 3.38 m/s and 66 W/m^2, Surin were 3.05 m/s and 43 W/m^2, and last, Ubon Ratchathani were 2.93 m/s and 34 W/m^2, respectively. The consequence was that the mean wind speed of each station was lower than the average cut-in wind speed for the wind turbine. Therefore, this study has continued to study at 60m and 80m hub-height above ground level, using WAsP software to extrapolate wind speeds for different hub heights. Figures 12-13 illustrate the mean wind speed and power density of the area around the study stations as criteria for wind farm selection site. Vestas V52-850 kW and Vestas V90-2,000 kW are turbine generators that will be installed to calculate the annual energy production at the wind farm sites. The result showed the wind farm site of each station at a hub height of 60m had a wind speed and power density of 4.59 m/s and 138 W/m^2 for Buri Ram, 5.95 m/s and 265 W/m^2 for Roi Et, 4.81 m/s and 147 W/m^2 for Sri Sa Ket, 5.07 m/s and 156 W/m^2 for Surin, 4.53 m/s and 105 W/m^2 for Ubon Ratchathani. Therefore, the AEP generated 10.674 GWh, 18.932 GWh, 12.152 GWh, 12.969 GWh, and 8.508 GWh respectively at each station. The result of the mean wind speed and power density of each station at 80m were 4.79 m/s and 159 W/m^2 for Buri Ram, 6.15 m/s and 311 W/m^2 for Roi Et, 5.0 m/s and 176 W/m^2 for Sri Sa Ket, 5.31 m/s and 184 W/m^2 for Surin, and 4.72 m/s and 125 W/m^2 for Ubon Ratchathani. At this hub-height, each wind farm site has generated an AEP of 33.437 GWh, 56.322 GWh, 45.737 GWh, 41.189 GWh, and 27.524 GWh respectively. For the economic feasibility of investment, table 29 demonstrated the cost of production and per-unit cost of energy generation that showed all of the wind farm sites in each province were economically feasible for investment except the wind farm site in Ubon Ratchathani province at 60m due to the negative economic indicators that resulted from low mean wind speed and high cost of production. Finally, the wind farm site in Roi Et province, from the results of annual energy production and economic feasibility, was indicated to be the most suitable wind farm site for investment.

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