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Research article

Optimal Wind Power Plant Layout Using Ant Colony Optimization

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Abstract: The optimal layout of wind power plants is very important as the arrangement of wind turbine generators (WTGs) profoundly affects the overall energy output of the wind power plant. To address this important issue, this research investigates the best layout for WTGs in wind power plants with different terrain features across three locations in Thailand using the Ant Colony Optimization (ACO) algorithm. The objective functions of maximizing the net annual energy production (AEP) and minimizing the wake losses were used to achieve the optimal wind power plant layout. Using the MERRA-2 database, computational fluid dynamics (CFD) wind flow modeling was performed to create 10x10 km^2 microscale wind resource maps of locations characterized by flat, semi-complex, and complex terrains to install wind power plants. The CFD wind flow modeling yielded wind speeds of 5.00 to 5.76, 4.21 to 8.90, and 3.10 to 4.45 m/s for the flat, semi-complex, and complex terrains, respectively, making them feasible for utility-scale wind power plants. WTGs of multiple blade diameters, ranging from 90 to 126 m, with a nominal capacity of 2.5 MW at 100 m above ground-level hub heights, were used in this study. The Gamesa G126-2.5MW WTG with a 126 m blade diameter produces the highest net AEP of 14.3, 76.1, and 38.9 GWh/yr for the three terrains. Hence, this WTG was used to perform an ACO-based optimization to improve the electricity production of the wind power plants. Such studies are important to improve the efficiency of wind power plants, thus extracting the maximum kinetic energy possible from the winds and improving the economic viability of wind power plants.

Keywords: Wind power plant; wind turbine generator; ant colony optimization; annual energy production; wake loss.

1. Introduction

With growing energy demand, concerns regarding global warming are also rising as most of our energy demand is met by burning greenhouse gas (GHG) emitting fossil fuels. Replacing fossil fuels with renewable sources is one of the most effective methods to combat the rising energy demand without polluting our environment. The adoption of renewable energy is on the fast track, resulting in sources like wind becoming more common worldwide. The Global Wind Energy Council (GWEC) reports 93.7 GW of new wind energy installation in 2021, bringing the total global wind energy capacity to 837 GW, an increase of 12.4 % from 2020 [1]. For its part, Thailand heavily relies on fossil fuels to meet its rising energy demand [2]. However, the country has ambitious plans to diversify its energy mix by developing renewable energy sources.

Thailand’s Alternative Energy Development Plan 2018-2037 (AEDP2018) will be the major roadmap for developing its energy sector. According to this plan, Thailand will have an installed capacity of 29,411 MW of renewable and alternative energy by 2037, of which 2,989 MW must come from wind energy [3]. Throughout the country, Thailand has nominal wind speeds averaging 4 to 5 m/s at 90 m above ground level (agl) [4]. However, specific locations in the country have sufficient wind resources to develop wind power. In parts of the Northeast, particularly near the Korat Plateau's edge and along the coast of Nakhon Si Thammarat Province, the relatively high wind speeds offer good wind energy development opportunities [5–7]. In addition, the central regions of the country along the Gulf of Thailand and the Andaman Sea also have relatively high wind energy development potentials [8-9]. The bay of Bangkok in the Gulf of Thailand has good wind speeds of 5.5-6.5 m/s at multiple heights simulated using CFD and Weather Research and Forecasting (WRF) atmospheric models offering wind energy production capacities ranging from 6,000-80,000 MW using different WTGs [10]. Using CFD wind flow modeling at multiple elevations, the wind potential of the Southernmost region of Thailand is assessed, resulting in a wind potential of 300 MW able to generate 690 GWh/year of electricity [11] A detailed wind resource mapping of the Nakhon Si Thammarat and Songkhla provinces in southern Thailand yielded a wind power generation protentional of 1,374 MW at 80 m agl and a 407 MW of wind energy using small wind turbines [12]. Finally, some studies even estimate the onshore wind energy potential of Thailand between 13 to 17 GW if given the proper regulatory and policy attention [13]. These studies suggest that Thailand has good onshore wind energy potential that can be developed to increase its renewable energy share in energy production. However, considering the social challenges faced by onshore wind energy developments, there should be a high emphasis on increasing the energy output from individual wind power plants and thus minimizing their numbers.

Wind power plants often cause visual and noise disturbances for residents living nearby [14]. Large wind turbines can cause significant visual disturbances and are facing increasing opposition from the public, especially from people living in highly aesthetic-valued areas [15]. With these factors influencing the development of new wind power plants, it is important to increase the energy output from the wind power plant to reduce the need for new wind power plant developments and to extract the maximum energy possible. One way of doing it is to improve the layout of the wind power plant by optimally arranging the WTGs since their wake significantly affects the overall energy output of the wind power plant.

Many studies have used various methods to design wind power plant layouts. Yang et al. [16] optimized the layout of a wind power plant to improve the energy output using the Simulated Annealing algorithm. Chen et al. [17] applied a Greedy algorithm to reduce the wake effect of multiple hub height WTGs on flat and complex terrains. Finally, using the objective function of levelized costs of energy (LCOE), multiple deterministic algorithms have been used to design optimal wind power plant layouts to reduce the LCOE in the presence of wake effects [18].

In this study, the layouts of the Pak Phanang Wind Farm, the Lamtakong Wind Farm, and the Romklao Wind Farm were optimized to increase the net AEP and to reduce the wake effects using the Ant Colony Optimization (ACO) algorithm. This study contributes to developing methodologies to improve the energy outputs from wind power plants and their economic efficiencies.

2. Materials and Methods

2.1 Study area

The terrains in Thailand are classified into five classes by the National Terrain Classification System (NTCS), as summarized in Table 1. This study considers three slope categories: flat, semi-complex, and complex terrains, as shown in Table 2, with their respective slope gradients.

Table 1. Slope classes are defined by the National Terrain Classification System (NTCS) of Thailand.

Slope Class	Gradient (%)
1	0 – 12
2	13 – 20
3	21 – 35
4	36 – 50
5	51+

Table 2. Practical slope descriptions.

Slope Class	Gradient (%)
Flat	0 – 20
Semi-complex	21 – 35
Complex	35+

Three wind power plant sites are studied (Fig. 1) to optimize their layout using the AOC algorithm. The Pak Phanang Wind Farm, located in southern Nakhon Si Thammarat province, has a flat terrain with a 3.73% slope gradient. The Lamtakong Wind Farm, situated in northeastern Nakhon Ratchasima province, has a semi-complex terrain with a 21.2% slope gradient. Finally, the Romklao Wind Farm, located in central Mukdaharn province, has a complex terrain with a 44.63% slope gradient.

2.2 Wind data

The wind data is a key component for the wind energy assessment of an area. This study used the MERRA-2 long-term wind database from 1985–2015 to generate virtual met masts (VMM). The MERRA-2 database presents wind speed and direction 50 m above ground level (agl). The positions of the three VMMs used in this study are given in Table 3. The average wind speeds for these VMM, based on the MERRA-2 wind database, are 4.21 m/s for the Pak Phanang Wind Farm, 4.34 m/s for the Lamthakong Wind Farm, and 4.23 m/s for the Romkhlao Wind Farm. The Weibull distribution analysis, presented in Fig. 2, reveals that the shape parameter (k) and the scale parameter (A) were as follows: Pak Phanang Wind Farm, k=2.686, A=4.738 m/s; Lamthakong Wind Farm, k=2.737, A=4.88 m/s; and Romkhlao Wind Farm, k=2.652, A=4.763 m/s.

2.3 Microscale wind resource map

Microscale wind resource maps are used to evaluate the technical power potential of the wind resources over the areas studied. CFD modeling was performed using the digital elevation model (DEM) presented in Fig. 3, roughness indices, and the wind data from the VMM for each site to determine the wind speeds within the domain of the three areas studied. These microscale wind resource maps were created using ArcGIS V10.2 with a spatial resolution of 90 m.

Table 3. The geographical position of three virtual met masts (VMM).

Wind Power Plant	Positions	Coordinate	
		Latitude	Longitude
Pak Phanang Wind Farm	Pak Phanang District, Nakhon Si Thammarat Province	8° 23' 13.71'' N	100° 14' 5.4'' E
Lamtakong Wind Farm	Sikhio District, Nakhon Ratchasima Province	14° 49' 0.2'' N	101° 33' 33.3'' E
Romkhlao Wind Farm	Nikhom Kham Soi District, Mukdahan Province	16° 22' 49.2'' N	104° 24' 51.1'' E

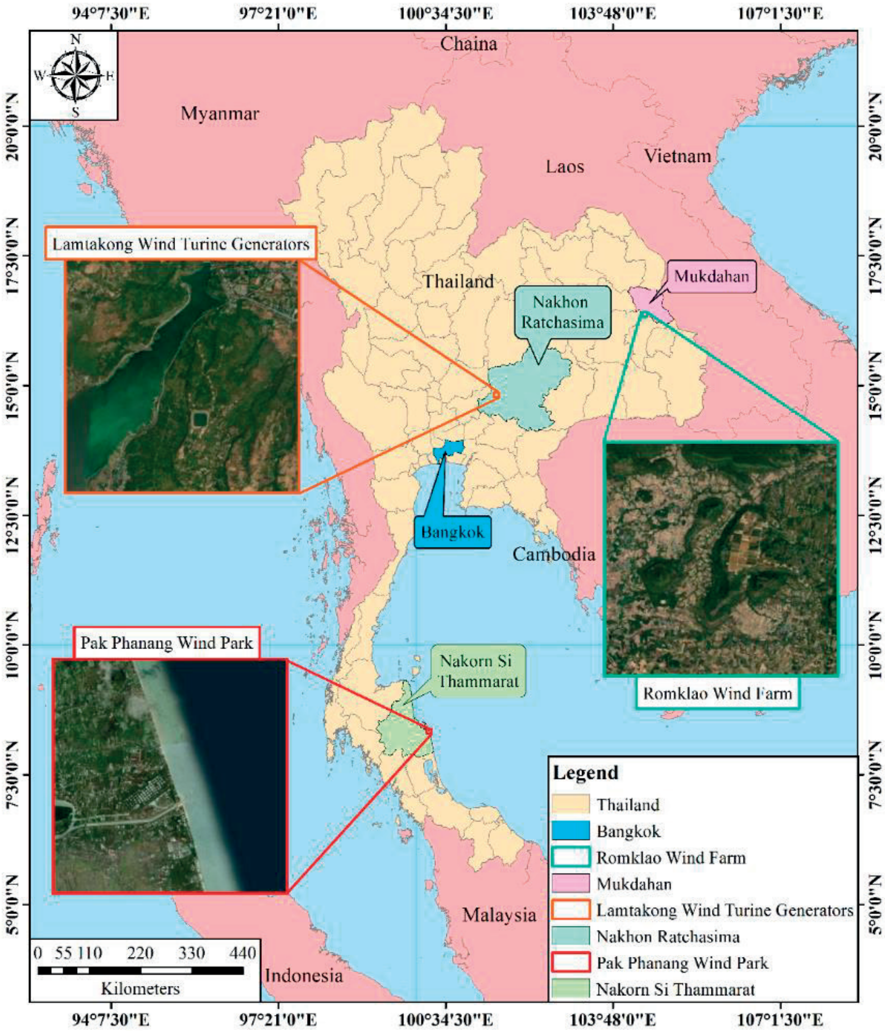

Figure 1. The Pak Phanang Wind Farm, the Lamtakong Wind Farm, and the Romklao Wind Farm.

2.4 Wind turbine generator

Multiple WTGs with a rated power of 2.5 MW and having different rotor diameters were tested in this study to find the optimal WTG to maximize the AEP and minimize the wake losses. The characteristics of the WTGs studied are presented in Table 4. Each WTG has a unique power curve, with power characteristics based on the cut-in wind speed (c_i), the cut-out wind speed (c_o), and the rated wind speed (v_{tated}). It is shown in Fig. 4.

Table 4. Characteristics of the wind turbine generators studied.

Hub Height (m)	Manufacturer/Model	Rated Power (MW)	Rotor Diameter (m)	Cut-in Speed (m/s)	Cut-out Speed (m/s)
100	Nordex N90/2500	2.5	90	3.0	25.0
100	Fuhrländer FL 2500/100	2.5	100	3.5	25.0
100	General Electric GE 2.5-103	2.5	103	3.0	25.0
100	FWT 104/2500	2.5	104	3.0	25.0
100	Gamesa G126-2.5MW	2.5	126	2.0	21.0

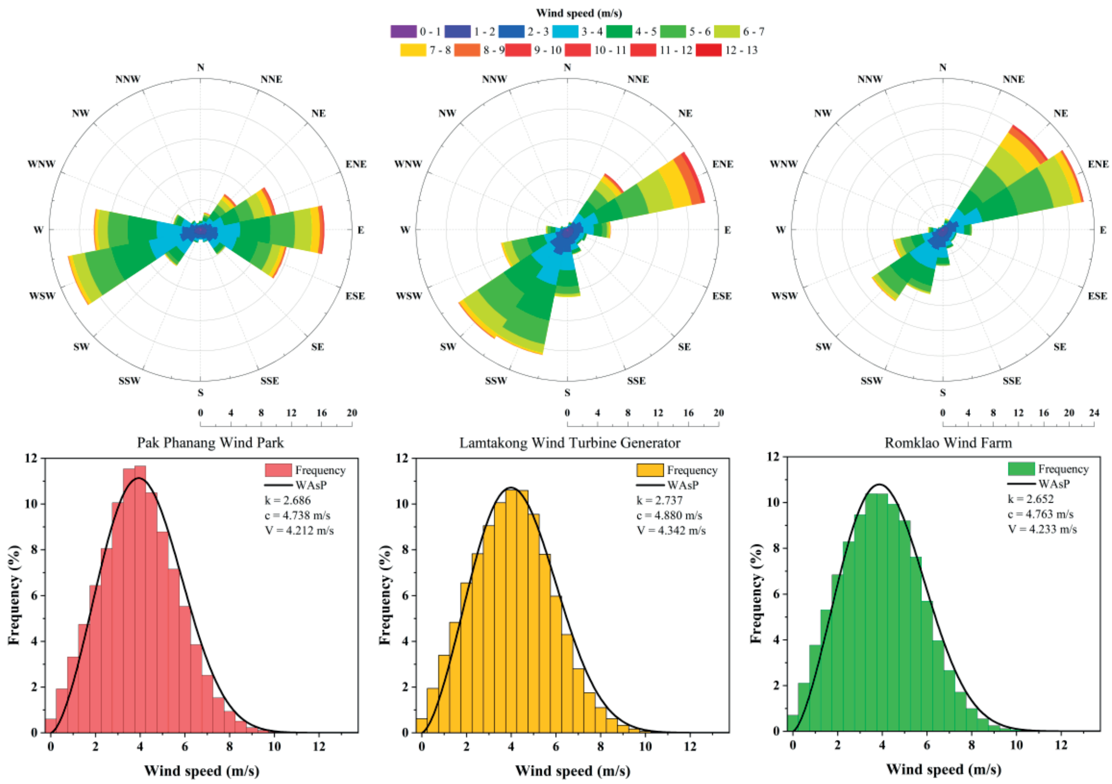

Figure 2. The wind roses and Weibull distributions at an elevation of 50 m agl based on the MERRA-2 database for the three sites studied.

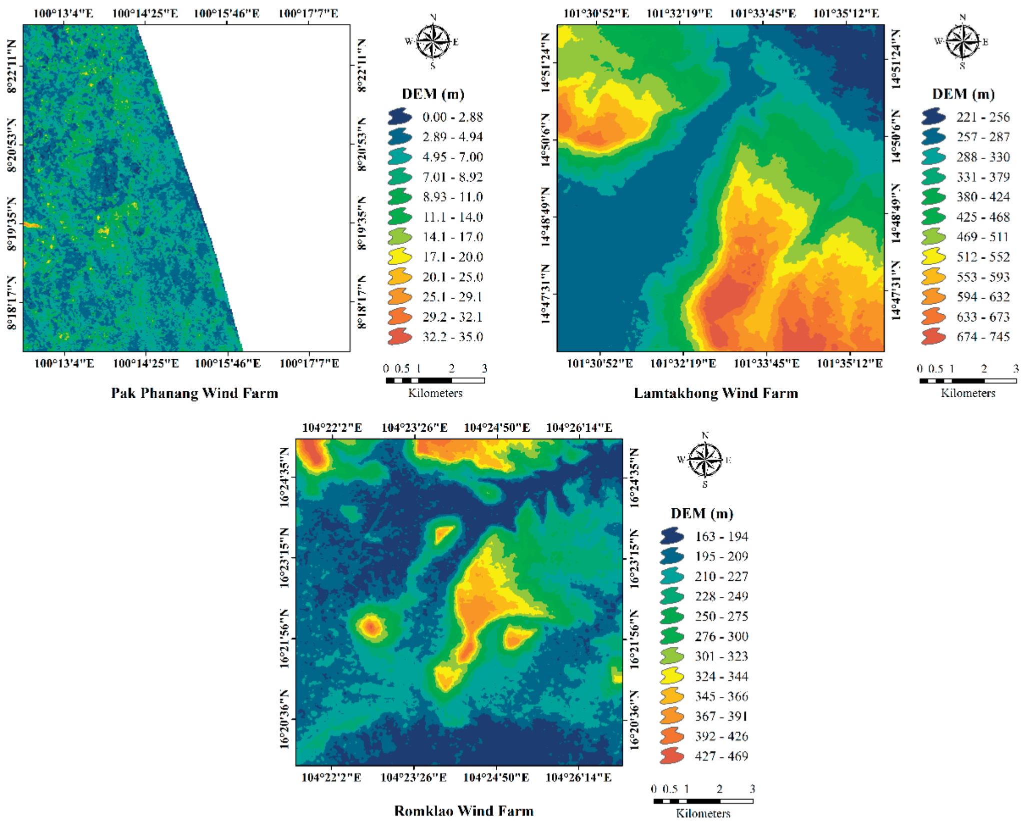

Figure 3. The digital elevation model (DEM) was used in this study.

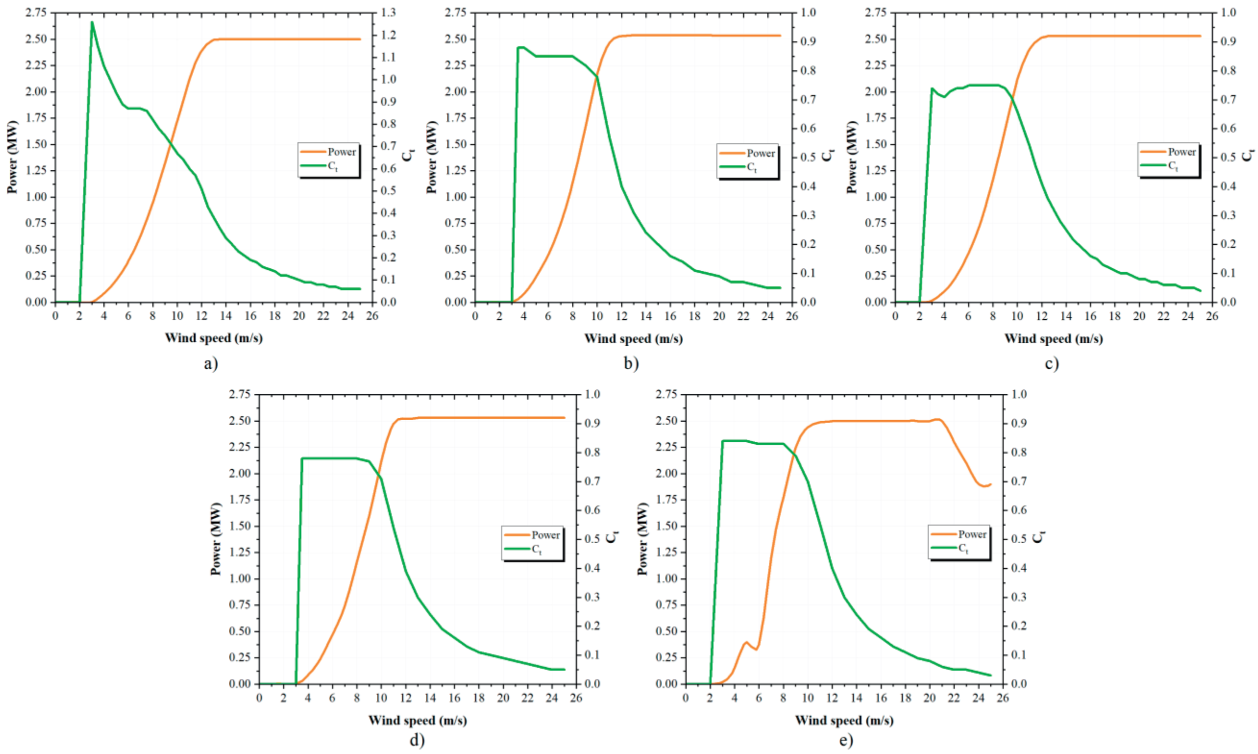

Figure 4. The power curves of the wind turbine generators studied: a) Nordex N90/2500; b) Fuhrländer FL 2500/100; c) General Electric GE 2.5-103; d) FWT 104/2500; and e) Gamesa G126-2.5MW.

2.5 Ant colony optimization algorithm

The Ant Colony Optimization (ACO) algorithm was developed for discrete optimization problems based on the ant colony's food-searching behavior. The ACO is a multistep optimization process, similar to an ant randomly finding food and leaving a chemical trail for its colony to follow to find the food source to bring back to the nest [19].

The ACO algorithm used in this study was performed using a MATLAB code. A study by Eroglu [19] used an objective function to locate the WTG with the x-y coordinate system at the specified distance between the WTG and the total power generated by the WTG.

The energy produced by the WTG is expressed as a linear equation. This shows that the energy produced depends on the wind speed, consisting of three parts, as shown in Eq. 1 [20]. In Part 1 is the wind speed that is less than the cut-in wind speed v_{cutin} which is the lowest wind speed at which the WTG starts to generate electricity, with the electrical power produced equal to 0. In Part 2, a linear equation as a function of the wind speed is applied between v_{cutin} and v_{rated} Which is the speed at which the nominal power of the WTG is determined. This linear equation consists of a slope. (λ) and a constant (η) to define the power curve. In Part 3, the WTG produces power at it nominal capacity (P_{rated}) between the rated wind speed v_{rated} and the cut-out wind speed v_{cutout}.

$$f(v) = \begin{Bmatrix} 0 & v < v_{cutin} \\ \lambda * v + \eta & v_{cutin} \leq v \geq v_{rate} \\ P_{rate,} & v_{cutout} > v > v_{rated} \end{Bmatrix} \tag{1}$$

Considering that the wind characteristics can be described by the Weibull distribution, which depends on the wind speed, the electrical energy produced can be expressed as in Eq. 2.

$$P(\theta) = \int_0^{\infty} f(v) p_v\big(v, k(\theta), c(\theta)\big)\, dv = \int_0^{\infty} f(v) \frac{k(\theta)}{c(\theta)} \left(\frac{v}{k(\theta)}\right)^{k(\theta)-1} e^{-\left(v/c(\theta)\right)^{k(\theta)}} dv \tag{2}$$

Where k is the shape parameter, $c(\theta)$ is the scale parameter at the direction (θ). The Weibull function depends on the wind direction and wind speed (v), whose direction is from 0º to 360º. Eq. 2 can be written as Eq. 3.

$$P(\theta) = \int_0^{360} p\,(\theta) d\theta \int_0^{\infty} f\,(v) \frac{k(\theta)}{c(\theta)} \left(\frac{v}{c(\theta)}\right)^{k(\theta)-1} e^{-\left(v/c(\theta)\right)^{k(\theta)}} dv \tag{3}$$

Eq. 3 shows that the wind speed is continuous. The wind speed is divided into equal ranges, described in terms of $N_v + 1$ from v_{cutin} to v_{rated}, with wind speed starting from $v_1, v_2, v_3, \ldots . v_{N_v}$ and $v_{cutin} < v_1, v_2, v_3, \ldots, v_{N_v} < v_{rated}$ when $v_0 = v_{cutin}$ and $v_{N_v+1} = v_{rated}$. The energy produced by the WTG can be obtained from Eq. 4.

$$\begin{aligned} P = {} & \lambda \sum_{l=1}^{N_v+1} \left(\frac{v_{j-1} + v_j}{2}\right) \int_0^{360} p_\theta\,(\theta) \left\{ e^{-\left(\frac{v_{j-1}}{c_i(\theta)}\right)^{k\theta}} - e^{-\left(\frac{v_j}{c_i(\theta)}\right)^{k\theta}} \right\} d\theta \\ & + P_{rated} \int_0^{360} p_\theta\,(\theta) e^{-\left(\frac{v_{rated}}{c_i(\theta)}\right)^{k\theta}} d\theta \\ & + \eta \int_0^{360} p_\theta(\theta) \left\{ e^{-\left(\frac{v_{cutin}}{c_i(\theta)}\right)^{k(\theta)}} - e^{-\left(\frac{v_{rated}}{c_i(\theta)}\right)^{k(\theta)}} \right\} d\theta \end{aligned} \tag{4}$$

where $c_i(\theta)$ is the scale parameter at the wind direction θ after the wake effect is calculated from Eq. 5, while Eq. 6 computes the decreasing speed Vel_def at a distance d of the WTGs.

$$c_i(\theta) = c(\theta) \times (Vel\_def) \tag{5}$$

$$Vel\_def = \left(1 - \frac{\sqrt{1 - C_T}}{(1 + kd/R)^2}\right) \tag{6}$$

In this research, the wind speed range is divided into 16 sectors, where $N_v + 1 = 16$, so the energy generated by the WTG can be calculated from Eqs. 7-9.

$$\begin{aligned} P_\lambda = {} & \lambda \sum_{l=1}^{N_v+1} \left(\frac{v_{j-1} + v_j}{2}\right) \sum_{l=1}^{N\theta+1} (\theta_{l=1} - \theta_l) w_{l-1} \\ & \times \left\{ e^{-\left(\frac{v_{j-1}}{c_i\left(\frac{\theta_{l-1}+\theta_l}{2}\right)}\right)^{k\left(\frac{\theta_{l-1}+\theta_l}{2}\right)}} - e^{-\left(\frac{v_j}{c_i\left(\frac{\theta_{l-1}+\theta_l}{2}\right)}\right)^{k\left(\frac{\theta_{l-1}+\theta_l}{2}\right)}} \right\} \end{aligned} \tag{7}$$

$$P_r = P_{rated} \sum_{l=1}^{N\theta+1} (\theta_{l-1} - \theta_l) w_{l-1} e^{-\left(\frac{v_{rated}}{c_i\left(\frac{\theta_{l-1}+\theta_l}{2}\right)}\right)^{k\left(\frac{\theta_{l-1}+\theta_l}{2}\right)}} \quad (8)$$

$$P_\eta = \eta \sum_{l=1}^{N\theta+1} (\theta_{l-1} - \theta_l) w_{l-1} \times \left\{ e^{-\left(\frac{v_{cutin}}{c_i\left(\frac{\theta_{l-1}+\theta_l}{2}\right)}\right)^{k\left(\frac{\theta_{l-1}+\theta_l}{2}\right)}} - e^{-\left(\frac{v_{rated}}{c_i\left(\frac{\theta_{l-1}+\theta_l}{2}\right)}\right)^{k\left(\frac{\theta_{l-1}+\theta_l}{2}\right)}} \right\} \quad (9)$$

where P_λ is the power in relation to the slope in the linear equation of the power curve (kW); P_r is the energy in relation to the maximum power that the wind turbine can produce (kW); and P_η is the power in relation to the constant in the linear equation of the power curve (kW).

From Eqs. 7-9, the electric power of a WTG can be calculated from Eq. 10 and the electricity generated by a wind power plant can be calculated from Eq. 11.

$$P_i = P_\lambda + P_r + P_\eta \quad (10)$$

$$P_f = \sum_{i=l}^{N_t} P_i \quad (11)$$

where P_i is the electric power as the WTG can produce (kW) and P_f is the total electrical energy generated from wind power plants (kW).

2.6 Analysis of electric power produced from wind power

For the electric power analysis, the Gross Annual Energy Production ($Gross\ AEP$), the Net Annual Energy Production ($Net\ AEP$), and the wind power generation efficiency calculated as a capacity factor (CF) was assessed. A higher Net AEP value indicates good wind energy production capacity in the targeted areas and is calculated using Eq 12.

$$Net\ AEP = Gross\ AEP - Wake\ Loss \quad (12)$$

The Gross AEP is calculated using the ACO algorithm, and the wake loss is the electricity production lost due to the wake effects of the WTGs in the wind power plant. The N.O. Jensen wake model was used in this investigation. The optimum layout of a considered wind power plant was simulated to analyze wake loss in WindSim computer software [23].

CF is defined as the availability of a WTG to produce electricity in a year and is given by Eq. 13 [24]. The CF of a WTG also indicates the efficiency of the WTG.

$$CF = \left(\frac{Net\ AEP}{Rated\ Capacity \times 8{,}760}\right) \times 100\% \quad (13)$$

3. Results and Discussion

3.1 Annual and Mean Wind Speeds

Generally, the shear coefficient is used to estimate wind velocity at higher elevations using the measurements from metrological instruments at lower elevations. The Power Law equation is the most well-known equation for calculating the shear coefficient [21,22], and it was used in this study to estimate the wind speed at 100 m agl based on the VMM reading at 50 m agl. The annual wind speeds of the targeted wind power plants were calculated at 100 m agl. The variation amongst flat, semi-complex, and complex terrain is not significant, with average annual wind speeds of 4.64, 4.79, and 4.67 m/s at Pak Phanang district of Nakhon Si Thammarat province, Sikhio district of Nakhon Ratchasima province and Nikhom Kham Soi District Mukdahan province, respectively. Similarly, the shape parameters in the study areas were 2.69, 2.74, and 2.65, respectively, while the scale parameters were 5.22, 5.38, and 5.25 m/s, respectively.

Using the WindSim tool, microscale wind resource maps, with a size of 10x10 km^2 and a 50 m resolution, were created for the three study areas, as shown in Fig. 5. The average annual wind speeds, at 100 m agl, at the targeted wind power plants of Pak Phanang Wind Farm, Lamtakong Wind Farm, and Romklao Wind Farm ranges from 5.00 to 5.76, 3.1 to 6.45, and 4.21 to 8.90 m/s, respectively.

3.2 Optimal suitability of wind power plants

Using the ACO algorithm in MATLAB, the optimization of the wind power plants was done. With 600 iterations and a processing time of 3.2 to 3.6 hours, the electricity produced in flat terrain Pak Phanang Wind Farm was between 8.6 and 14.3 GWh/yr using multiple WTGs, as shown in Tables 5 and 6. With 14.3 GWh/yr and a CF of 16.31%, the Gamesa G126-2.5MW wind turbine produced the highest AEP, while the Nordex N90/2500 WTG produced the least amount of AEP with 8.6 GWh/yr.

Similarly, with 400 iterations and a processing time of 2.1 hours, the electricity production in the semi-complex Lamtakong Wind Farm was in the range of 52.9 to 72.2 GWh/yr, as shown in Tables 7 and 8. The Gamesa G126-2.5MW WTG produced the highest AEP and CF with 72.2 GWh/yr and 29.0%, respectively, while the Nordex N90/2500 WTG produced the least amount of AEP with 52.9 GWh/yr.

Table 5. AEP of each wind turbine in flat terrain

WTG	HH (m)	No. of WTG	Capacity (MW)	Gross AEP (GWh/y)	V_{avg} (m/s)	Wake Losses (%)	Net AEP (GWh/y)	CF (%)
N90/2500	100	4	10	9.7	4.70	10.9	8.6	9.9
FL 2500/100	100	4	10	11.3	4.68	1.7	11.1	12.6
GE 2.5-103	100	4	10	11.6	4.68	15.1	9.8	11.2
FWT 104/2500	100	4	10	11.3	4.68	4.9	10.7	12.3
G126-2.5MW	100	4	10	15.4	4.70	7.2	14.3	16.3

Note: HH = Hub Height; WTG = Wind Turbine Generator

Table 6. Iteration and time consumption in flat terrain

Turbine	Iterations	Time Consumptions (hr)
N90/2500	600	3.63
FL 2500/100	600	3.22
GE 2.5-103	600	3.20
FWT 104/2500	600	3.23
G126-2.5MW	600	3.18

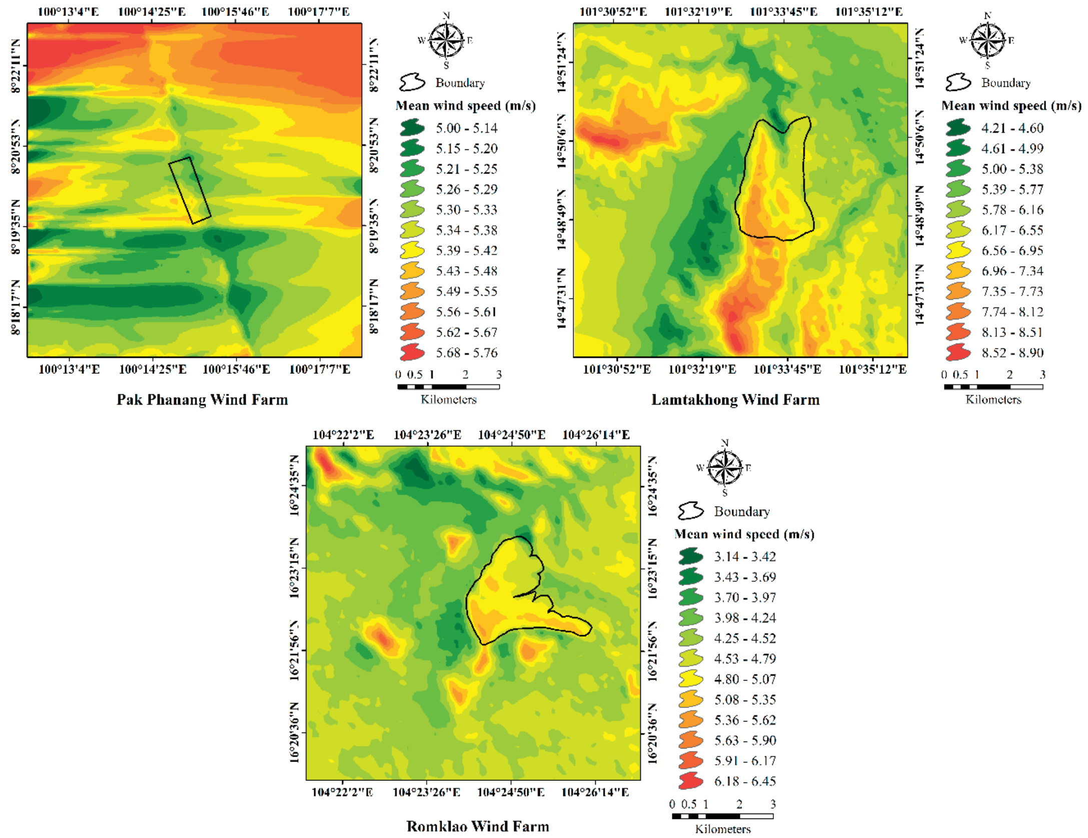

Figure 5. The average annual wind speeds of in the region of the Pak Phanang Wind Farm, the Lamtakong Wind Farm, and the Romklao Wind Farm.

Table 7. AEP of each wind turbine in semi-complex terrain

Turbine	HH (m)	No. of WTG	Capacity (MW)	Gross AEP (GWh/y)	V_{avg} (m/s)	Wake Losses (%)	Net AEP (GWh/y)	CF (%)
N90/2500	100	12	30	55.7	5.8	5.1	52.9	20.11
FL 2500/100	100	12	30	64.3	5.8	6.0	60.4	23.00
GE 2.5-103	100	12	30	65.3	5.8	5.6	61.6	23.46
FWT 104/2500	100	12	30	61.0	5.6	5.1	57.9	22.03
G126-2.5MW	100	12	30	81.5	5.8	6.6	76.1	28.97

Note: HH = Hub Height; WTG = Wind Turbine Generator

Table 8. Iteration and time consumption in semi-complex terrain

Turbine	Iterations	Time Consumptions (hr)
N90/2500	400	2.08
FL 2500/100	400	2.18
GE 2.5-103	400	2.17
FWT 104/2500	400	2.08
G126-2.5MW	400	2.13

In the same way, 800 iterations were performed for the complex terrain of Romklao Wind Farm with a processing time of 4.17-5.02 hours. The electricity production ranged from 22.8 to 38.9 GWh/yr using multiple WTGs, as summarized in Tables 9 and 10. Similarly to the other two wind power plant sites, the

Gamesa G126-2.5MW produced the highest AEP and CF of 38.9 GWh/yr and 13.7%, respectively, while the Nordex N90/2500 produced the least AEP of 22.8 GWh/yr with the lowest CF of 8.0%.

In all three wind power plants with distinct terrains, the Gamesa G126-2.5MW wind turbine performed better, producing the highest AEP and CF with relatively low wake losses. This is due to its larger rotor diameter and lower cut-in speed. Therefore, the final optimization of all three targeted wind power plants was done using this WTG. Using the Gamesa G126-2.5 MW WTG, the ACO-optimized layout of the flat, semi-complex, and complex terrain wind power plants produced net AEP of 14.3, 76.1, and 38.9 GWh/yr, thus improving the electricity production of the wind power plants. The ACO-based optimized wind power plant layouts are presented in Figs 6 - 8. The optimized layouts have significant differences in the positions of WTGs compared to the original layout.

Table 9. AEP of each wind turbine in complex terrain

WTG	HH (m)	No. of WTG	Capacity (MW)	Gross AEP (GWh/y)	V_{avg} (m/s)	Wake Losses (%)	Net AEP (GWh/y)	C.F. (%)
N90/2500	100	13	32.5	25.2	4.32	9.3	22.8	8.0
FL 2500/100	100	13	32.5	32.5	4.46	7.1	30.2	10.6
GE 2.5-103	100	13	32.5	36.7	4.58	2.7	35.7	12.53
FWT 104/2500	100	13	32.5	30.6	4.37	10.0	27.5	9.7
G126-2.5MW	100	13	32.5	42.7	4.38	9.1	38.9	13.7

Note: HH = Hub Height; WTG = Wind Turbine Generator.

Table 10. Iteration and time consumption in complex terrain

Turbine	Iterations	Time Consumptions (hr)
N90/2500	800	5.02
FL 2500/100	800	4.17
GE 2.5-103	800	4.18
FWT 104/2500	800	4.22
G126-2.5MW	800	4.23

4. Conclusions

Wind energy is one of the important renewable energy sources and, along with solar energy, is becoming a primary source. An important challenge in wind power development is optimizing the power production, where wind power plant operators work to maximize the energy output. One way to improve the energy output from wind power plants is by optimizing their layout, as the positions of the WTGs in the wind power plants profoundly affect the overall energy output due to their wake effects. It is, therefore very important to plan an optimal wind power plant layout in the design phase of the development, as the positions of the WTGs cannot be changed after installation.

To achieve this target, this study employed the Ant Colony Optimization (ACO) algorithm to optimize the layout of wind power plants, with the objective functions of increasing the annual energy production (AEP) and the capacity factor (CF) of the plant, while reducing the wake effects. Three wind power plants in different parts of Thailand, i.e., Pak Phanang Wind Farm, Lamtakong Wind Farm, and Romklao Wind Farm, have been studied, having flat, semi-complex, and complex terrains, respectively. Using the MERRA-2 long-term wind database, CFD wind flow modeling was used to map the microscale wind resource maps over the study areas, which revealed acceptable wind speeds for utility-scale wind power plants.

The optimization used multiple commercially available WTGs with different rotor diameters and power characteristics to find the ideal WTG producing the highest AEP and CF with relatively low wake losses. The Gamesa G126-2.5MW WTG performed the best in all three wind power plant locations, producing the highest AEP of 14.3, 76.1, and 38.9 GWh/y in flat, semi-complex, and complex terrains, respectively, with relatively low wake losses making it the ideal WTG for the layout optimization. Optimizing the layout improved The net AEP for the wind power plants. Such studies are important to improve the efficiency of wind power plants, thus extracting the maximum kinetic energy possible from the winds and improving the economic viability of wind power plants. However, the comparison between metaheuristic algorithms should be performed for further study.

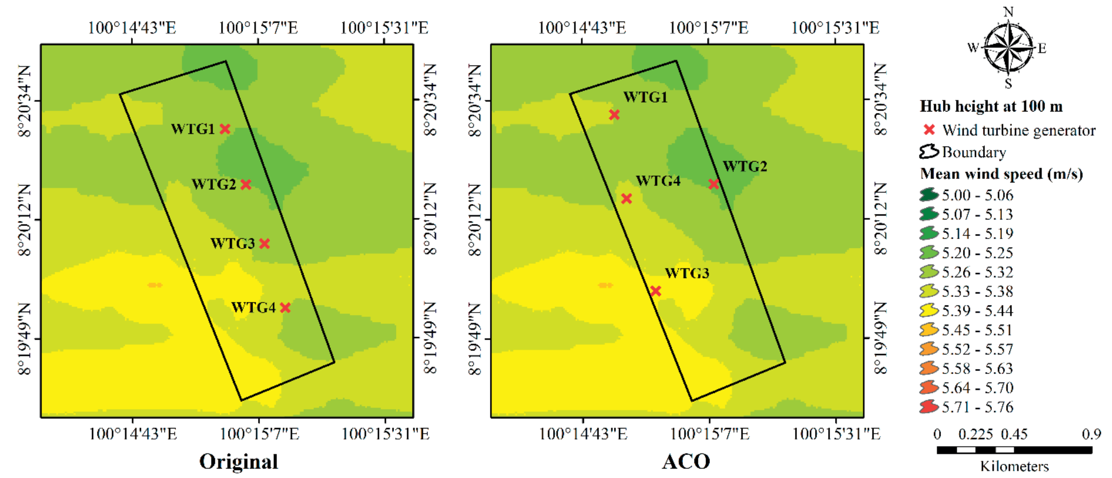

Figure 6. The original (left) and ACO (right) wind turbine locations in the Pak Phanang Wind Farm.

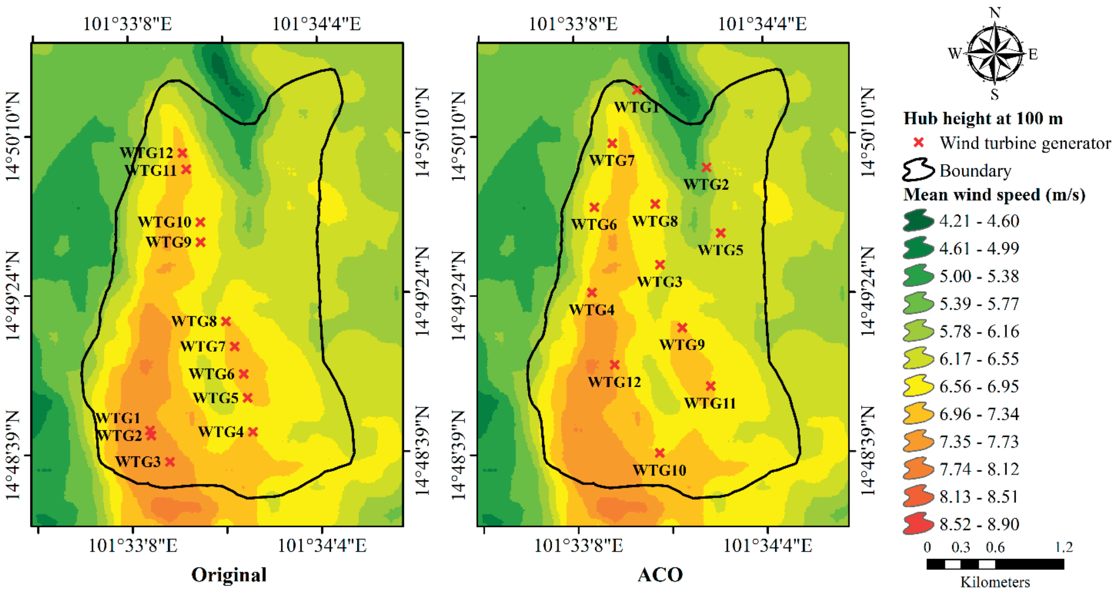

Figure 7. The original (left) and ACO (right) wind turbine locations in the Lamtakong Wind Farm.

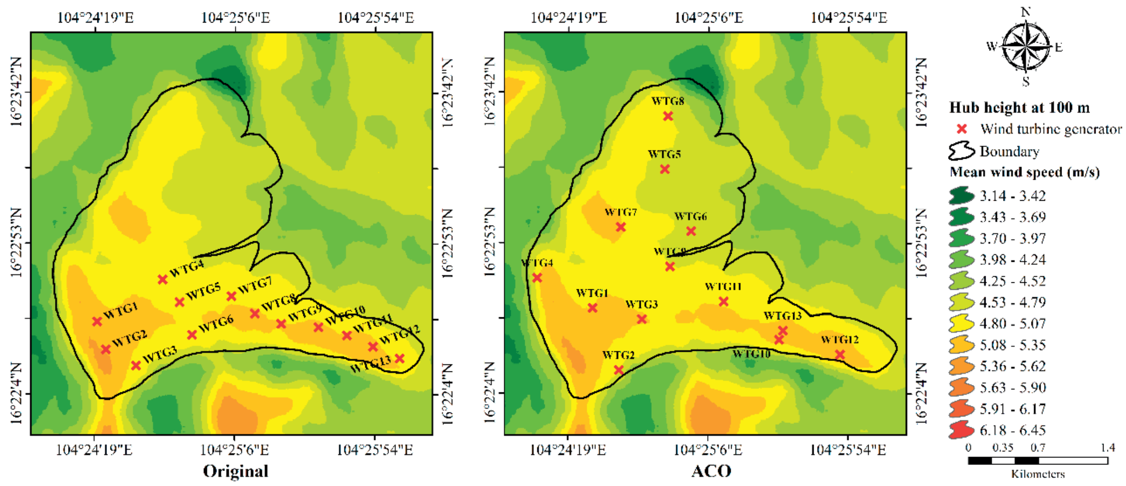

Figure 8. The original (left) and ACO (right) wind turbine locations in the Romklao Wind Farm.

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