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Assessment Wind Energy in the Central Region of Thailand

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Abstract

This study evaluates the wind energy potential in the central region of Thailand by using data from seven wind measurement stations (Ayutthaya, Bangna, Chainat, Kamphaeng Saen, Lopburi, Nakhon Sawan, and Pathum Thani) and two wind turbines, namely AN Bonus 1300/62 and Vestas Wind System A/S. The analysis was conducted using the Wind Atlas Analysis and Application Program (WAsP) to examine the collected wind speed data over three years from the seven stations. The objective was to identify the top three areas with the highest annual energy production (AEP). Additionally, the study included an economic analysis using various metrics, such as the present value of costs (PVC), benefit-cost ratio (BCR), payback period (PBP), and levelized cost of electricity (LCOE). The results indicate that the AN Bonus 1300/62 model provides higher values in areas with high wind speeds and relatively high electricity demand, whereas the Vestas V52 model is suitable for areas with low wind speeds and lower investment requirements. Based on these findings, the authors recommend prioritizing wind energy development in the provinces of Ayutthaya, Nakhon Sawan, and Lopburi using the AN Bonus 1300/62 model, as these areas have high wind speeds and relatively high electricity demand. Overall, this research provides valuable insights for policymakers and investors, enabling them to make informed decisions regarding renewable energy investments in Thailand.

1. Introduction

The increasing global demand for energy, along with environmental challenges caused by the use of fossil fuels, requires the exploration of alternative energy sources [1]. Thailand heavily relies on fossil fuels for generating electricity [2] and is faced with significant challenges and a genuine search for sustainable solutions in the energy sector. With growing concerns about energy security, greenhouse gas emissions, and resulting climate change, renewable energy sources with low carbon footprints [3] have become attractive options for global electricity production [3]. To address the impacts on Thailand's energy sector, as outlined in the Power Development Plan 2015 (PDP 2015) [4] and Alternative Energy Development Plan 2015 (AEDP 2015) [5], the Ministry of Energy has set targets in the AEDP 2015 for solar energy, small-scale hydropower, large-scale hydropower, and wind power, with installed capacities of 6,000 MW, 3,282 MW, 3,002 MW, and an additional 7,400 MW from other alternative energy sources. Furthermore, additional adjustments were made in 2018 when the AEDP 2018 increased the targets for solar energy, small-scale hydropower, large-scale hydropower, and wind power to 9,290 MW, 69 MW, and 1,485 MW, respectively. However, the limited potential of renewable energy resources in the country poses a significant obstacle to their development [6]. The central region of

Thailand [7], which includes 22 provinces [8], faces high electricity demand [9] due to commercial activities, industries, and tourist attractions. In this context, assessing the wind energy potential in a region is crucial for sustainable energy supply [1], [10]. Previous studies conducted by Niyontham et al. [11] focused on the central region of Thailand, including the central region and parts of the eastern, southern, and western regions, which comprise more than 26 provinces. This study revealed that areas with an average wind speed greater than 6.0 m/s were found in the northwestern and southern regions. Another study conducted by Muneerat et al. [12] installed wind speed measuring instruments at heights of 10, 15, 20, 25, and 30 m and analyzed the data using the Wind Analysis and Application Program (WAsP). The study found that the maximum wind speeds at Songkhla station ranged from 3.16 to 12.15 m/s, while in Narathiwat province, the average wind speed ranged from 1.13 to 1.72m/s, with power densities of the Songkhla station ranging from 24 to 1,372 W/m^2 and 2 to 5 W/m^2 for the Narathiwat station. Carina P. Paton et al. [13] conducted a study in Bangkok, the capital city, and the surrounding areas at elevations ranging from 100 to 300 m above ground level. The wind resource map simulated the wind resources at a 100-meter distance from the ground. The lowest wind speed was found north of the city center (<125 W m^-2), while the highest wind speed was observed on the southwest coast (200 W m^-2). Wind resources increase with altitude, and in the range of 200-300 meters and higher, there is a slight variation throughout the province (200-300 W m^-2) [13]. Quan and Leephakpreeda [10] presented a study in central Thailand, which reported average wind speeds ranging from 3 to 5 m/s annually. They proposed Vestas V60 850 kW as a feasible wind turbine model for low wind speed conditions [9], and another research on a 15 MW wind power plant in central Thailand [14] utilized five wind turbine generators (WTGs) with hub heights ranging from 80 m to 120 m above ground level (agl). The study revealed an average wind speed of 5.8 m/s at a hub height of 120 m agl, annual energy production (AEP) of approximately 41 GWh, a capacity factor (CF) of 30%, an AEP 6% of wake loss, and a CO_2eq emissions reduction of 231 kt CO_2eq per year. The levelized cost of electricity (LCOE) was estimated at around 0.093 US$/kWh, and a suggested feed-in tariff (FIT) value of 0.195 US$/kWh was proposed [14].

The objective of this study is to provide a more comprehensive research approach by conducting an analysis of provincial areas that include all provinces with more than seven weather stations [15]. These provinces include Ayutthaya, Bangna, Chainat, Kamphaeng Saen, Lopburi, Nakhon Sawan, and Pathum Thani. Data collected from 2018 to 2020, at 10-minute intervals and at a height of 10 m above the ground [16], will be used to evaluate the wind energy potential in central Thailand [7]. The analysis will be conducted using the Wind Atlas Analysis and Application Program (WAsP) [3], [17], [18] to determine the wind speed and direction at various altitudes above the ground.

Furthermore, this study assessed the economic aspects of wind power generation, including optimal site selection and wind turbine technology [19]–[21]. Economic analysis was carried out using four indicators: Present Value Cost (PVC) [22], Benefit-Cost Ratio (BCR) [23], payback period (PBP) [23], and levelized cost of energy (LCOE) [24]. These indicators provide valuable insights into the feasibility of wind power as a sustainable alternative to fossil fuels [2] for electricity generation in central Thailand. This will contribute to the advancement of renewable energy sources in the central region, reduce the nation's dependence on fossil fuels, and promote sustainable development [25]. The projected outcomes highlight the potential of wind energy as a significant contributor to Thailand's energy mix, encouraging the adoption of greener and more environmentally friendly power generation systems.

2. Methodology

2.1 The Scope of the Study

Topographic simulations play a crucial role in assessing wind resources for wind-power development [26]. In this study, the Wind Atlas Analysis and Application Program (WAsP) software [3], [17], [18], which is a widely used tool in the wind power industry, was employed for terrain simulations [27]. Wind data from over seven weather stations [15], including Ayutthaya, Bang Na, Chainat, Kamphaeng Saen, Lop Buri, Nakhon Sawan, and Pathum Thani, collected between 2018 and 2020 at 10-minute intervals and an altitude of 10 meters above the ground [16], is imported for analysis.

Vector maps, comprising elevation maps and roughness maps, were utilized to generate baseline computational references for a specific site [28]. Elevation maps present contour lines, whereas rough maps depict roughness variations. To ensure simulation accuracy, appropriate map projections, such as the Universal Transverse Mercator (UTM) or World Geodetic System (WGS) 1984, which define a coordinate system based on latitude and longitude positions [29], are employed. This approach ensures that the simulation aligns with real-world locations and facilitates meaningful comparisons with other relevant studies [30]–[32].

In this study, the vector map was expanded to cover an area of 30 × 30 km surrounding the meteorological station [15], referencing the coordinates provided in Table 1. The aim of this study was to evaluate the wind

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potential in a selected area. Utilizing WAsP software [3], [17], [18], [33] for terrain modeling, valuable insights into the available wind resources within these regions have been sought [34]–[36]. The information derived from this analysis can assist wind energy developers in making informed decisions regarding the feasibility of wind energy projects [37].

Finally, topographic simulation using WAsP software is a crucial step in estimating wind resources for wind power development [38], [39], empowering developers to make informed decisions regarding the site's potential. Our study provides significant insights into the wind resources around meteorological stations and serves as a valuable reference for future wind power projects in these regions [40].

Table 1 *The site location and UTM zone of the meteorological station*

Station	Location		Universal Transverse Mercator (UTM) Zone
	Latitude (m E)	Longitude (m N)	
1. Lop buri	675228.84	1636833.19	47 P
2. Nakorn sawan	621349.21	1732964.36	47 P
3. Chai nat	628022.91	1676173.45	47 P
4. Ayutthaya	685852.27	1607540.98	47 P
5. Kampaeng saen, Nakhon pathom	604744.15	1549212.80	47 P
6. Pratumtani	674941.33	1561178.63	47 P
7. Bang na, Bangkok	673640.68	1511560.32	47 P

2.1.1 Elevation Map

Elevation maps are important for simulating terrain and estimating wind resources for wind energy development [27], [29]. These maps depict the elevation of the terrain at each grid point, which significantly influences the resulting wind-flow patterns. Accurate and detailed elevation maps are essential, with contour lines representing the elevation lines. The maps should include a horizontal scale that extends 2-3 times the size of the reference area [28].

The accuracy and level of detail in elevation maps are of utmost importance [41], with the coordinates and elevations expressed in meters. The GWA-Warehouse Terrain Database will be utilized to ensure the conversion of relevant data and subsequent generation of precise terrain representations [18]. It is crucial to verify the accuracy of the elevation ranges depicted on the final map.

The information obtained from elevation maps is fundamental for the successful design and placement of wind turbines [42]–[44], aiding in determining the optimal locations with favorable wind conditions. This maximizes the energy production potential of wind farms by relying on elevation map references. Wind energy developers can make informed decisions regarding the placement and layout of turbines [45], ultimately leading to more efficient and effective wind energy projects [46], [47].

2.1.2 Roughness Map

To obtain a realistic assessment of the energy potential in each country, it is necessary to identify geographical areas unsuitable for onshore wind turbines [48]. Land cover statistics were derived from the GlobCover dataset [49] and are presented in Table 2. Each land type was appropriately scaled from 0 to 1, reflecting the likelihood of its suitability for wind turbine development, considering factors such as competition, land use, and other surface features [50].

Roughness maps are another crucial factor in topographic simulations and wind resource assessments for wind energy development [28]. The GWA-Roughness-GlobCover dataset was used to classify land cover based on 12 different roughness lengths, enabling the creation of a comprehensive roughness characterization [51].

In addition to elevation maps, the roughness map should have a horizontal scale magnified 2-3 times that of the reference site. In the WAsP map editor, it is essential to set the map projections and map datums correctly to ensure the accurate positioning of sites on the map [28]. This helps to avoid potential low-frequency roll (LFR) errors that can impact the accuracy of wind flow predictions and subsequent wind turbine design [52], [53]. This ensures precise design and successful deployment of wind turbines [54].

Table 2 *The land cover specification in the GlobCover database to roughness lengths*

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

2.2 Simulation of Wind Potential Map in the Study Area

The WAsP model [3], [17], [18] has been widely recognized as a reliable tool for estimating the wind resource potential and plays a crucial role in the planning and design of wind energy systems [55]. It considers parameters such as wind speed and terrain to provide accurate and dependable wind-resource estimates at specific sites [45]. Numerous studies have used WAsP models to estimate wind resources in various regions, including China, India, and Thailand [56]. The Danish Riso National Laboratory's WAsP program has emerged as a convenient tool for assessing wind resources by simplifying mathematical models based on various assumptions [57]. Typically, WAsP programs exhibit errors of less than 10% [58], [59].

The implementation of WAsP involves utilizing its modeling submodules. The first step involved inputting the wind data (2.1) into the WAsP Climate Analyst program to visualize the data through wind rose plots and Weibull Distribution analysis. In the subsequent step, the WAsP Map Editor program was employed to input the station coordinates (Table 1) and generate the elevation, surface roughness, and vector maps. Finally, the data obtained from Steps 1 and 2 were further processed in WAsP 12 to create a wind resource assessment model and evaluate wind farm projects for two specific wind turbine models, namely, AN Bonus 1300/62 and Vestas Wind System A/S. The simulation involved the installation of five wind turbine towers in the area surrounding each station.

2.3 Simulation of Annual Energy Production of the Wind Farm

Accurately predicting the wind energy potential of an area requires the consideration of various factors, including topography, roughness, and wind speed [7], [19], [34]. The utilization of WAsP software enables the integration of these factors, thereby facilitating the generation of reliable wind weather forecasts at specified hub elevations above ground for wind farm sites [19]. These forecasts play a crucial role in estimating the expected energy yields, which in turn significantly impact the economic viability of wind farm projects [60].

To determine the optimal locations for wind farms [42]–[44], comprehensive analyses incorporating diverse geographic and meteorological datasets are indispensable. These analyses encompass parameters, such as elevation, roughness, average wind speed, and energy density maps. Through meticulous evaluation of these datasets, wind energy planners can identify sites that maximize the energy yield and ensure the economic feasibility of the project.

Based on the information obtained from WAsP 12 (2.2), the program-generated data can be presented, encompassing both variables (including air density, Weibull-A, Weibull-k, mean speed, power density, elevation, RIX, site roughness length, turbulence intensity, flow inclination, and delta-RIX) and parameters (net AEP (MWh), gross AEP (MWh), wake loss (%), and capacity factor (%)).

2.4 Evaluation of Economic Feasibility

Economic valuation plays a crucial role in determining the cost-effectiveness of wind power generation within a specific area [19], [20], [38], [39]. This process involves a comprehensive assessment of various cost factors including land use, turbine costs, construction costs, grid connection fees, and other capital expenses [19]. Additionally, loan payments are considered to estimate the total project costs [21].

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The land use cost was calculated based on the installed area of an individual wind turbine, considering the impeller diameter and height of the turbine [61]. The simulation was conducted using the WAsP software [3], [17], [18], and the construction and engineering costs were estimated based on the average prices specified in the references (as shown in Table 4). An exchange rate of 31.9807 THB/USD was used for such projections [62]. Furthermore, the obtained parameter (Net AEP (MWh)) was used to calculate the average annual income (as shown in Table 4) considering the electricity purchase per unit according to the Feed-in-Tariff (FiT) policy supported by the Thai government. The current FiT rate was set to 6.0600 baht/kWh [14], [62].

Furthermore, the economic feasibility assessment comprises four crucial financial indicators: present value cost (PVC) [22], benefit-to-cost ratio (BCR) [23], payback period (PBP) [23], and leveled cost of energy (LCOE) [24]. By utilizing these economic assessment methods, wind power projects can be evaluated for their financial viability and cost-effectiveness, providing valuable insights into the decision-making process.

2.4.1 Operations and Sales of Electricity into the System

The development of renewable energy projects encompasses various financial aspects, including the operation and sale of electricity to the grid. When calculating the costs, revenues, and profits associated with such projects, it is crucial to use a reliable exchange rate. For this study, the average exchange rate of the Bank of Thailand for 2021, which is 31.9807 baht/US dollar, was employed to ensure the reliability of the financial analysis of renewable energy projects [63].

Comprehensive financial analysis plays a vital role in determining the feasibility and profitability of renewable energy projects [64]. One important aspect of economic analysis is the estimation of the cost of energy production per kilowatt hour. This can be achieved through reliable methods, such as the levelized cost of electricity (LCOE) and present value cost (PVC). In this study, the cost of energy production was estimated based on specific assumptions, including a 20-year equipment lifespan, 15% interest rate, 12% inflation rate, 25% operating maintenance and repair costs, and 10% scrap value [65], [66]. These financial calculations are crucial in assisting investors and developers in making informed decisions regarding renewable energy projects.

Furthermore, the cost distribution of wind energy projects varies depending on the wind turbine size. Smaller turbines tend to have a higher average cost per kilowatt than larger turbines do. Table 3 presents the average specific cost and the range of the specific costs for wind turbines at their rated power. The average costs for the Vestas V52 and AN Bonus 1300/62 wind turbine models were $4,600,000.00 and $7,475,000.00, respectively [64]. As indicated in Table 3, the estimated costs for wind farms using these turbine models are $6,478,873.24 and $10,528,169.01, respectively. These estimates offer valuable insights into the cost distribution of wind-power projects.

Table 3 *Average specific costs and range of specific costs of wind turbines based on rated power*

Wind turbine size (kW)	Average specific cost ($/kW)	Range of specific costs ($/kW)
<20	2600	2200–3000
20–200	1775	1250–2300
>200	1150	700–1600

2.4.2 Present Value of Cost (PVC)

The present value of cost (PVC) is a financial calculation that determines the current value of future costs, accounting for the concept of the time value of money [22]. It incorporates various factors, such as investment cost (I), operation and maintenance cost (C_(0/m)), interest rate (i), inflation rate (r), project lifetime (t), and salvage value of the wind turbine (s). Equation 1 was used to calculate the PVC, which considers the power generated by the wind turbine at a specific site.

$$PVC = I + C_{0/m}\left[\frac{1+i}{r-i}\right]\chi\left[1-\left(\frac{1+i}{1+r}\right)^{t}\right] - s\left(\frac{1+i}{1+r}\right)^{t} \quad (1)$$

2.4.3 Benefit-Cost Ratio (B/C ratio)

The benefit-cost ratio (BCR) is a financial metric that assesses the overall relationship between the costs and benefits of an investment project [23]. Equation 2 is used to calculate the BCR, which compares the O&M costs (C_(0/m)) with the value of the selling unit. The value of the selling unit is determined by multiplying the annual power generation (AEP) in kilowatt-hours (kWh) by the feed-in-tariff rate (FiT) in Thai Baht per kilowatt-hour (THB/kWh). The BCR is used as a criterion to determine whether an investment should be accepted or rejected. Generally, an investment is accepted if the BCR exceeds one and rejected if it is less than one.

$$BCR = \frac{1 + C_{0/m}}{\text{Value of selling unit}} \tag{2}$$

2.4.4 Payback Period (PBP)

The payback period (PBP) is a financial metric used to estimate the time required for an investment to generate sufficient cash flow to recover the initial investment and capital expenditure [18], [67]. Equation 3 calculates the payback period by dividing the investment by net annual cash flow. The payback period is a useful tool for evaluating investment risk. A shorter payback period indicates lower risk, as the investment is expected to generate returns more quickly.

$$PBP = \frac{\text{Investment}}{\text{Net annual cash flow}} \tag{3}$$

2.4.5 Levelized Cost of Energy (LCOE)

The levelized cost of energy (LCOE) is a financial metric used to assess and compare the costs of different energy production methods [24]. Specifically, for wind turbine power generation, LCOE represents the average total cost of constructing and operating a wind turbine per unit of electricity generated over the assumed project lifetime. Equation 4 is used to calculate the LCOE by dividing the present value of cost (PVC) by the annual power generation (AEP) in kilowatt-hours (kWh) multiplied by 20 years [64].

The LCOE enables the comparison of energy costs from various sources, considering both capital and operational expenses throughout the project's lifetime. This study provides valuable insights into the long-term economic viability of different energy production options.

$$LCOE = \frac{PVC}{AEPx20} \tag{4}$$

3. Results

The aim of this study was to analyze the wind energy potential and simulate the terrain, particularly high elevation and ruggedness, in different regions of Thailand. This analysis supports sustainable development efforts and facilitates informed decision-making regarding the feasibility of future wind energy projects [37] in these regions [40].

3.1 Topography Simulation of Elevation and Roughness

Upon analyzing various provinces, it was observed that Lop Buri, Ayutthaya, and Pathum Thani exhibited relatively high elevations. On the other hand, the Nakhon Pathom displayed predominantly flat topography, but still holds potential for wind turbine installation. Based on these data, areas with slightly higher elevations were deemed suitable for the establishment of wind farms. The classification of roughness length based on land cover type indicated that areas with lower roughness lengths approaching zero were favorable for wind farm setups. Lower roughness values generally correspond to smoother surfaces, leading to higher air velocities. To ensure standardized and accurate measurements, the Universal Transverse Mercator (UTM) coordinate system, specifically Zone 47, and Datum WGS-1984 [28] were employed for terrain simulations of elevation and roughness. These considerations are crucial for selecting the optimal location for a wind farm [42]–[44].

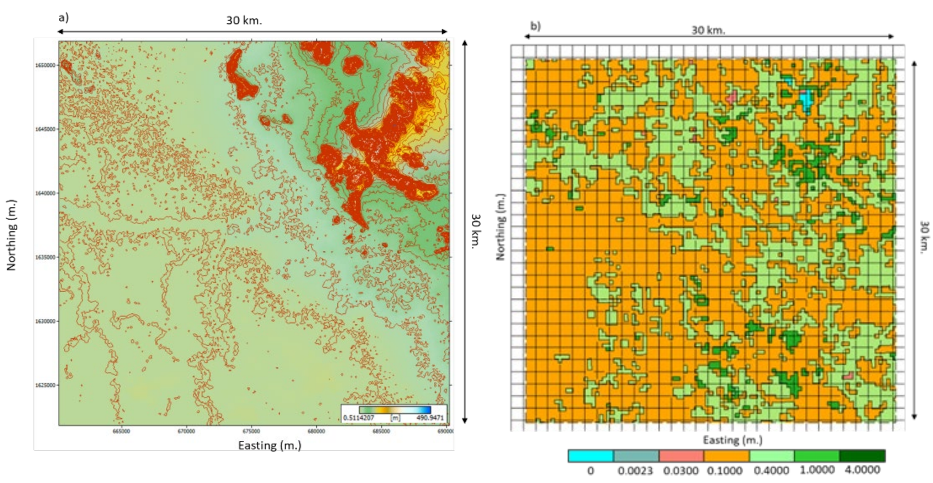

Fig. 1 *Elevation and roughness map of LOP BURI Weather Observing Station*

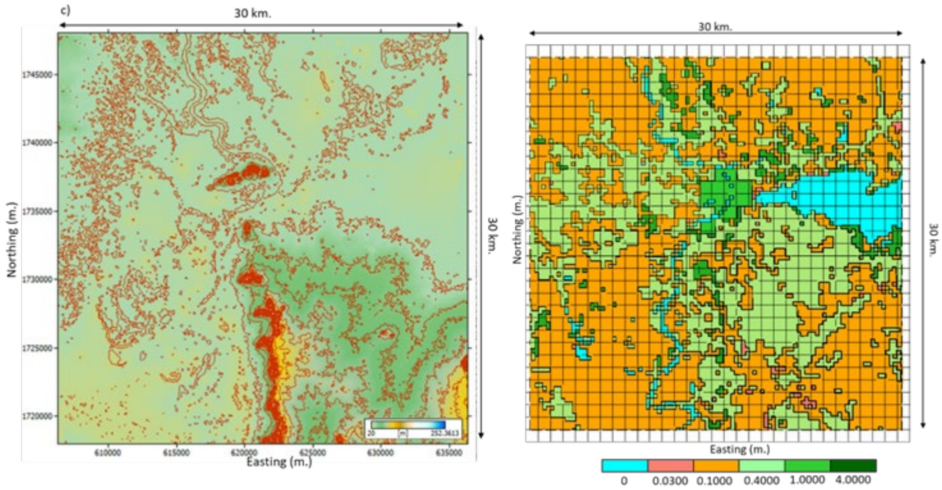

Fig. 2 *Elevation and roughness map of NAKORN SAWAN Weather Observing Station*

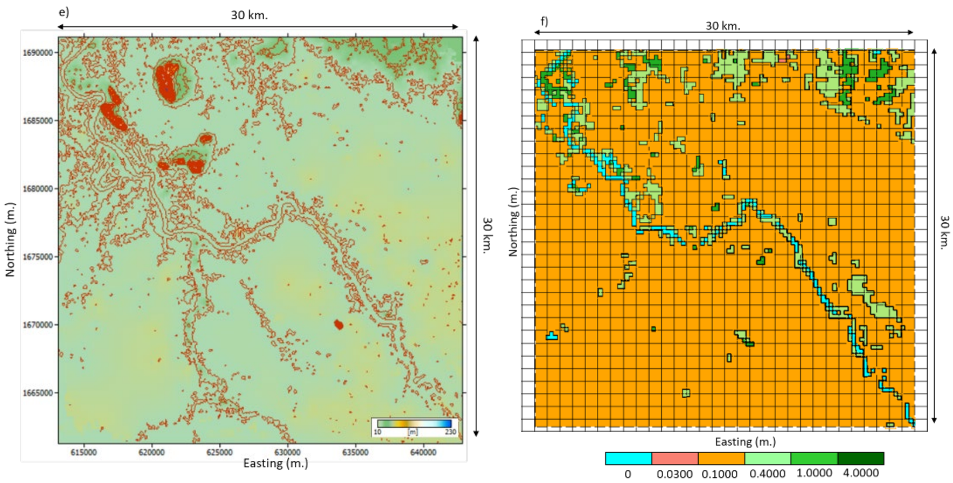

Fig. 3 *Elevation and roughness map of CHAI NAT Weather Observing Station*

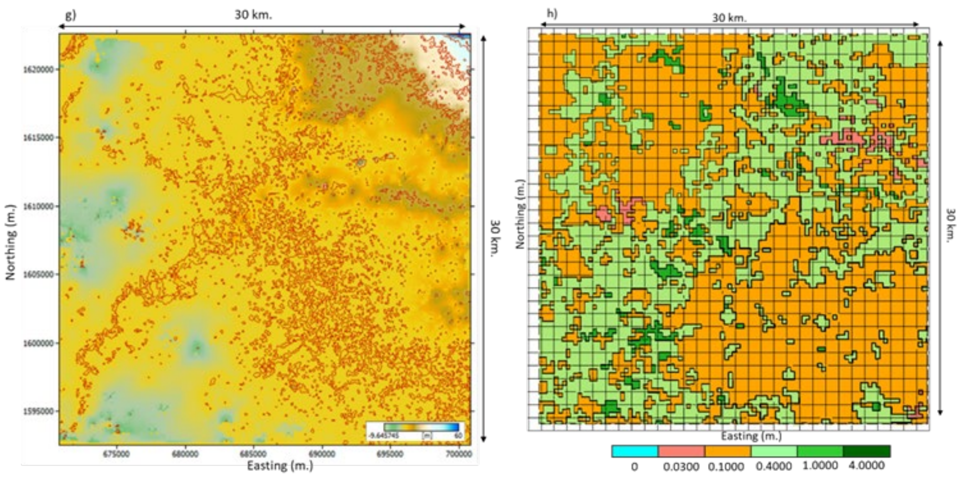

Fig. 4 *Elevation and roughness map of AYUTTHAYA Weather Observing Station*

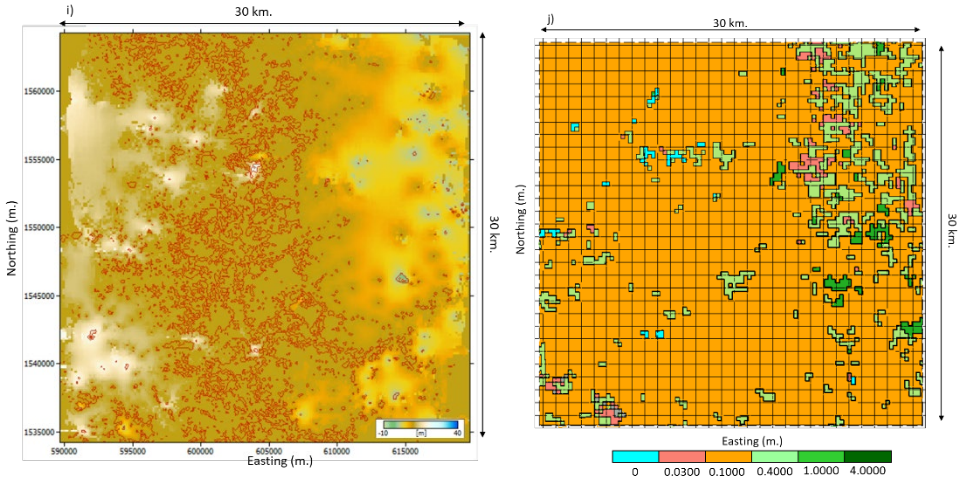

Fig. 5 *Elevation and roughness map of KAMPAENG SAEN, NAKHON PATHOM Weather Observing Station*

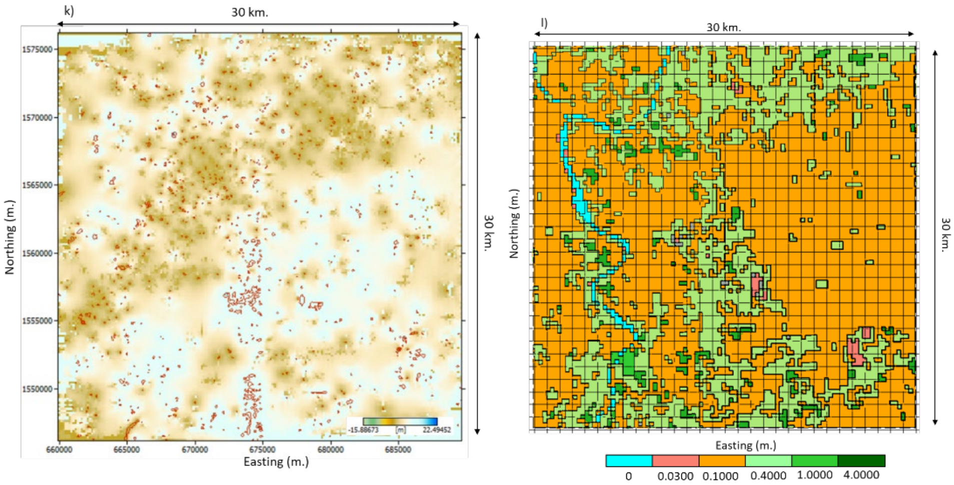

Fig. 6 *Elevation and roughness map of PRATUM THANI Weather Observing Station*

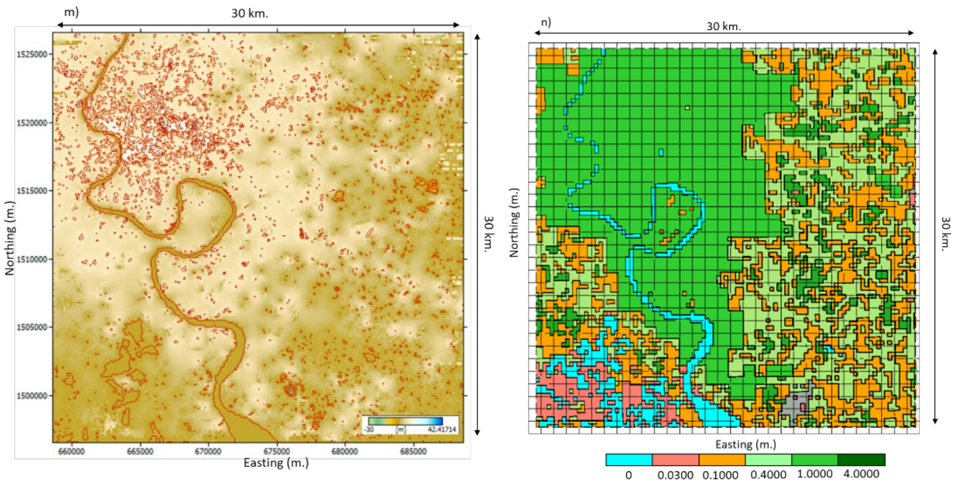

Fig. 7 *Elevation and roughness map of BANG NA, BANGKOK Weather Observing Station*

3.2 Simulation of Wind Potential Energy

The analysis conducted in this study focused on evaluating the wind conditions at various meteorological stations and at different hub heights for wind farms. The prevailing wind direction exhibited variations across

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the meteorological stations and hub heights. In Lop Buri, the most common wind directions were observed at angles of 150° and 180°, with the 180° wind direction exhibiting a maximum average wind speed of 3.61 m/s and a power density of 56 W/m^2. In contrast, Ayutthaya experienced wind most frequently at an angle of 60°, displaying a robust average wind speed of 5.21 m/s and a power density of 250 W/m^2. These findings offer valuable insights for assessing the feasibility of on-site wind-power generation at various hub heights.

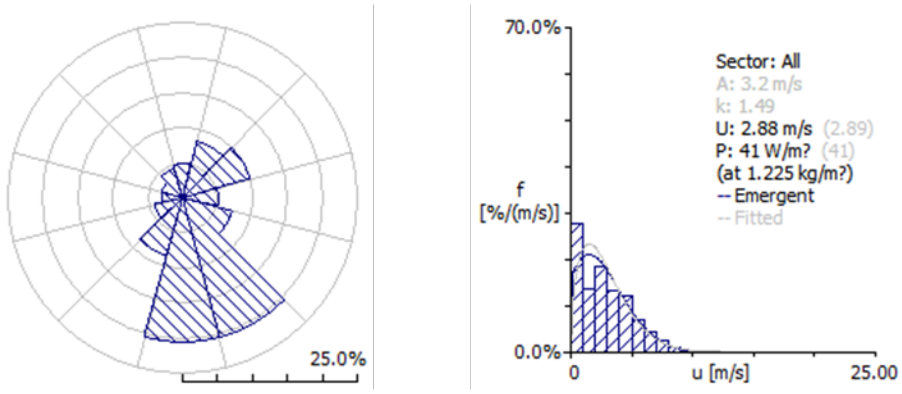

Fig. 8 *Wind rose and Weibull distribution of wind farm site at Lop Buri at 10 m*

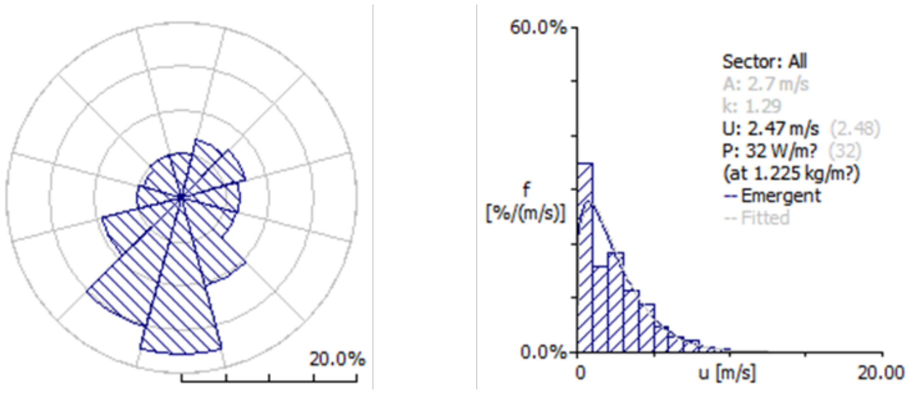

Fig. 9 *Wind rose and Weibull distribution of wind farm site at Nakorn Sawan at 10 m*

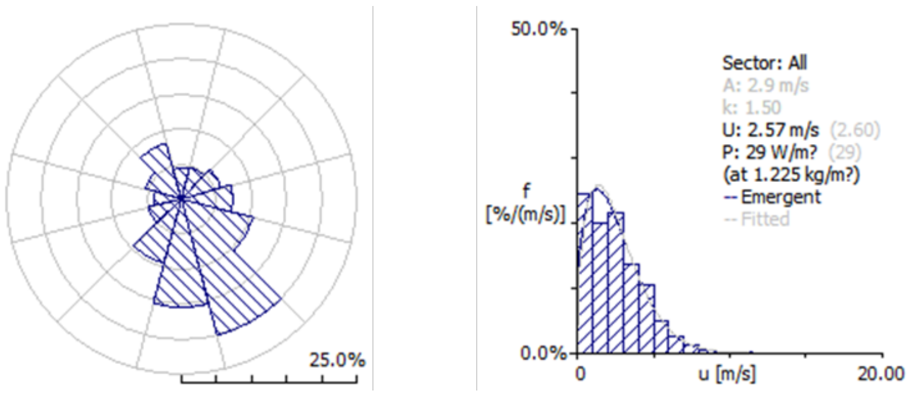

Fig. 10 *Wind rose and Weibull distribution of wind farm site at Chai Nat at 10 m*

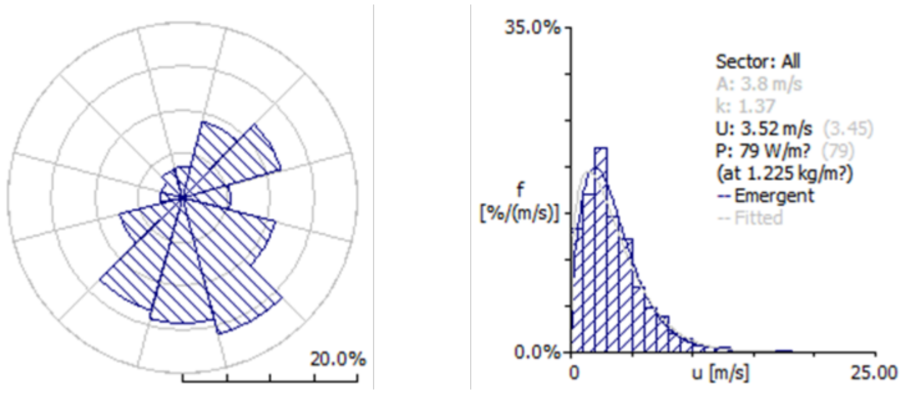

Fig. 11 *Wind rose and Weibull distribution of wind farm site at Ayutthaya 10 m*

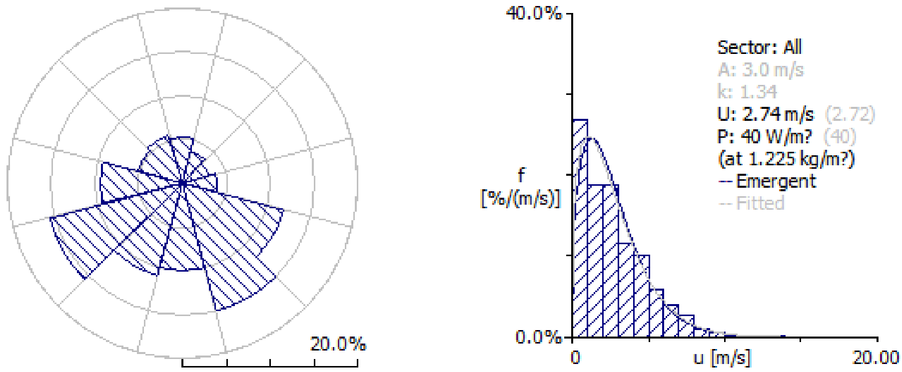

Fig. 12 *Wind rose and Weibull distribution of wind farm site at Nakhon Pathom (Kampaeng Saen) 10 m*

This section presents a comprehensive study that investigates wind energy potential by analyzing the wind climate conditions at various meteorological stations and different hub heights for wind farms. The study employed Weibull parameters to estimate the wind climate, including the average wind speed, power density, and frequency of the prevailing winds. The findings revealed variations in wind direction across different meteorological stations and hub heights, particularly in the Lopburi Province. The most frequently occurring wind directions were observed at the angles of 150° and 180°. Among these, the 180° direction exhibited the highest average wind speed of 3.61 m/s with a power density of 56 W/m^2. Conversely, Ayutthaya experienced wind most frequently at a 60° angle, demonstrating a strong average wind speed of 5.21 m/s and a power density of 250 W/m^2.

Furthermore, the study emphasized the impact of hub elevation on prevailing wind direction, average wind speed, and energy density at a center elevation of 60 m in Lopburi Province. The most common wind direction was observed from 60°, with an average wind speed of 6.43 m/s and a power density of 259 W/m^2. When the hub elevation was increased to 90 m, the prevailing wind direction remained at 60°, while the average wind speed and power density increased to 7.14 m/s and 339 W/m^2, respectively.

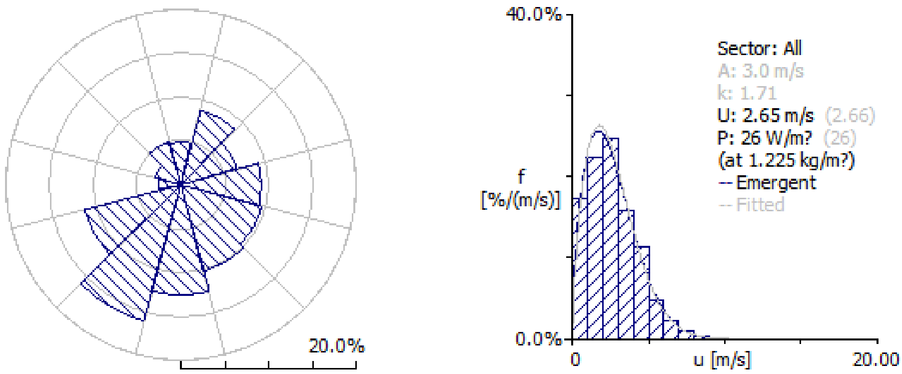

Fig. 13 *Wind rose and Weibull distribution of wind farm site at Pathum Thani 10 m*

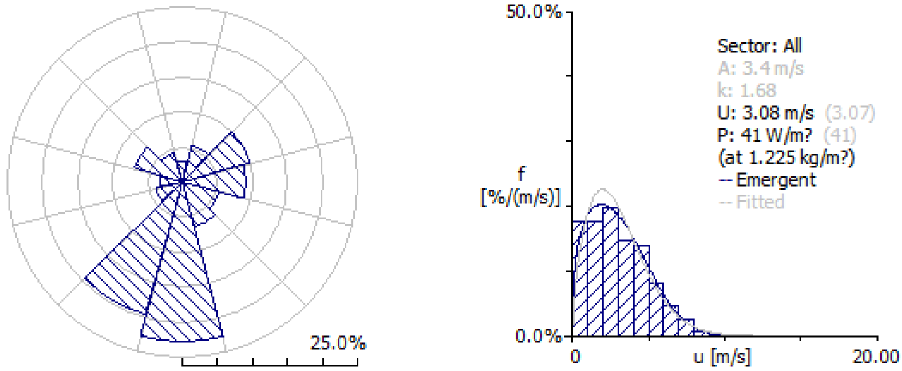

Fig. 14 *Wind rose and Weibull distribution of wind farm site at Bangkok (Bang Na)10 m*

3.3 Wind Energy Potential

This section focuses on assessing the wind energy potential in different districts of Thailand by utilizing wind energy data obtained from selected meteorological stations in the respective regions. The study identified Ayutthaya and Bangkok (Bang Na) had the highest wind power capacity, with annual energy production (AEP) values of 7,827 MWh and 10,637 MWh, respectively. Additionally, Nakhon Sawan and Ayutthaya districts exhibited significant wind power capacity, with AEP values of 7,282 MWh and 13,212 MWh, respectively, at an elevation of 90 m above the ground level. These findings play a crucial role in promoting sustainable energy development in Thailand by providing valuable insights into a region's energy production capacity. This information is particularly significant for investors and developers when they make informed decisions.

3.4 Financial and Technical Performance

This section examines various performance indicators to assess the financial and technical aspects of wind-power projects. The analyzed efficiency indicators include annual energy production (AEP), project cost of value (PVC), net present value (NPV), and leveled energy cost (LCOE). The results indicate that the AN Bonus 1300/62 wind turbines exhibit higher annual energy production (AEP) than the Vestas V52 wind turbines. However, the Vestas V52 model demonstrates lower project cost of value (PVC), net present value (NPV), and leveled energy cost (LCOE) values, indicating higher financial viability. Furthermore, the cost per megawatt-hour ($/MWh) for the AN Bonus 1300/62 model is set at 282.79, whereas that for the Vestas V52 model is set at 174.02. These figures highlight the technical aspects of the studied wind turbine models.

Table 4 *Compare financial values*

Station	Total net AEP (MWh)	Net annual cash flow ($/year)	PVC ($)	BCR	PBP (year)	LCOE ($/MWh)
AN Bonus 1300/62 wind turbine model.						
Ayutthaya	13,212.00	2,503,532.44	12,500,290.95	1.05	4.21	47.31
Bang Na	18,012.00	3,413,081.01	12,500,290.95	0.77	3.08	34.70
Chai Nat	5,030.00	953,131.11	12,500,290.95	2.76	11.05	124.26
Kampaeng Saen	6.27	1,187.15	12,500,290.95	2,217.11	8,868.44	99,762.90
Lop Buri	6,310.00	1,195,677.39	12,500,290.95	2.20	8.81	99.05
Nakorn Sawan	7,282.00	1,379,860.98	12,500,290.95	1.91	7.63	85.83
Pathum Thani	6.29	1,192.27	12,500,290.95	2,207.60	8,830.38	99,334.80
Vestas V52 wind turbine model						
Ayutthaya	7,827.00	1,483,132.64	7,692,489.75	1.09	4.37	49.14
Bang Na	10,637.00	2,015,597.53	7,692,489.75	0.80	3.21	36.16
Chai Nat	2,934.06	555,973.12	7,692,489.75	2.91	11.65	131.09

Station	Total net AEP (MWh)	Net annual cash flow ($/year)	PVC ($)	BCR	PBP (year)	LCOE ($/MWh)
Kampaeng Saen	3,664.89	694,458.15	7,692,489.75	2.33	9.33	104.95
Lop Buri	3,438.63	651,583.16	7,692,489.75	2.49	9.94	111.85
Nakorn Sawan	4,519.27	856,352.68	7,692,489.75	1.89	7.57	85.11
Pathum Thani	3,666.89	694,835.42	7,692,489.75	2.33	9.32	104.89

3.5 Inference from Research Results

The analysis of these findings provides valuable insights into the feasibility of wind energy projects based on topographic simulations and wind potential energy analysis. Elevation topographical simulations and roughness analysis revealed that areas with slightly higher elevations are considered suitable for wind farm installations because of their smoother surfaces, which are more likely to experience higher wind speeds. These findings emphasize the importance of considering the elevation and roughness when selecting an appropriate location for a wind farm. Moreover, simulations conducted for wind potential analysis play a crucial role in evaluating the feasibility of wind power projects by assessing factors such as strong wind direction, average wind speed, and energy density. This analysis aids in determining the viability of harnessing the wind energy in specific areas. The inferences drawn from these findings provide essential guidance for decision-making processes related to wind energy projects. They enable informed choices regarding the project location and feasibility.

4. Conclusions

Based on an in-depth analysis of monthly and yearly wind speed, wind direction, and temperature data, this study aimed to assess the potential of wind energy in the central region of Thailand. The results revealed that the central region, particularly the northeastern and eastern regions, harbors significant wind energy sources. The analysis of wind speed data indicated that the highest wind speeds were observed in March, April, and May, whereas the lowest wind speeds were recorded in July, August, and September. Additionally, the prevailing wind direction in the area predominantly originates from the northeast, followed by the east and southeast. The average temperature ranged between 24 °C and 32°C, providing insights into the climatic conditions relevant to wind power generation.

Moreover, the study employed the Wind Atlas Analysis and Application Program (WAsP) to generate monthly and yearly wind maps. The wind map results highlight that the northeastern part of the study area experienced the highest wind speeds, making it an attractive location for wind power projects. The economic analysis conducted in this study demonstrated the feasibility of the proposed wind power project, with a specific focus on the Bangkok (Bang Na) area. The AN Bonus 1300/62 wind turbine in this area exhibits a benefit-to-cost ratio (BCR) of 0.77, a payback period (PBP) of 3.08 years, and an adjusted cost of energy (LCOE) of $34.70/kilogram-watt hour. However, owing to economic and spatial limitations in the city, the development of projects in this area has become challenging. In contrast, the Ayutthaya area has AN Bonus 1300/62 wind turbine with a benefit-to-cost ratio (BCR) of 1.05, a payback period (PBP) of 4.21 years, and a leveled cost of energy (LCOE) of $47.31 USD/kWh. This establishes it as a recommended area for further research, affirming the economic potential of wind-power generation in the central region of Thailand.

In summary, this study successfully evaluated the wind energy potential in central Thailand, providing valuable insights into the wind resources in selected regions. These findings serve as valuable resources for wind energy developers, enabling them to make informed decisions regarding the viability and economic feasibility of wind energy projects in the region.

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