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Optimum Wind Farm Layout Considering Energy Yield And Wake Losses in Kyonkadun, Ayeyarwaddy Region, Myanmar

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ABSTRACT: *To consider development of wind farm, the most important factor is the site's windresource.This paper selected windy area in Kyonkadun, Ayeyarwaddy region, Myanmar as to downloading wind data nearby MERRA_2 (Modern-Era Retrospective analysis for Research and Applications) reanalysis dataset at latitude 16.06 N and 95.63 E longitude. WAsP (Wind Analysis and Application Program), methodology was adopted for the estimation of wind potential and modeling of wind farm layout in the study area. In the flow modeling by WAsP, higher WPD (wind power density) range from 232 W/m ^{2} to 236.5 W/m ^{2} was extracted for deployment of wind turbine. Two possible wind farm layout configurations (3D× 5D and 5D× 7D) explored for maximum energy yield and minimum wake losses. Standard correction factors considered for arriving net annual energy production, AEP (P_{50} level) and subsequently applied uncertainty factors for arriving P_{90} level of AEP. These optimized layouts propose to support the wind turbine manufacturing/ investor point of view to be implemented the wind power project in rural area, Myanmar.*

Keywords:*energy production, WAsP, wind farm, wake losses, Myanmar*

I. INTRODUCTION

Myanmar's present energy architecture is facing many challenging issues and still struggling to meet the increasing demand of an expanding economy and a growing population. The country's total primary energy supply was about 18 million tons of oil equivalent (MTOE) in 2012. Of this, 54% (9.7 MTOE) was from biomass, 16.6% (3.0 MTOE) from hydro, 15.3% (2.8 MTOE) from oil, 11.45% from gas, and 2.6% from coal. Total installed capacity in 2013 was 3,735 MW—2,780 MW (66.9%) from hydropower, 996 MW (29.5%) from gas, and 120 MW (3.6%) from coal [1]. Currently, as the electrification rate in the country stands at a mere 28.9% [2], the government aims to increase electricity generation from renewable energy resources. According to National Electricity Master Plan (NEMP), renewable energy (only solar and wind) will be 9% (2,000MW) of installed capacity in 2030. Though attention to renewable energy such as solar and wind power is increasing for future power resources, there is no circumstance to introduce them by promoting measures against relatively high generation cost [3]. As for wind power of Myanmar, it is known that there is 4,032 MW technical potential for development of wind energy, particularly in the Shan and Chin states, high areas of the central region, and along the coast [4]. However, wind energy development in Myanmar is only in initial stage such as experimental and research phase. The early studied wind data on potential available wind energy of Myanmar has not yet been fully explored because the data are insufficient to evaluate and find the suitable sites for the wind power project development. In large-scale wind power project plan, two foreign companies, Gunkul Engineering Public Co., Ltd. of Thailand and China Three Gorges Corporation signed an MOU (Memorandum of Understanding). Following this, feasibility studies of 18 sites were initiated. From the next phase of MOU signing with China Three Gorges Corporation, the first wind power project in the Pathein area of Ayayawady Region with the installed capacity of 30 MW will enrich energy organization in Myanmar and partly solve the electricity demand of local residents [5]. Hence, the development of wind energy in Myanmar has weakness compared with other developing countries.

Therefore, this article aims to provide a wind energy potential estimation and to perform micrositting study in Kyonkadun village, Ayeyarwaddy region, by using WAsP (WAsP 11.5). The WAsP software developed by Risø DTU was frequently used for analysis of wind data and application of wind farm in previous research articles by several researchers [6-10]. In this paper, two wind farm layout models will be designed by adoption WAsP methodology [11]. With regards to the results of data analysis, this study can observe optimum wind farm layout configurations with maximum energy yield and minimum wake losses for wind power project development in Myanmar from a starting point.

II. MATERIAL AND METHOD

2.1 Site Description

In the previous wind resource study [12], Ayeyarwaddy region is one of the promising areas in Myanmar. From this result, one of the villages of Ayeyarwaddy region selects for rural electrification because the resource area has not yet connected to the national grid. The study area is in Kyonkadun village, Ayeyarwady region, Myanmar. As it is approximately 9 km inland from the Andaman Sea, it might be a safety area of cyclone. The geographical nature of the area is low density of population, significant naked spaces and absence of protected zones. Due to the recorded data nearby MERRA_2 reanalysis dataset at latitude 16.06 N and 95.63 E longitude (in UTM coordinate system), the selected area of this study has a good wind penetration and can be feasible for future sustainable energy source in Myanmar through by wind energy. Therefore, this area qualifies for the motivation and facilitate of micrositing in this study. The location of the study area and its satellite imagery in Google earth can be seen in Fig.1.

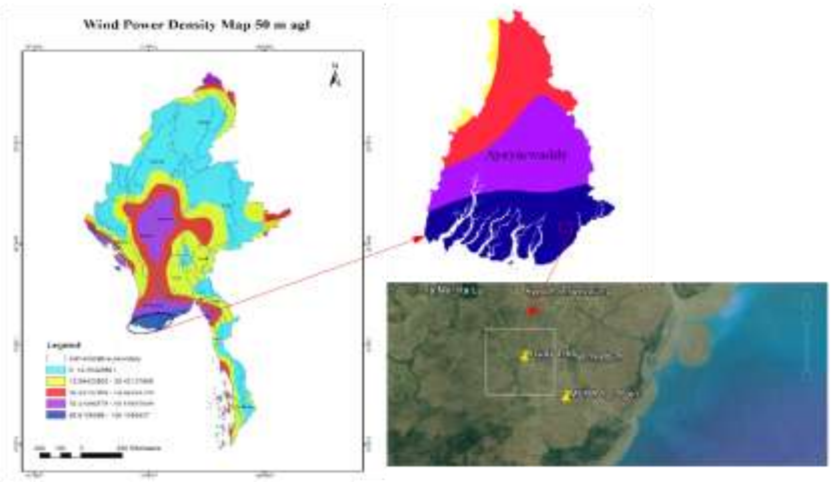

Figure: 1 Location of Study Area

2.2 Wind Characteristics

Required wind speed and direction data of study area, MERRA_2 reanalysis data were downloaded from WindPRO software [13]. The data were measured periodically every one hour averages and 0.5° × 0.67° regularly during 16 years period between January 2000 and up to December 2016. The monthly mean wind speed of study area is shown in Fig.2. The mean of months is 5.26 m/s and higher wind speed is in May to September annually.

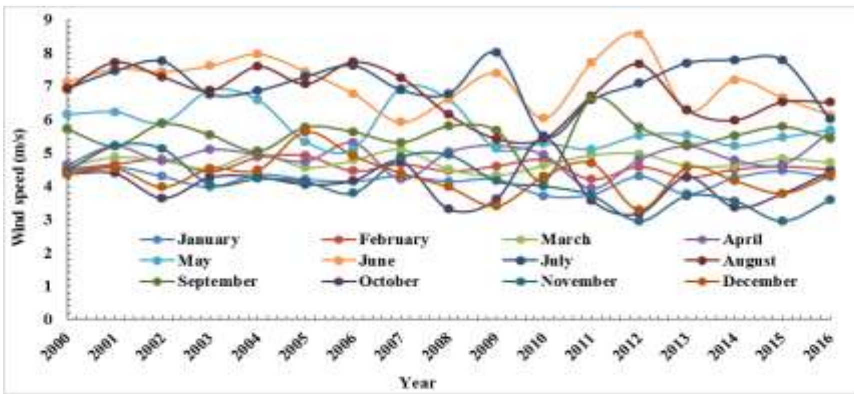

Figure: 2 Monthly Mean Wind Speed of Study Area

Using Weibull probability density function, the regional wind climate of the study area is estimated. The scale and shape parameters are 6m/s (A) and 2.57 (k) respectively. Concerning the wind rose diagram, the prevailing wind direction in the area is from south west. The average wind speed of this area is 5.33m/s of wind speed and 144W/m^2 of wind power density which are shown in Fig. 3.

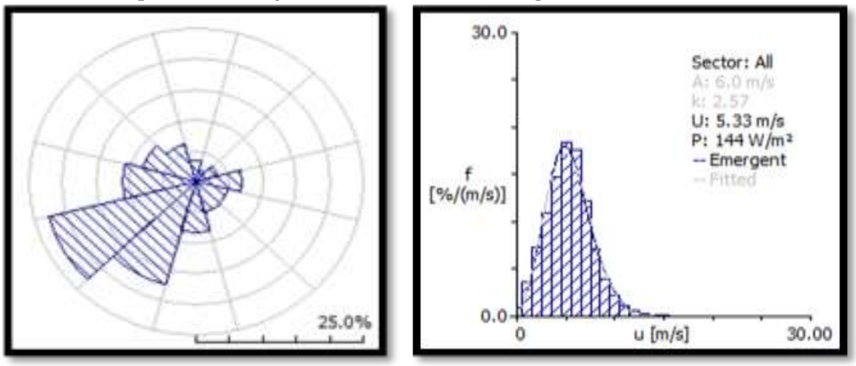

Figure: 3 Wind Direction and Wind Speed with Weibull Distribution at 50 m Height

2.3 Terrain Characteristics

For the topo map, digital terrain maps are derived from SRTM 30 (Shuttle Radar topographic Mission) [14] and produced a height contour map with 5 m interval by ArcGIS 10.1 functions. Simultaneously, the nature of the surface terrain distinguished in roughness parameter for forest, water bodies and settlement, which influence the wind speed. The selected area of topographic model (56.25 m^2) with digitized map is shown in Fig.4.

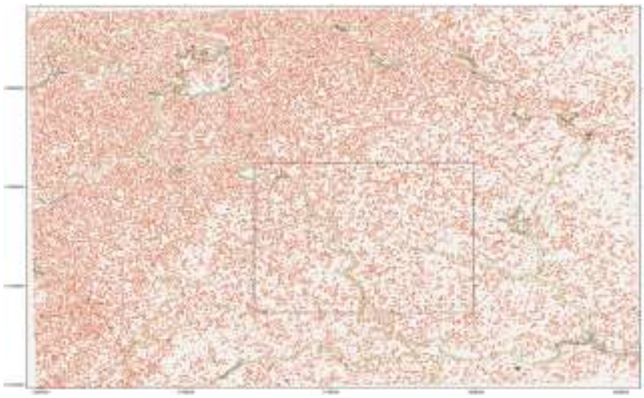

Figure: 4 Digitized Topographic Map of Selected Area

2.4 Adoption of WAsP Methodology

In prediction wind resource and micrositing of study area, WAsP software is used to play a key role. WAsP is a PC-program for the vertical and horizontal extrapolation of wind climate statistics. It contains a complete set of models to enable calculation of the effects of sheltering obstacles, surface roughness changes and terrain height variations to generate the wind atlas. Conceptually, the WAsP methodology consists of five main calculation blocks:

***Analysis of raw wind data*-**This option enables an analysis of any time-series of wind measurements to provide a statistical summary of the observed, site-specific wind climate. This part is implemented in separate software tools: the WAsP Climate Analyst and the older Observed Wind Climate (OWC) Wizard.

Generation of wind atlas data- Analyzed wind data can be converted into a generalized wind climate or wind atlas data set. The wind atlas data sets are site-independent and the wind distributions have been referenced to certain standard conditions.

***Wind climate estimation*-** Using a wind atlas data set calculated by WAsP, the program can estimate the wind climate at any specific point and height by performing the inverse calculation. By introducing descriptions of the terrain around the predicted site, the models can predict the actual, expected wind climate at this site.

***Estimation of wind power potential*-** The total energy content of the mean wind is calculated by WAsP. Furthermore, an estimate of the actual mean energy production of wind turbine can be obtained by providing WAsP with the power curve of the wind turbine in question.

***Calculation of wind farm production*-** Given the power and thrust coefficient curves of the wind turbine and the wind farm layout, WAsP can finally estimate the wake losses for each turbine in a farm and thereby the net annual energy production of each wind turbine and of the entire farm, i.e. the gross production minus the wake losses.

This can be expressed more simply as:

At each turbine site,

Generalized wind climate + turbine site description —> predicted wind climate (PWC)

Predicted wind climate + power curve —> annual energy production (AEP) of wind turbine

Wind farm production,

Predicted wind climates + WTG characteristics —> gross annual energy production of wind farm

Predicted wind climates + WTG characteristics + wind farm layout —> wind farm wake losses

Gross annual energy productions + wake losses —> net annual energy production of wind farm

The above WAsP methodological [12] steps conducted to optimize wind farm layout of study area for future development of wind power project in rural area, Myanmar.

III. RESULTS

3.1 Wind Resource Mapping

When WAsP created a generalized wind climate for study area, the mean wind speed has calculated from the 16 years of MERRA_2 reanalysis wind data. The observed wind climate has thereby been referenced to certain standard conditions, i.e. wind roses and wind speed distributions for five standard heights and five roughness classes in a number of sectors (usually 12 sectors) of directions. The site air density is 1.162 kg/m^3 (Air density calculated is based on MERRA_2 Temperature data and site altitude). Actual details of the terrain characteristics were collected through satellite imaginary and Google maps at the site and its surroundings. Since there is no significant obstacle offering shelter effect at the point of observation, no obstacle file was created. Based on the digitized 5 m interval contour map and other basic inputs, wind resource mapping of region generated at 100m height with the spatial resolution of 25 m × 25 m and represented by each color range of mean wind power density from 223W/m^2 to 236.5 W/m^2. The results demonstrated that wind power potential map of study area as shown in Fig.5. The high quality wind penetration areas were extracted from the wind resource map for the deployment of wind turbine. The red colors are displayed in the highest area of the region and range from 232W/m^2 to 236.5 W/m^2 of wind power density. The higher wind potential areas are shown in Fig.6.

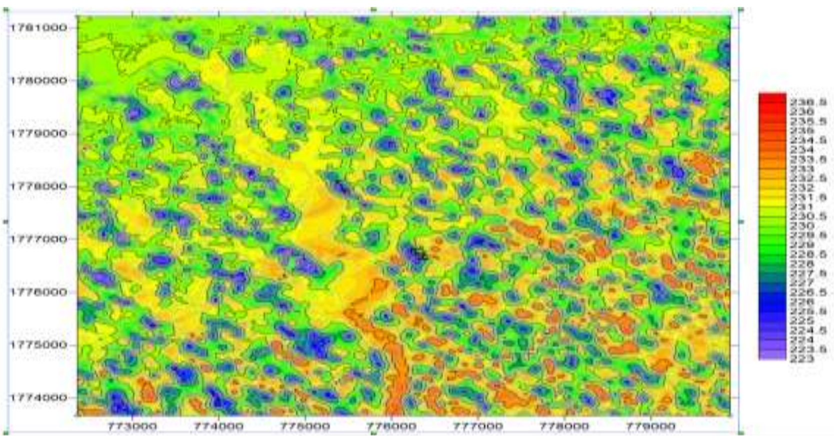

Figure: 5 Wind Potential Map at 100 m Height for Study Area

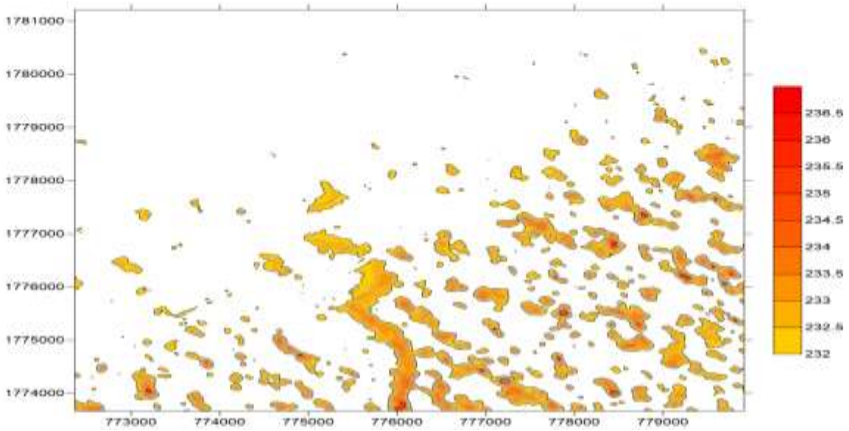

Figure: 6 Available Area for Installing Wind Turbines

3.2 Wind Farm Layout

For the simulation of wind farm in the higher red spot area of the region, 2MW normalized wind turbine generator, WTG (Rotor diameter -100m, Hub Height -100m) was selected. With the available proposed wind turbine power curve (see in Fig.7), it can estimate the annual energy production (AEP) at each of the turbines in the wind farm layout.

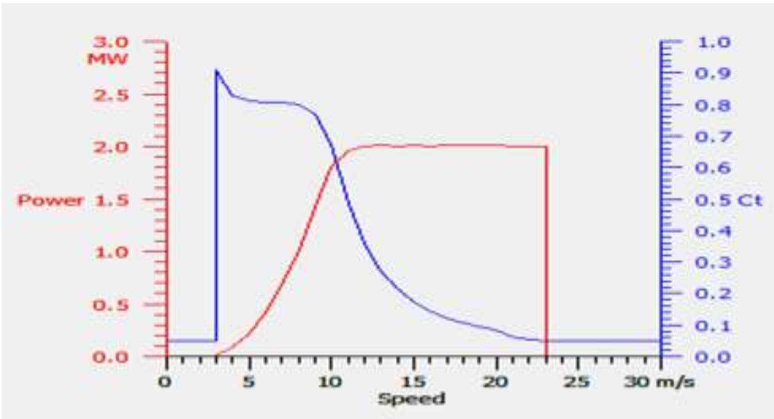

Figure: 7 Power Curve of 2MW Wind Turbine

The thrust coefficient curves of the turbine and the wind farm layout are then used to estimate the wake losses for each turbine. The net annual energy yield can then be estimated. Due to the wind speed reduction in wakes from up-wind turbines, the WAsP model implemented the Park model to estimate wake effects. This is a very important feature for wind farm analysis because placement in a low wind speed location produce very little power and placing a turbine within the proximity of another turbine can significantly lower the production at one of the sites due to wake effects. Hence, for the study area, two wind farm configurations (3D× 5D and 5D× 7D) were used in WAsP Park model with number of 41 wind turbines for 82 MW and 31 wind turbines for 62 MW of wind farm generation capacity respectively. The sitting of wind turbines in the park at higher wind power density (red spot), areas of the region were shown in Fig.8 and Fig.9.

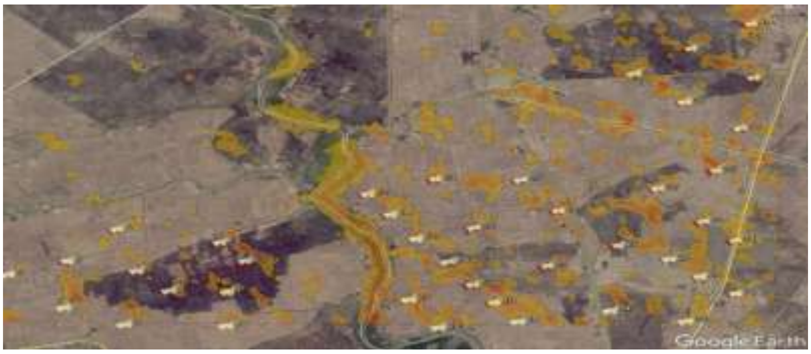

Figure: 8 Wind Farm Layout (3D× 5D) in Study Area

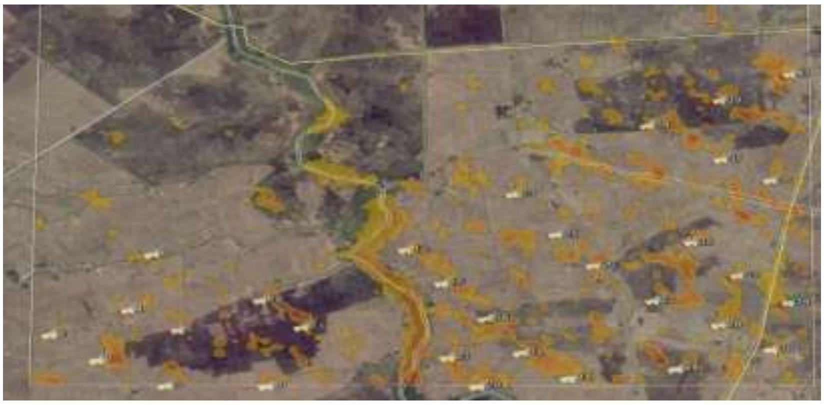

Figure: 9 Wind Farm Layout (5D× 7D) in Study Area

When these wind turbines were parked in two configurations and simulated in WAsP, potential annual energy production and average wake losses were estimated. As wind atlas was prepared for Europe using WAsP indicates that the prediction may differ up to +/- 15% or more, WAsP model has its own limitations. Therefore, standard correction factors based on the industrial practice were assumed in the study for estimation of net energy production (P_{50}) given in Table I.

Table I. Standard Correction Factors

Machine Availability	95%
Grid Availability	95%
Electrical Transmission Losses	3%
Anticipated Adjacent Wind farm wake losses	5%
Air density correction	5%

Applied these standard correction factors, the result of wind farm net annual energy (GWh) (P_{50}), wind farm net capacity utilization factor, CUF (%) and average wake loss (%) were examined for developer/manufactures point of view as shown in Table II.

Table II. P_{50} Results

Study WTG	Configuration	No of WTG	Wind Farm Capacity (MW)	Average Wake loss (%)	Wind Farm Net Energy (GWh) (P_{50})	Wind Farm Net CUF (%) (P_{50})
2MW	3D x 5D	41	82	9.67	167.27	23.3%
	5D x 7D	31	62	6.44	130.87	24.1%

The 3D×5D configuration result showed that the total net energy (P_{50}) for 41 wind turbines were 167.27 GWh, with net capacity utilization factor (P_{50}) around 23.3% and average wake losses 9.67%. In 5D× 7D configuration, total net energy (P_{50}) for 31 wind turbines were 130.87 GWh, with net capacity utilization factor (P_{50}) around 24.1% and average wake losses 6.44%. Based on the wind farm capacities and number of turbines, the P_{50} results were captured in Fig.10 with two configurations.

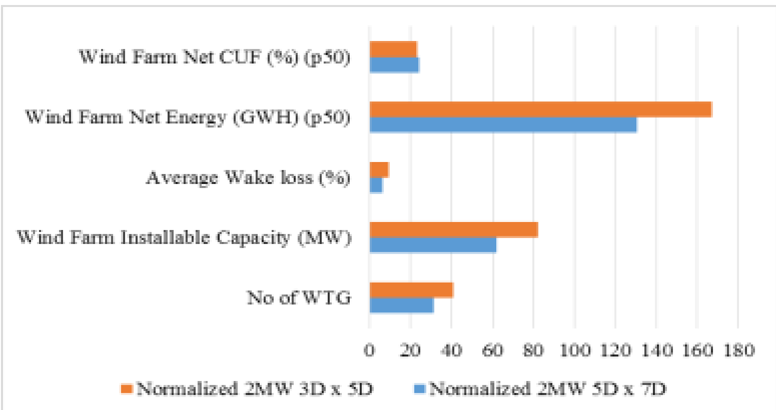

Figure: 10 Comparison Results between Two Wind Farm Layout Configurations

Although 3D× 5D configuration has greater wind farm net energy, the wind farm net CUF is lower and wake loss is higher than 5D× 7D configuration. However, this study results carried out two possible wind farm configurations for the area with minimum wake losses (<10%) in individual wind turbines and indicative wind farm CUF (>20%). Additionally, uncertainty factors were also considered for capacity P_{90} level (Confidence of Probability) in the study. These factors were shown in Table III.

Table III. Lists of Uncertainty Factors

1	Wind Measurement (For MERRA_2 data set)
2	Inter annual variation
3	Vertical Extrapolation
4	Horizontal Extrapolation
5	Input file accuracy (Orography + Roughness)
6	Power curve

Regarding to the RSS (Root Sum Square) values, Uncertainty factor is 15.9%, the resultant AEP at P_{90} level were 133.04 GWh of net energy, 18.5% of CUF in 3D×5D configuration with 41 wind turbines. Consequently, 104.09 GWh of net energy and 19.2% capacity utilization were estimated in 5D×7D configuration with 31 wind turbines. These results are shown in Table IV.

Table IV. P_{90} Results

Study WTG	Configuration	No of WTG	Wind Farm Capacity (MW)	Average Wake loss (%)	Wind Farm Net Energy (GWh) (P_{90})	Wind Farm Net CUF (%) (P_{90})
2MW	3D x 5D	41	82	11.6	133.04	18.5%
	5D x 7D	31	62	7.82	104.09	19.2%

Comparing results of these two layout configurations included with standard correction factors and uncertainty factors, in 5D× 7D configuration has higher capacity utilization factor and lower wake loss although the net energy is less than 3D× 5D. Possible use of more wind turbines, higher energy can be generated by 3D × 5D configuration for the area. When wind turbine and land area are limited in the area, 5D× 7D configuration will be suitable one. Therefore, depending on the demand side, the required layout plan could be selected for the area. Moreover, considering of P_{50} and P_{90} results proved that the area has potential for developing wind farm project and can generate electricity by wind energy in rural area, Myanmar. This theoretical concept prompts to give a guideline to the researchers, policy makers and practitioners who plan to make micrositing in the other areas of wind farm project, Myanmar to fulfill NEMP targeted 9% (2,000MW) of installed capacity by wind and solar project in 2030.

IV. CONCLUSION

The paper discusses the possibility of wind power generation for rural community in Kyonkadun ,Ayeyarwaddy region, Myanmar. Based on 16 years nearby MERRA_2 re-analysis dataset, the wind resource map of study area was generated at 100m height. This resource map is indicating a good magnitude of the wind resource; wind speed is about 5.5 m/s and 236.5 W/m^2 of wind power density. Therefore, this study identified the promising area for future wind farm feasibility investigation.

From the result wind potential map, micrositing has been carried out in the Kyonkadam area with two wind farm layout configurations (3D× 5D and 5D× 7D) included with standard correction factors and uncertainty factors to estimate AEP at different probability levels. While the 3D× 5D layout configuration has greater wind farm net energy production, higher wakeless and lower CUF, the 5D× 7D has lower AEP, less wake losses and higher CUF. Therefore, this hypothesis offered a preliminary overview wind farm layout to support companies, investors and government institutions to be a better understanding of wind project considerations not only in this area but also other windy areas in Myanmar.

As input data taken from the public domain as MERRA_2 reanalysis data, topography (SRTM 30) and WTG Power & Thrust Curve (normalized 2MW), this study would also substantiate as a sample project for the other windy areas, not only in Myanmar but also in other countries where onsite wind measurement has not yet started.

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