Evaluation of projected decadal wind energy potential in Chiang Mai

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Abstract. One of the alternative energy sources which have globally pay more attention is wind power. In this research, the Weibull wind speed distribution was applied to evaluate wind energy potential during the period of 2081-2090. The projected wind datasets in this study were simulated by the Non hydrostatic Regional Climate Model (NHRCM). The boundary condition was the 20 km resolution MRI Atmospheric General Circulation Model (AGCM20) under the RCP8.5 scenario. The surface wind datasets in Chiang Mai were analyzed to 3-time intervals, i.e., May-August, September-December and January-April. Two averaged Weibull distribution parameters, i.e., k, shape parameter, and c, scale parameter were determined. The shape and scale parameters fluctuated 1.15 to 1.34 and 0.38 m/s to 0.74 m/s, respectively. It was found that the surface mean wind speed from May through August was stronger than from September through December.

1. Introduction

Wind energy is one of the sustainable energy sources which is dynamic and depends on weather conditions. It can be applied for small-scale usages such as battery charging, water pumping to industrial scales such as wind power plants. Wind speeds and directions in a local area may differ from the general circulation of the atmosphere. Wind speed plays an important role in wind energy potential. To evaluate wind energy potential on a regional scale, the wind speed probability distribution must be determined accurately. History record of observed wind speed may be evaluated wind potential for the current climate at a certain stationary location.

A regional climate model is a tool for simulating wind speed at any point over the region. It can be done either over the current climate to investigate the new points where possibly provide high wind energy potential or evaluate the potential of wind energy resources in the future concerned with climate change effect. There are regional and global climate models provided by various institutes for simulating climate parameters, including wind speed. Those models have been developing to improve model performances to understand past climate and project future climate with higher degrees of confidence. A higher resolution climate model is commonly run with more detailed processes to provide surface climate parameters in probability density function and extreme study. Using realistic RCM to project surface wind resource is limited.

Some regions, for example, Thailand, are affected by the prevailing winds. During the southwest monsoon period, mid-May to mid-October, the wind blows in from the Bay of Bengal and reaches the western part of the mountainous area in Thailand. During the northeast monsoon period, November to January, the wind comes from cold and dry higher latitudes. In this work, the surface wind projected by high-resolution RCM energy was statistically analyzed using the Weibull distribution to evaluate wind energy potential in Chiang Mai, Thailand. The finding of this study possibly provides more information to quantitative wind speed distribution at the end of this century.

2. Materials and methods

2.1. Simulation of wind data

The decadal wind datasets in Chiang Mai were collected from the projected climate simulation of the Non-hydrostatic Regional Climate Model (NHRCM), a high-resolution climate model developed by the Japan Meteorological Agency. The regional model was driven by the 20 km resolution MRI Atmospheric General Circulation Model (AGCM20) under the high emission scenario, Representative Concentration Pathway (RCP) 8.5. The model simulation was set in 5 km resolution which the mountainous and complex topography was applied in the simulation. The selected domain covers Indochina, part of the South China Sea and Bay of Bengal which has land and sea interaction impact. The Initial time condition was selected at the beginning of April when it was in the period of the dry season to avoid the atmosphere and land moisture effects. Parameterization schemes are Kain-Fritsch scheme for cumulus convection and Mellor-Yamada for Planetary Boundary Layer [1]. One month simulation was abandoned as model spin-up. Daily wind simulations for the whole period of 2081-2090 were manipulated by using the nearest grid point method to collect wind datasets in Chiang Mai for wind potential energy analysis.

2.2. Weibull distribution

The probabilistic model of wind speed Weibull distribution was commonly analyzed to study wind potential at different locations. Two functions, i.e., the probability density function (PDF) and the cumulative distribution function (CDF), were also determined in this study [2]. The Weibull density probability function, $f(v)$ expresses the probability of the wind or the frequency of occurrence which has a certain speed (v) in m/s during the selected period [3]. It can be determined by equation (1).

$$f(v)=\frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^{k}} \tag{1}$$

where k is the nondimensional shape parameter and c is the scale parameter [4, 5].

The cumulative distribution function of the velocity v, $F(v)$, implied the probability of the wind which below a certain speed. It can be determined by integrating PDF as shown in equation (2).

$$F(v)=\int_{0}^{\infty} f(v)dv = 1-e^{-\left(\frac{v}{c}\right)^{k}} \tag{2}$$

The k and c parameters can be determined by the graphical method. Firstly, The CDF can be rewritten as the following equation.

$$1-F(v)=e^{-\left(\frac{v}{c}\right)^{k}}$$

Using logarithm transformation, it can be rewritten as a linear equation.

$$\ln\left\{-\ln\left[1-F(v)\right]\right\} = k\ln(v_i) - k\ln c \tag{3}$$

By plotting the linear regression between $\ln(v_i)$ as x-axis and $\ln\left\{-\ln\left[1-F(v)\right]\right\}$ as y-axis. It is clearly seen that k is the slope and $-k\ln c$ is the y-intercept. The small value of k parameter indicates that the behavior distribution of wind speed reduces to an exponential distribution. On the other hand, the increased shape parameter gradually transforms wind speed distribution to normal distribution. The scale parameter, c, corresponds to wind speed distribution around the average. Increasing the value of c parameter affects increasing wind speed variability while maintaining its shape.

3. Results and discussion

The surface wind speeds and directions in Chiang Mai during 2081-2090 were collected from the NHRCM simulation under RCP 8.5 scenario. The data were analyzed in 3-time intervals, i.e., May-August, September-December, and January-April. The Weibull shape and scale parameter were determined by the graphical method shown in table 1. The minimum value of k implies that the smallest wind speed distribution around the average during the southwest monsoon active period was found in the future.

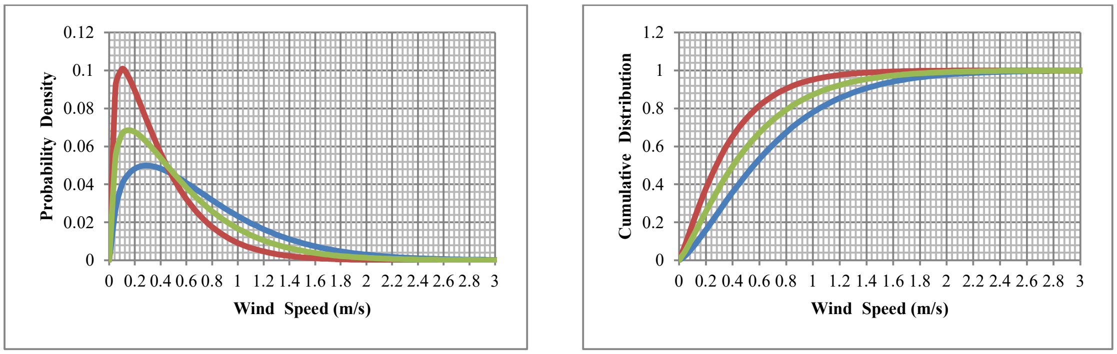
The calculation of k and c were applied to display the Weibull distribution and cumulative Weibull distributions. The Weibull probability density functions indicated the frequency of surface wind speed were shown in figure 1 (a). The graph displays the most prevalent wind speed during three-time intervals. The most prevalent wind speed was 0.1 m/s during September-December and January-April, while the range of 0.2-0.4 m/s was found as the most prevalent wind speed during May-August. It is suggested that the falling frequency indicates less probability at a certain wind speed. In the future, the probability of occurrence of the wind speed beyond 2.4 m/s was less in Chiang Mai.

The mean wind speed variations for the future period ranged from 0.4 m/s during September-December to 0.8 m/s during May-August (figure 2). The strongest in monthly mean wind speeds were found in June, July, February, and March, respectively, while the weakest wind speeds were found in November and December, respectively (data not shown here). It implies that the wind speed during the middle of the monsoon active period is stronger than the other period. On the other hand, the periods excluding the wet season have the least maximum mean wind speed.

The Weibull cumulative distribution functions were shown in figure 1 (b). CDF analysis revealed that at Chiang Mai, 50% of the data ranged from 0.25 to 0.6 m/s and below, while 80% of the data ranged from less than 0.6-1.2 m/s, across the period considered. The wider variation of wind speeds was also found above 50% of the data. From this analysis, it was found that wind speed below 1.7 m/s (1.45 m/s) was more prevailing at the probability of 95% occurrence during the southwest (northeast) monsoon active.

Table 1. The shape and scale parameter at Chiang Mai.

time interval	k	c
May-August	1.34	0.74
September-December	1.15	0.38
January-April	1.20	0.55



(a) (b)

Figure 1. (a) Weibull probability distribution functions (b) cumulative distribution functions at Chiang Mai during May-August (blue), September-December (red) and January-April (green).

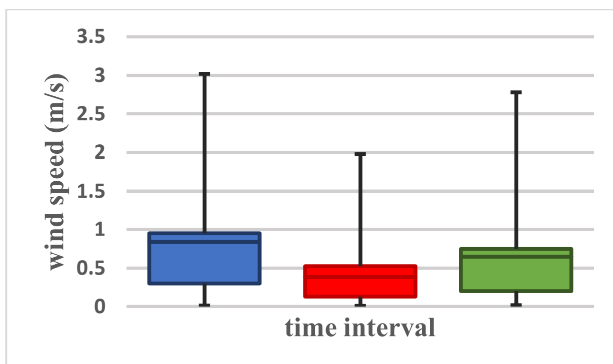


Figure 2. Box plot of wind speed during May-August (blue), September-December (red) and January-April (green). The line within the box plots indicates the median value, while the box bottom and top show the 25th and 75th percentile, respectively. Whiskers indicate the maximum and minimum.

4. Conclusion

The Weibull probability density functions of wind speeds were the right-skewed distributions during all three intervals. It was found that 90% of total wind speeds were less than 1.3, 0.5, and 1.1 m/s during May-August, September-December, and January-April, respectively. It could be noticed that the wind speeds at Chiang Mai in the future during May to August were higher than other periods.

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