Wind Resource Maps for Cambodia

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Abstract: This paper presents maps of the monthly and annual mean wind speed and direction at the height of 50 m above the ground in Cambodia. The wind speed is calculated by the Karlsruhe Atmospheric Mesoscale Model using atmospheric data from NCEP/NCAR for the years 1977-2006 as input data. Average wind speed is calculated by using the wind class approach. Wind data from four new wind measuring stations in Cambodia and from nearby wind measuring stations in Vietnam and Thailand are used to validate the model. The validation results show that the values of the calculated and measured wind speeds are in reasonable agreement. The values of wind speed obtained from the model are then used to generate the wind resource maps. The annual map reveals that relatively high wind speed areas are situated in the northeastern part of the country with the maximum annual mean wind speeds of 5-6 m/s.

Keywords: wind energy, atmospheric mesoscale model, Cambodia, wind resource map.

1. Introduction

Cambodia is located in the tropical zone of Southeast Asia. The main commercial energy supply of the country is imported fossil fuels. To strengthen its economic development, the country is seeking domestic renewable energy resources. Like other Southeast Asian countries, wind is considered as a potential energy resource for Cambodia because the country is situated in an area where the Asian monsoons prevail [1-2]. As energy of a wind stream depends strongly on wind speed, information on wind speed at a location of interest is an essential prerequisite for wind energy development at that location. In general, wind speed varies with locations. As a result, geographical distributions of wind speeds in the form of wind resource maps are useful for wind energy developers. The maps can be used to select an optimal site for an installation of wind turbines. Due to their importance, a number of wind resource maps have been developed for many parts of the world [3-12].

Ideally, such maps should be obtained from an accurate long-term wind data collected from a large number of well exposed stations covering an area of interest. However, due to the equipment and operating costs, the existing wind measuring stations are too sparse in most part of the world, especially in developing countries. For a case of Cambodia, prior to this study, only a few wind measuring stations were available for meteorological purposes and wind data from these stations are not sufficient for the development of wind resource maps.

As wind is a movement of the mass of air in the atmosphere, it is possible to calculate wind speed and its directions over an area of interest by using an atmospheric model [13]. This technique has the advantage that it can be used to calculate a long-term average wind speed by employing historical large-scale atmospheric data available for most parts of the world as input data of the model. Wind data from a few existing measurement stations can be used only for model validation.

Due to this advantage, a number of atmospheric models have been employed to calculate wind speed in many countries [5-12,14-18]. The objective of this work is to generate wind resource maps which demonstrate a wind energy potential of Cambodia. In this research project, four new wind measuring stations are also established in different parts of the country for the model validation.

2. Methodology

In this study, wind resource maps for Cambodia are generated using an atmospheric mesoscale model. The process for generating the wind resource maps consists of the selection of the atmospheric model, preparation of terrain and atmospheric data, wind class analysis, wind calculation, model validation and generation of wind resource maps. Details of each step are described as follows.

2.1 Selection of an atmospheric model for calculating wind

In general, wind maps can be broadly categorized as a microscale map, a mesoscale map and a large scale map. A microscale wind map usually covers a small area with a high resolution, approximately from a few meters to several hundred meters whereas a mesoscale wind map is normally generated for a specific part of a country or the entire area of a country with a resolution of a few kilometers. For the case of a large scale wind map, it usually demonstrates the general pattern of geographical distribution of wind speed over a large region with a resolution of a few degrees of latitude and longitude. A microscale wind map is a useful tool for micrositing of a wind farm. At present, there are several commercial softwares available for producing such a map (eg. WAsP from Risø National Laboratory, Technical University of Denmark and Meteodyn WT from Meteodyn Co. Ltd, France). The wind calculations of these softwares are normally based on statistical approaches or computational fluid dynamics (CFD). Due to the small area covered by the map, the Coriolis force is not taken into account in the models used by these softwares. A mesoscale wind map is normally produced by using an atmospheric mesoscale model which includes the effect of the Coriolis force. This is because the flow of wind usually crosses several degrees of latitude and consequently the earth's rotation significantly affects the movement of air. For the case of a large scale wind map, it can be generated by using a general circulation model (GCM) with the resolution of a few degrees of latitudes and longitudes.

As this work is aimed to create wind resource maps which demonstrate wind energy potential of Cambodia, the mesoscale wind map is the most suitable to construct for this purpose. To generate such map, Karlsruhe Atmospheric Mesoscale Mode (KAMM) is chosen for the wind calculation as it has been successfully used to calculate mesoscale wind in several countries [9,17-18].

KAMM is a 3-dimensional non-hydrostatic and incompressible model. The basic equations are described by Adrian and Fiedler [19]. It represents the fundamental physics of atmospheric motion including the conservation of mass, the conservation of momentum and the conservation of energy. This model is able to predict wind speed and its direction by calculating the heat balance and humidity balance, which are determined from fluid dynamic and thermodynamic equations taking into account of local topographic features, land-use variation and the roughness of terrains.

2.2 Preparation of terrain and atmospheric data

In order to compute wind speed and its direction, KAMM requires roughness and elevation data of terrains together with atmospheric basic state data. The preparations of the data are described as follows.

Elevation data

The elevation data derived from NASA's Shuttle Radar Topography Mission (SRTM30) dataset (version 2) are used in this study. The data are in a latitude-longitude projection at 30 arc second resolution. These data are converted into a Universal Transverse Mercator (UTM) coordinate system with a spatial resolution of 5 km as required by KAMM.

Terrain roughness

The roughness length data are derived from the United States Geological Survey (USGS) Global Cover Classification, also known as GLCC. By means of a look-up table, the land-use types are converted into roughness lengths. This roughness data are also converted into the UTM coordinate system.

Atmospheric basic state data

For each domain of calculation, KAMM requires vertical profile of wind speed in north – south and east – west directions, potential temperature and relative humidity at only one location in the domain of calculation to initialize the model. As the shape of the area of Cambodia is similar to a rectangle with the width of about 500 km and the length of approximately 600 km, one domain is sufficient for wind calculation. This domain has a rectangular shape with latitude between 9.90°N and 14.90°N, and the longitude between 101.80°E and 108.20°E. In this study, the reanalysis datasets of National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) at 11.25°N, 106.25°E with a resolution of 2.5° × 2.5° for a 30-year period (1977-2006) are used to initialize the model [20]. The data consist of geostrophic wind, geopotential height, temperature, and relative humidity at 1000 hPa, 850 hPa, 700 hPa, and 500 hPa isobaric surfaces. The geostrophic wind is converted into east-west and north-south components of the wind at the heights of 0 m, 1500 m, 3000 m and 5500 m above the ground level.

2.3 Wind class analysis

In general, wind resource maps of an area of interest are aimed to demonstrate wind climatology of that area. Therefore, long-term wind data are needed to generate such maps. In principle, for the case of Cambodia, hourly wind speed over the country encompassing the 30-year period should be calculated and the results are averaged to obtain the mean wind speed. However, to use KAMM to calculate directly the hourly wind speed for such long period requires a great deal of computing time. To avoid this problem, we propose to use the wind class technique developed at Risø to generate wind data [14].

This technique is based on the fact that the atmospheric basic state data, which is the main input of KAMM, can be classified into classes according to the wind speed, wind direction, and the stability of the atmosphere. In addition, the probability of occurrence of each wind class can be calculated.

With the information on the wind speed, wind direction and the probability of occurrence of all classes, the mean wind speed can be finally obtained. The technique has the advantage that it requires only the calculation of the wind speed and its direction for each class, thus reducing the computing time.

In this work, the atmospheric basic state data at the selected position in the calculation domain (11.25°N, 106.25°E) over the 30-year period (1977-2006) are classified into 149 classes, according to the wind speed, wind direction, and the stability of the atmosphere. The stability is quantified by the square of the inverse Froude number ($1/Fr^2$) [14]. This classification can be shown as a diagram in Fig. 1.

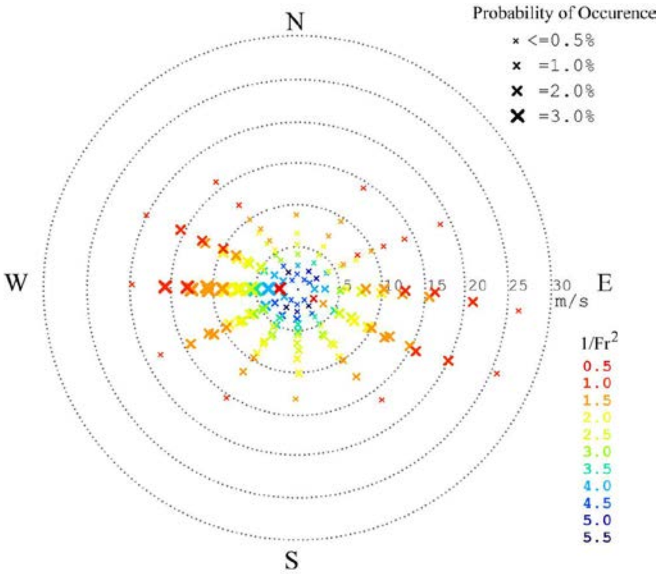

Figure 1. The wind classes at the position 11.25°N, 106.25°E in Cambodia over the period of 30 years (1977-2006). The "×" represents each wind class. The distance from the center of the diagram to position of each class represents the wind speed. The angle in clockwise direction between the north-south line and the radius line passing the position of the class (×) indicates the wind direction. The colour and size of the "×" represent the atmospheric stability indicated by ($1/Fr^2$), and the probability of occurrence, respectively.

The calculation of wind speed is carried out by employing a supercomputer with 240 processors (Dell PowerEdge 750) of RisØ National Laboratory, Technical University of Denmark [21]. With this supercomputer, the calculation of wind speed for 149 wind classes requires the computing time of about 20 minutes. KAMM has been run to calculate directly hourly wind speed for 15 years by using a supercomputer (NEC, model SX8) of Karlsruhe Institute of Technology, Germany [22] and the computing time needed for this calculation is approximately 1800 hours. Based on the capacity of these two supercomputers and the computing tasks, the wind class approach uses much less computing time than the direct calculation of hourly wind speed over a 30-year period by the factor of 10^4.

In the next step, the basic state data of each wind class are used as input of KAMM for wind calculation over the country.

2.4 Wind calculation

As the centered finite difference model is used in KAMM, the space over Cambodia is divided into 3-dimensional grids with the horizontal resolution of 5 km x 5 km. In the vertical direction, the calculation domain extends from the sea level to the height of 10 km and it is divided into 50 levels for the wind calculation. The interval between the two consecutive levels is not uniform with closely spaced levels near the ground.

In calculating wind for each class, the basic state data of that class at the position: 11.25°N and 106.25°E at 7.00 am local time is given to KAMM then it calculates the wind speed and its direction at all the 3-dimensional grids for every hour. The similar calculation is carried out for all wind classes. In the final step, the values of wind speed at each grid calculated from all wind classes are averaged using the probability of occurrence of each class as a weighting factor.

2.5 Model of validation

Wind measurements

In order to validate the model, four wind monitoring stations are established in Cambodia. These stations are located at Siem Reap (13.38 °N, 103.83 °E), Kompong Thom (12.69 °N, 104.90 °E), Phnom Penh (11.56 °N, 104.85 °E) and Sihanouke Ville (10.62 °N, 103.50 °E). The wind masts at Siem Reap, Kompong Thom and Sihanouke Ville are 50 m in height whereas the wind mast at Phnom Penh is 30 m in height. For each station, anemometer (Nexgen wind, model Maximum#40) with data logger (Nomad2, model Secondwind) is installed at the top of the wind mast. The wind data obtained for all stations are regularly transferred by email to our laboratory at Silpakorn University in Thailand. Approximately, one-year period of wind data from these stations are obtained and used for the model validation. In addition, wind data for the period of 1-2 years from Thai and 6-8 years from Vietnamese meteorological stations situated near the Cambodian border are also employed for the validation. The wind measurements at the Vietnamese stations and Thai stations are carried out at the heights of 10 meters and 40 meters, respectively. The positions of all stations whose wind data are used for model validation are shown in Fig. 2.

Figure 2. The positions of the stations whose data are used for the model validation.

Method validation

The results obtained from KAMM are mesoscale wind with the resolution of 5 km × 5 km whereas the wind data from the measurements are obtained from specific locations. Consequently, they cannot be directly compared. To overcome this problem, both wind data from the calculation and those from the measurements are converted into generalized wind.

The generalized wind is the wind over a flat terrain with a given value of height and roughness length [14]. Therefore the effect of the elevation of terrain is removed. In this study, the WAsP software developed by Risø (www.wasp.dk) is used for converting the calculated and measured winds into the generalized wind and results are compared (Fig. 3).

From Fig. 3, it is observed that the data points are scattered around the 1:1 line with the root mean square difference (RMSD) of 13.8% and mean bias difference (MBD) of -1.1% with respect to the mean measured wind speed. This result indicates that the model performs reasonably in predicting the wind speed in this region.

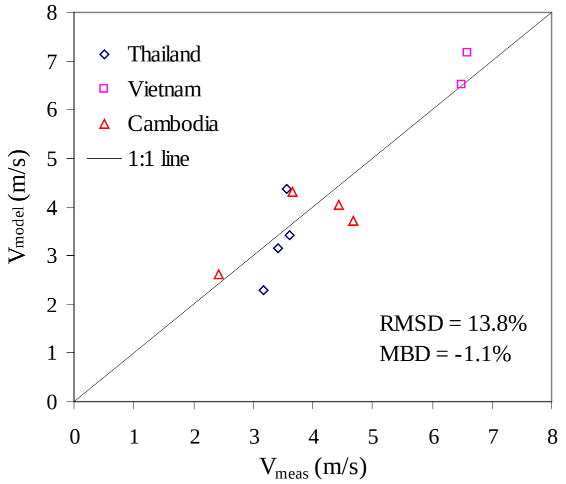

Figure 3. The comparison between the generalized yearly mean wind speed from the model (V_{model}) and that from the measurements (V_{meas}) at the height of 50 m and the roughness length of 0.03 m.

After the validation, the values of mean wind speed obtained from the model for the height of 50 m above the ground are displayed as monthly and yearly maps, as depicted in Fig. 4 and 5, respectively.

3. Results and discussion

From Fig. 4, in January and February, the area in the northeast of Cambodia has an average wind speed of 6-7 m/s, as a result of the winter monsoon from the South China Sea blowing through Vietnam to the northeast of Cambodia. The topography of this area also helps to increase the wind speed. The wind speed of approximately 5 m/s can be observed in the mountainous area of the southwest, while only a relatively low wind speed of 2-3 m/s is observed in the south. In March, less area of high wind speed can be observed, as compared to that of January and February. In March, the overall wind speed is low because these months correspond to the transitional period from the winter monsoon to the summer monsoon. In May, the summer monsoon starts to blow from the Gulf of Thailand to Cambodia. The wind speed increases slowly from June to August as the summer monsoon intensifies. In this period, the wind speed in the mountainous area in the southwest is approximately 5-6 m/s. The mountains in the southwest area help to enhance the wind speed. In September, wind speed is relatively low as this month corresponds to the end of the summer monsoon. In general, October corresponds to the transitional period from the summer monsoon to the winter monsoon with the increase of wind speed in the northeastern part of the country. The areas with the wind speed of 5 m/s are observed in the northeast of Cambodia. These areas significantly expand in November and December.

Fig. 5 shows the annual mean wind speed. The areas with the annual mean wind speed of approximately 5-6 m/s are found in the northeast and the mountainous area in the southwest. In addition, it is observed that most parts of the country have a low annual mean wind speed.

Based on the annual wind speed data, the average of wind power is also calculated and displayed as a map (Fig. 6). It was found that most areas of Cambodia exhibit low wind power, being less than 50 W/m^2. In addition, the areas with relatively high wind power (200-300 W/m^2) are found in the northeastern Cambodia and along the mountain range in the southwest part of the country.

The geographical distribution of wind speed and wind power incorporated with information on infrastructure required for wind turbine installation can be used to select optimum sites for wind farms in Cambodia.

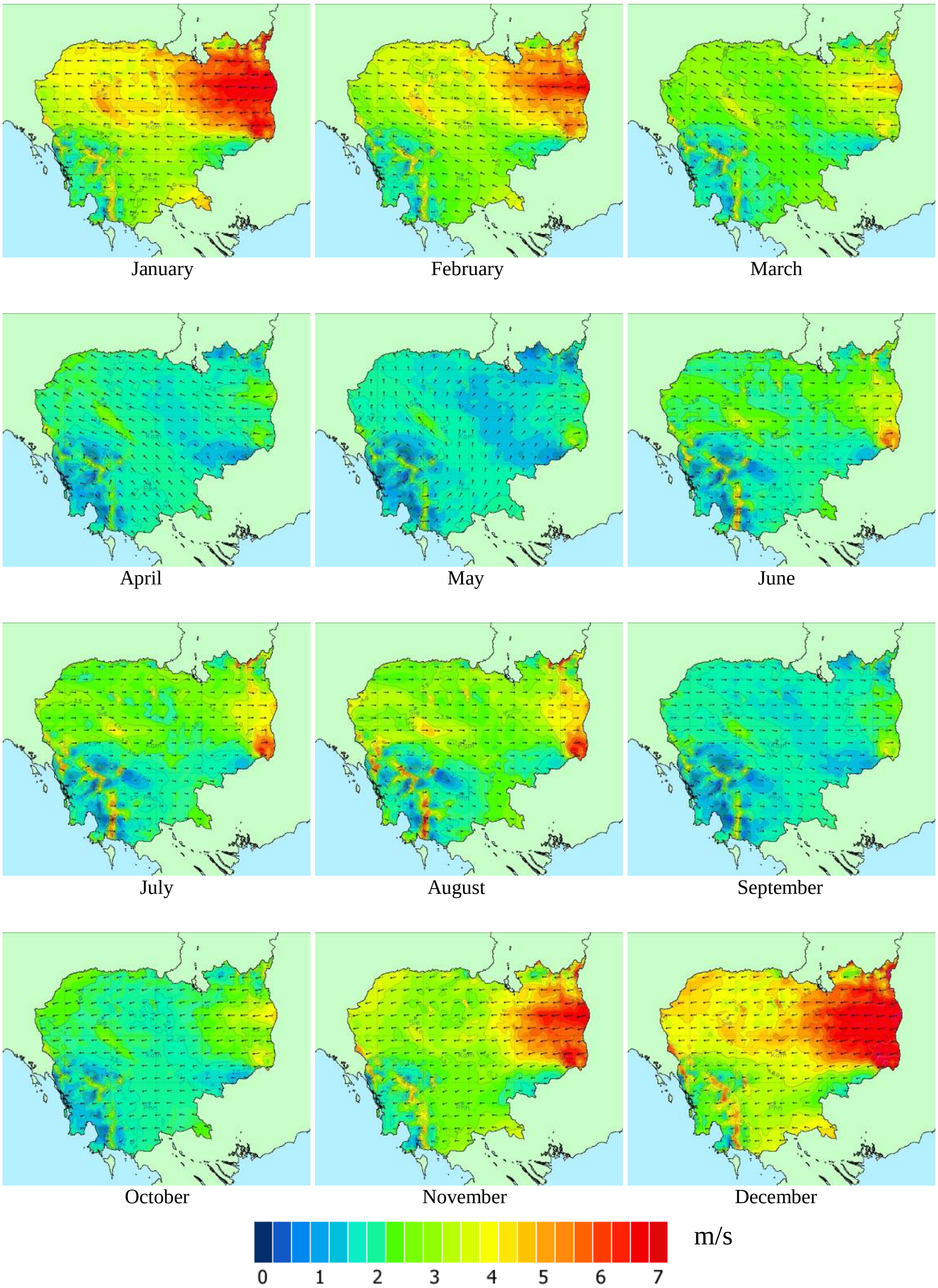

Figure 4. Wind maps showing monthly mean wind speed and direction at the height of 50 m above the ground.

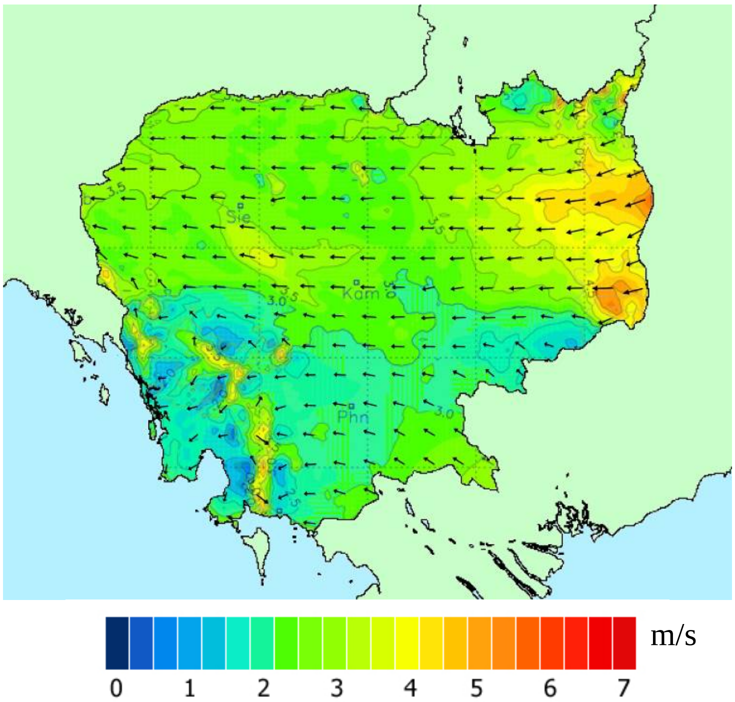

Figure 5. Wind map showing annual mean wind speed and direction at the height of 50 m.

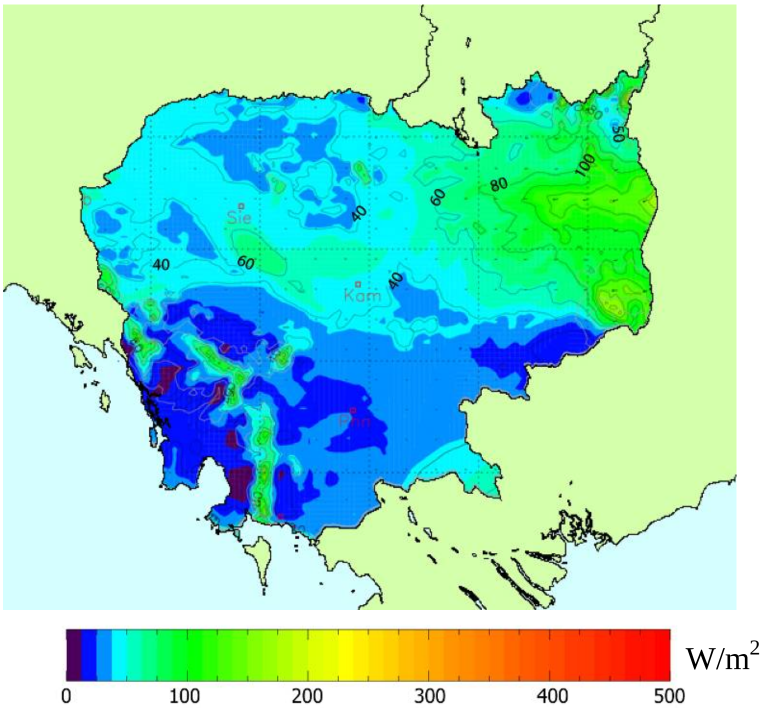

Figure 6. Map showing annual average of wind power density at the height of 50 m.

Conclusions

The wind resource maps of Cambodia have been generated. The wind class approach uses much less computing time than the direct calculation of hourly wind speed over a 30-year period by the factor of 10^4. Four new wind measuring stations were established in this work. Apart from the usefulness of the stations for the model validation, these stations also provide wind data for other applications such as in meteorology and environmental studies. The generalized wind speed derived from the model reasonably agrees with that obtained from the measurements, with the discrepancy in terms of RMSD of 13.8% and MBD of -1.1%. The maximum annual mean wind speed of 5-6 m/s is found in the northeastern part of Cambodia.

Acknowledgements

The authors would like to thank the Department of Alternative Energy Development and Efficiency (DEDE) for inviting Silpakorn University to carry out this project. The author also would like to thank the Ministry of Industry, Mines and Energy (MIME) of Cambodia for supporting this project. Dr. J. Badger is gratefully acknowledged for his assistance in calculating wind. Finally, we are grateful to RisØ for providing the computing facility and technical supports.

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