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Evaluation of wind energy potential over Thailand by using an atmospheric mesoscale model and a GIS approach

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ABSTRACT

The wind energy potential of Thailand was evaluated by using an atmospheric mesoscale model and a Geographic Information System (GIS) approach. The Karlsruhe Atmospheric Mesoscale Model (KAMM) was used to calculate hourly wind speed in Thailand over the period of 15 years (1995–2009) with a horizontal spatial resolution of 3×3 km^2. Input data consisted in vertical profiles of wind velocity, air temperature and relative humidity obtained from radiosonde soundings at four meteorological stations as well as roughness and terrain elevation taken over the entire country. The values of hourly wind speed were averaged to obtain the mean monthly and mean yearly wind speeds. Values of mean monthly wind speed calculated from the model were compared with those obtained from the measurements at four sites typifying the main climatic regions of the country. Measured and estimated values of the mean wind speed were in reasonable agreement, with a Root Mean Square Error (RMSE) of 9.3%. The model was run to estimate mean annual wind speeds at 100 m above ground level and results were displayed as a wind resource map. This map was incorporated into a GIS computer program. Digital maps of land-use and prohibited areas for the installation of wind turbines (e.g. urban areas, national parks and reserved forests) were also used as input into the program. With a given set of criteria, areas which have high potential for wind energy development were quantitatively identified.

1. Introduction

Among the renewable energy resources, wind power is a very large energy resource with proven technologies and low emission of greenhouse gases (Mathew, 2006). The generation of electricity from wind energy rapidly increases especially in mid and high latitude countries due to abundant wind resources (WWEA, 2009). In some European countries such as Denmark, Portugal and Spain, wind energy contributes significantly to total energy used for generating electricity.

For the case of Thailand, the electricity generation in 2012 was 32,600 MW and 67% of total energy used for generating electricity was produced from natural gas (EPPO, 2013). Due to environmental problems and national energy security, the Thai government has set up the alternative energy development plan. According to the plan, the overall ratio of alternative energy has a target of 25% out of total energy consumption by 2021 and the utilization of wind energy for generating electricity is also included in this plan.

A preliminary step in using wind energy is to have information on the carrying capacity of the local wind to drive wind turbines. As a result, wind energy potential has been evaluated in many parts of the world (Tolun et al., 1995; Sopian et al., 1995; Shabbaneh and Hasan, 1997; Hillring and Krieg, 1998; Borhan, 1998; Buskirk et al., 1998; Merzouk, 2000; TrueWind Solution, 2001; Kasperski, 2002; Bilgili et al., 2004; Ozerdem and Turkeli, 2005; Ozerdem et al., 2006; Ilinca et al., 2008; Radics and Bartholy, 2008; Major et al., 2008; Eskin et al., 2008; Himri et al., 2008; Ouammi et al., 2010; Lima and Filho, 2010).

To evaluate wind energy potential of an area, it is necessary to know information on the wind speed of that area. Ideally, such information should be obtained from a dense array of wind measurements taken from masts. However, due to the cost, the number of instrumented masts in many parts of the world and especially in developing countries, is too sparse to provide sufficient wind data for the evaluation of wind energy potential.

Wind speed is a rate of movement of an air mass and is therefore governed by the laws of conservation of mass, energy

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and momentum. Consequently, it is possible to calculate wind speed and direction over an area of interest by using an atmospheric model formulated from such laws (Pielke et al., 1992; Grell et al., 1994). This technique is useful for providing wind data for an area where wind measurements are not available (Mortensen et al., 2005; Frank and Landberg, 1997).

Several investigators in the last few decades have attempted to assess the potential for wind energy of Thailand. Exell et al. (1981) used existing 10 m wind data from the Thai Meteorological Department (TMD) to show average wind speed and its direction at 44 meteorological stations across the country. A further study (Suwantragul et al., 1984) processed surface wind measurements from 62 TMD stations which were normalized to a 10 m height. These were spatially extrapolated and interpolated to provide monthly wind speed and wind power maps. However the wind maps produced by these studies are very coarse and have a low spatial resolution. The results were displayed as contour maps which make it difficult to identify potential areas of interest. Therefore, only preliminary information on wind energy potential may be obtained from the studies. Using the WindMap software along with a digital elevation model, the Department of Energy Development and Promotion (DEDP), Thailand and a consulting company Fellow Engineers Consultants Company extended 10 m wind data in both the vertical and horizontal domains so as to produce monthly and yearly averaged wind speed maps for the country (DEDP, 2001).

It may be argued that a modeling approach along with suitable terrain information would best represent the wind field. In 2001, the World Bank and a consulting company TrueWind Solution conducted a study that used an atmospheric mesoscale model (MesoMap) to simulate historical wind conditions at 30 m and 65 m above the ground in Southeast Asia including Thailand (TrueWind Solution, 2001). The calculations were based on weather data including temperature, pressure, moisture, turbulent kinetic energy and heat flux which were collected from a representative number of days within a 15-year period (1984–1998). Presentations were based on color maps at the heights of 30 m and 65 m. Later on, Major et al. (2008) reviewed the wind energy potential for generating electricity in Thailand by means of a wide-ranging literature survey. They concluded that the benefits of economic wind power electricity generation were probably confined to small remote isolated installations and the challenges of improving low wind turbine performance were widely discussed. Despite the significant progress made by the above studies, there is need for improvements. Wind data need to be estimated at elevations of 80 m or higher in accordance with modern wind turbine design. Finally, there is need to use long-term statistics based on continuous data as year to year variations in weather systems are significant in Southeast Asia (Zhang et al., 1997; Wang et al., 2001).

In this study, we propose to evaluate quantitatively the wind energy potential for Thailand using detailed meteorological data and a mesoscale dynamic model over a 15-year period. In addition, a Geographic Information System (GIS) was also employed to objectively identify areas which have high potential for wind energy development.

2. Methodology

The method for the evaluation of wind energy potential proposed in this work consists of the selection of an atmospheric model, preparation of input data for the model, calculation of wind speed, model validation, generation of wind resource maps, and identification of high potential areas for wind energy developments. The details of each step are described as follows.

2.1. Selection of an atmospheric model

There are a number of atmospheric models which can be used to calculate wind field over an area of interest (Pielke et al., 1992; Grell et al., 1994; Adrian and Fiedler, 1991). Model selection depends on several factors such as the size of the area, spatial resolution requirements and availability of computing resources. As a compromise between resolution and computing time, atmospheric mesoscale models with spatial resolution of 1–10 km are commonly used for calculating wind field over a region or country for wind energy applications (Mortensen et al., 2005; Frank and Landberg, 1997).

Mesoscale models such as MM5 or WRF is available. However the above models have been mainly used in weather forecasting and atmospheric research. In this work, an atmospheric mesoscale model developed at the University of Karlsruhe in Germany (commonly called KAMM) was selected to calculate the wind field over Thailand. This is because KAMM has been applied for mapping wind in many parts of the globe with satisfactory results (e.g. Mortensen et al., 2005; Frank and Landberg, 1997; Hussain et al., 2007). In addition, it has also been successfully used in complex terrains (Adrian and Fiedler, 1991; Kalthoff et al., 2003) and there are such terrains in the North and the South of Thailand. The only main disadvantage of KAMM is that it has to be run on a supercomputer which is not available in Thailand. In this work such a high performance computer was provided by the Steinbuch Center for Computing of Karlsruhe Institute of Technology (KIT) in Germany under a collaboration between Silpakorn University and KIT.

The numerical simulation model KAMM is a 3-dimensional and non-hydrostatic mesoscale model whose basic equations were described in Adrian and Fiedler (1991). The model solves the momentum, heat and humidity equations. These equations are transformed into a coordinate system which follows the terrain. The parameterization of the turbulent fluxes is done according to the eddy diffusivity concept (Hinze, 1975). The scheme of Orlanski (1976) is used for the lateral boundary condition whereas the method proposed by Klemp and Durran (1983) is employed for the upper boundary condition. KAMM can predict localized wind speed by calculating the momentum, heat and humidity balances taking into account local topography features, land-use variation and terrain roughness. As the main input data, KAMM requires the large scale forcing in the form of a single vertical profile of geotrophic wind, virtual potential temperature and relative humidity. The model's outputs are space and time-dependent distributions of horizontal and vertical components of wind, potential temperature and humidity. At regional scale, the model is used to calculate atmospheric flows in the domain of 100 km $\times$ 100 km to 1000 km $\times$ 1000 km in size with a typical horizontal resolution of 2.5–10 km. In the vertical direction, the model extends from the surface to the height of 10 km using 50 model levels with a terrain following coordinate system. The interval of the levels is not uniform. This allows more closely spaced vertical levels near the terrain.

In this work, KAMM was used to simulate the evolution of wind speed and directions. Atmospheric data including temperature, humidity, wind speed and direction at various heights above the ground obtained from the upper air measurements were used as inputs of KAMM. For one input at 7.00 local time of the day, wind speed and direction data are simulated at a 1 hour time step at the horizontal resolution of 3×3 km^2 for 15 years (1995–2009). This creates great computational demands, necessitating the use of a powerful supercomputer. Moreover, to calculate at every grid node to cover the whole area of Thailand is time consuming. Therefore, to reduce the CPU time, the entire area of the country was divided into 4 calculation domains (Fig. 1). There are several reasons for