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Offshore Wind Energy Mapping for Thailand using Coupled MC2/MS-Micro Modeling

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ABSTRACT

The main objective of this paper is to investigate the offshore wind energy potential of the Gulf of Thailand using coupled MC2/MS-Micro modeling. A coupled mesoscale-microscale model is used, along with R1 NCEP/NCAR global reanalysis database, to generate a high resolution (200 m) wind resource map. Results show that interesting potential areas for offshore wind farm development have wind speeds of up to 6.5 m/s, especially in the upper part of the Gulf of Thailand, covering a surface of 2,112 km^2. With a total potential installed capacity of 5,000 MW, the annual energy production is estimated at 9.64 TWh/year.

Keywords: Atmospheric Modeling, Wind Resource Assessment, Wind Energy, Wind Turbine Generator, Wind Power

INTRODUCTION

Offshore wind energy is emerging as a promising technology in wind energy conversion systems. Offshore wind resources are abundant in comparison to onshore wind resources. Offshore winds are also stronger, less turbulent, and more consistent in terms of availability than land-based winds. Furthermore, higher energy productions are accomplished due to larger wind turbine ratings and stronger wind profiles [1].

For its part, there are many factors affecting offshore wind farm development, e.g., the wind resource and wind farm siting, wind turbine technology, wind farm installation, grid interconnection and power evacuation, wind power control and operation, and related factors such as policy and planning, as well as economic and ecological aspects.

Among these factors, the offshore wind resource and wind farm siting are the primary factors to be investigated. The offshore wind resource can be quantified using three major schemes, i.e., wind mapping using sophisticated mesoscale atmospheric modeling, coupled with microscale wind flow modeling

[2]; direct measurements by either offshore met tower installations [3] or buoy equipped with anemometers, or through a LIDAR campaign [4]; and remote sensing techniques such as Synthetic Aperture Radar (SAR) or QuikSCAT satellite images [5-6].

Wind resource maps seem to be the preferred approach in performing offshore wind resource quantification, especially in the initial step of offshore wind farm development. Besides the wind resource, the site selection for the commissioning of offshore wind turbines includes the identification of the available area, delimiting the bathymetry of the area based on current turbine technology, exclusion zones, and power generation costs [7-8].

The main objective of this paper is to investigate the offshore wind resource potential in the Gulf of Thailand using a coupled mesoscale atmospheric modeling and microscale wind flow modeling.

Offshore Wind Atlas Methodology

1) *Input*

In order to predict the mesoscale wind speeds in the area of interest, a mesoscale atmospheric modeling, i.e., the Mesoscale Compressible Community (MC2) model, was executed with model inputs that include the NCEP/NCAR R1 (1958-2000) global reanalysis database, digital topography maps and reclassified roughness heights from land-use maps, as illustrated in Figs. 1 - 3.

2) *Coupled Mesoscale Atmospheric Modeling/Microscale Wind Flow Modeling*

An offshore wind atlas is developed based on a set of quadrilateral mesoscale domains called "tiles"; the juxtaposition of nine partially overlapping tiles covering the area studied is shown in Fig. 1. On each tile, the climate is characterized by a large set of weather conditions, providing over 200 different possible atmospheric states. The climatic modeling then consists in finding a spatial solution for the wind flow in each of these states. Results are then post-processed with a statistical model representing the dominant winds in order to obtain weighted average wind velocities.

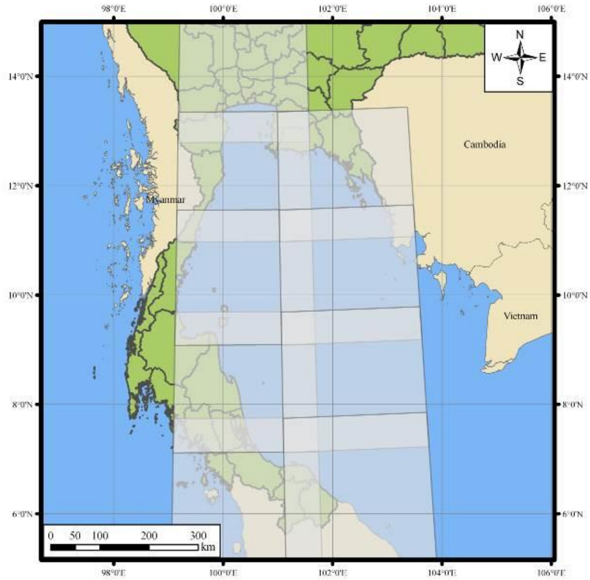

Fig 1 Meso-grid of the computational domain for the atmospheric modeling for offshore wind resource assessment in the Gulf of Thailand.

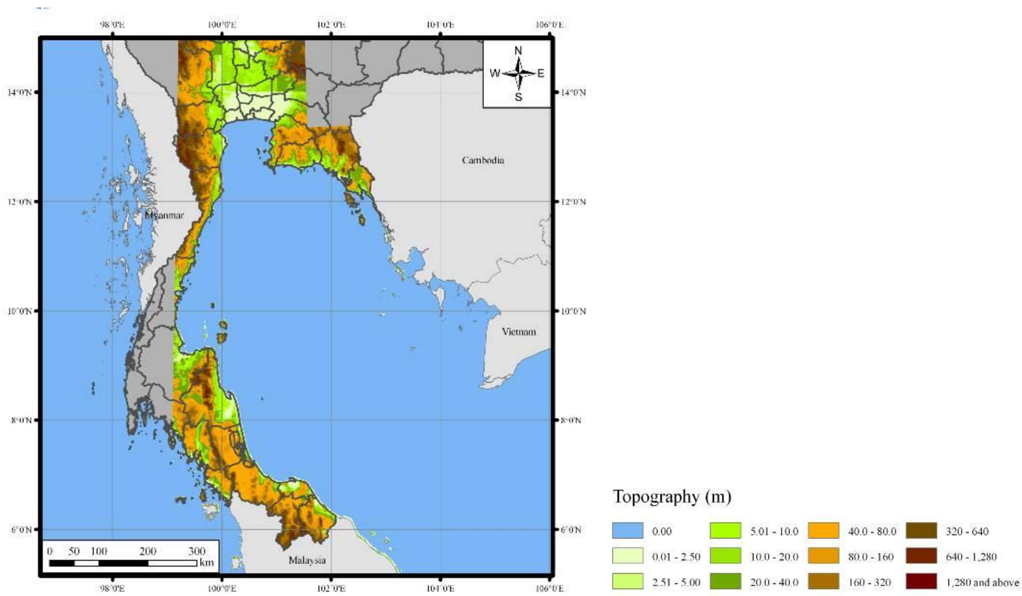

Fig. 2 Digital elevation model for the input of the atmospheric modeling for theoffshore wind resource assessment in the Gulf of Thailand.

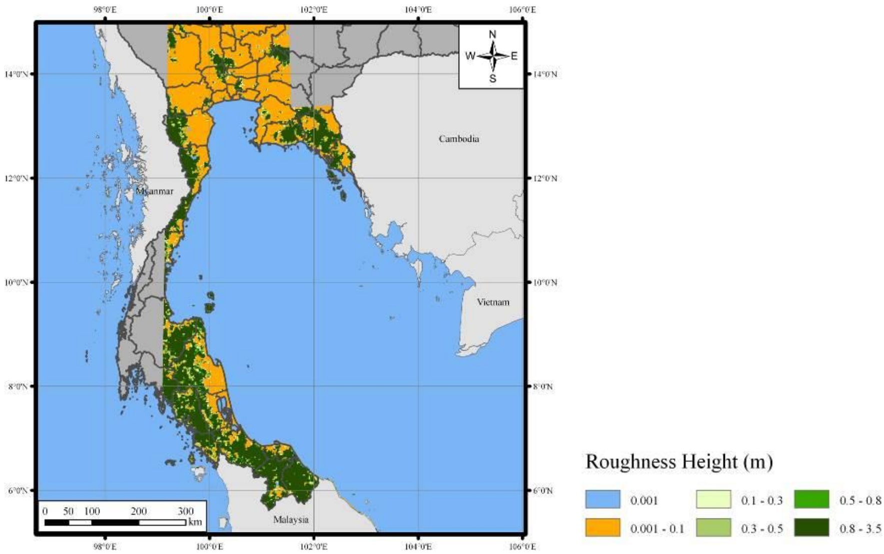

Fig. 3 Roughness height for the input of the atmospheric modeling for the offshore wind resource assessment in the Gulf of Thailand.

The statistical-dynamical downscaling method [9] is applied to produce the offshore wind atlas. The method consists of using large scale long term atmospheric data and their statistical properties to run a mesoscale model and post-process its output in order to get a small scale picture of atmospheric motions. This method involves the following steps: wind climate classification, mesoscale simulations, statistical post-processing, and microscale modeling.

1) Wind climate classification

The 3D representation of atmospheric states available every six hours at 2.5 degree resolution over the globe, known as NCAR/NCEP reanalysis [10], is chosen for the climate database. The elements of the database are classified [11] using three parameters: the geostrophic wind direction at 0 m (16 equal sectors), the geostrophic wind speed at 0 m (9 classes 2 m/s wide from 0 to 18 m/s and 5 classes 4 m/s wide from 18 to 38 m/s which gives all together 14 classes) and the sign of 0 – 1,500 m geostrophic wind shear (positive or negative).

Each element of the long time series (every 6 hours for 43 years from 1958 until 2000) of the geostrophic wind vector at 0 m from the database is attributed to a particular climate state. For each database grid point, the classification procedure allows determining the climate states that occurred during the analyzed period and the number of their realizations which defines their frequency of occurrence. This information is necessary to initialize the mesoscale model and to do the post-processing.

2) Mesoscale simulations

The simulations are performed with the Mesoscale Compressible Community (MC2) model [12], a state-of-the-art atmospheric model widely used by Environment Canada,

Canadian universities, and others worldwide. The Polar Stereographic grid with 5 km resolution that is the closest to the Gulf of Thailand is chosen. This grid is split into 9 partially overlapping grids to cover the whole Gulf of Thailand. The orography and land use data are interpolated to the model resolution from the GDEM database at 5 m resolution. The roughness field is determined entirely from the land use data obtained by the Land Development Department (LDD) of Thailand. The center of each domain is associated with the nearest grid point of the NCAR/NCEP global database. Due to the classification procedure, this point is characterized by a specific set of climate states and their frequency of occurrence. For each climate state, a simulation with the MC2 model is performed. This includes the initialization with the climate states data which are downscaled to the model resolution. The simplified physics scheme without radiation, condensation or diurnal cycle is used in order to accelerate model convergence to the final state. The time step is 120 seconds and there is a nine-hour adaptation period for the initial flow to the surface geophysical properties.

3) Statistical post-processing

For each domain, the entire set of model outputs are combined using the frequencies of the climate states simulated as their weight. Seasonal atlases are created using seasonal frequencies of the climate states as weights to the same model outputs used for the annual atlas. This gives a set of 2D data, at the model resolution, characterizing the wind potential of the domain.

4) Microscale modeling

Statistical post-processing prepares data to be used by a microscale model, namely, MS-Micro of Environment Canada [13] to refine the wind flow near the sea surface. The most important field for microscale modelling is the frequency distribution of the mean wind speeds by sector and class.

C. Output

The mean wind speed and power are the output of the coupled mesoscale atmospheric modeling and microscale wind flow modeling. Mean wind speed maps are prepared at heights of 80 m and 100 m above sea level (a.s.l.).

D. Offshore Wind Map Validation

The offshore wind map was validated with observed wind speeds at 80 m and 100 m a.g.l. in coastal areas. The details of each met mast installed along the coastal line of the Gulf of Thailand are given in Table 1. The relative error was analyzed in order to validate the offshore wind map.

Table 1 Details for each met masts

No.	Province	District	Height (a.g.l.)	Year of Observation
1	Chumporn	Pratiew	120	2012
2	Prachuabkhirikhun	Hua Hin	120	2012
3	Petchaburi	Thayang	120	2012
4	Surathani	Kanchanadit	120	2012
5	Nakhon Si Thammarat	Pak Phanang	120	2012
6	Rayong	Muang	120	2006-2010

RESULTS AND DISCUSSION

Mesoscale wind maps at 100 m and 120 m heights are shown in Figs. 4 - 5, respectively. It can be seen that an interesting potential area for wind power generation is found in the upper part of the Gulf of Thailand. Further, the potential increases with the height above sea level. Furthermore, it was found that the Bay of Bangkok is the area with the highest potential, with annual average wind speeds in the range of 6.0 - 6.5 m/s. The power of wind speeds at the height of 120 m is in Class 2. This area has a surface area of 2,112 km^2, corresponding to a potential power capacity of 5,052 MW.

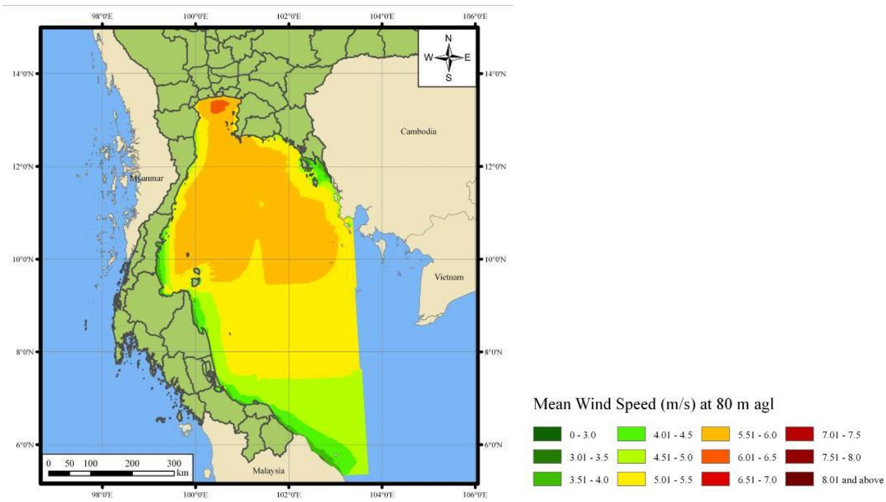

Fig 4 Mesoscale wind map at 100 m a.g.l. for the Gulf of Thailand (resolution 5 km).

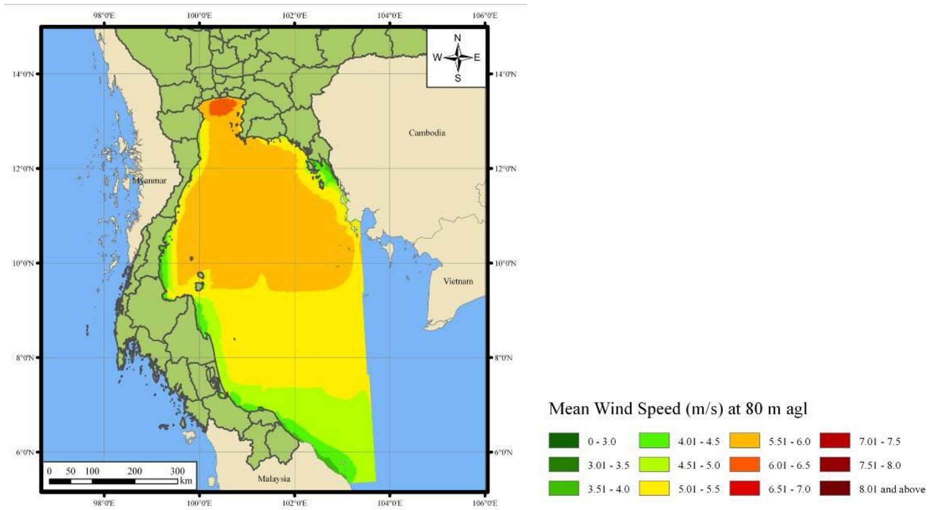

Fig. 5 Mesoscale wind map at 120 m a.g.l. for the Gulf of Thailand (resolution 5 km).

Microscale wind maps at 100 m and 120 m height are presented in Figs. 6 – 7, respectively. The areas of interest include the zones where the predicted wind speeds are in the range of 6.5 m/s.

Validation of the wind maps at each height shows that the relative errors are in the range of ±20%. More details for each met mast validation are given in Table 2.

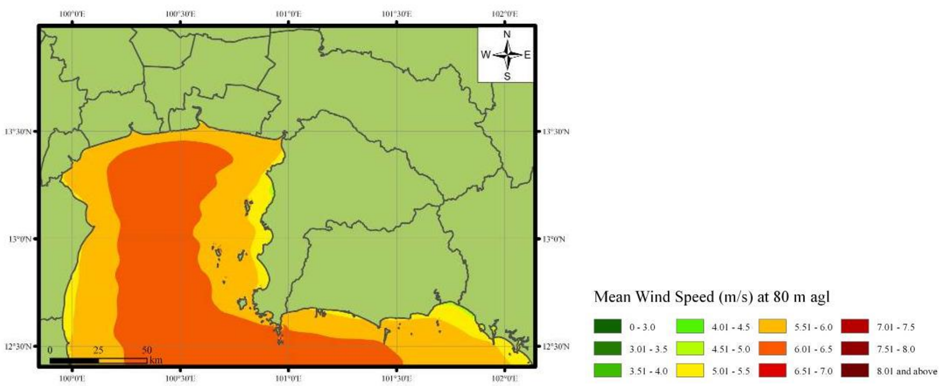

Fig 6 Microscale wind map at 100 m a.g.l. for the Gulf of Thailand (resolution 200 m).

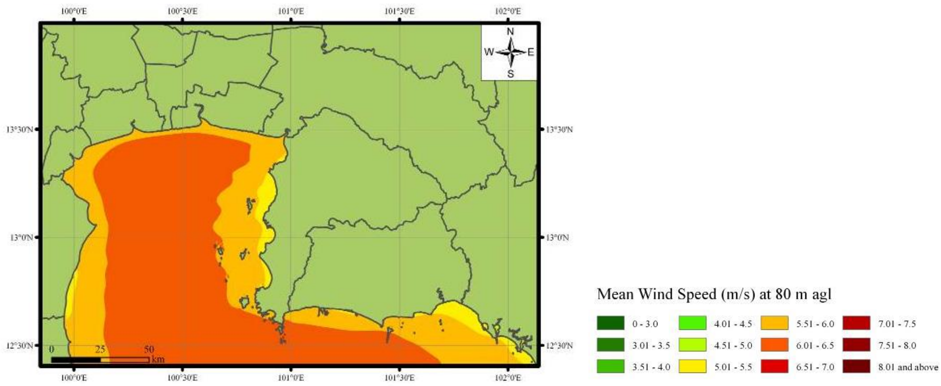

Fig 7 Microscale wind map at 120 m a.g.l. for the Gulf of Thailand (resolution 200 m).

A generic wind turbine generator of 3 MW capacity was used to compute the annual energy production (AEP) and the capacity factor (CF). The 10D x 10D constraint, where D is the width of the swept area of the blades, has been used as the spatial area of a single turbine to minimize wake effects. Thus, a set of 1,667 turbines was positioned in the area, resulting in the potential installation of 5,001 MW of wind power capacity. Results show that under these conditions, the offshore wind resource in the Gulf of Thailand could produce energy of 9.64 TWh/year. The capacity factor of the 5,001 MW wind power capacity is in the order of 22%.

Table 2 Predicted and observed mean speeds (m/s) and relative errors (%)

No.	Province	District	Predicted	Observed	Error
1	Chumporn	Pratiew	4.73	4.80	-1.52
2	Prachuabkhirikhun	Hua Hin	4.74	5.13	-8.21
3	Petchaburi	Thayang	4.12	4.73	-14.66
4	Surat Thani	Thachang	2.53	2.11	16.59
5	Surat Thani	Kanchanadit	3.10	3.57	-15.29
6	Nakhon Si Thammarat	Khanom	2.85	2.92	-2.29
7	Nakhon Si Thammarat	Sichon	2.33	2.36	-1.38
8	Nakhon Si Thammarat	Thasala	3.45	2.79	19.14
9	Nakhon Si Thammarat	Pak Phanang	3.80	3.47	8.81
10	Nakhon Si Thammarat	Huasai	4.27	3.46	19.11
11	Solng Khla	Ranot	3.60	3.53	1.82
12	Solng Khla	Sathing Phra	3.62	4.30	-18.72
13	Surat Thani	Phangan	3.95	4.72	-19.57
14	Nakhon Si Thammarat	Pak Phanang	5.14	4.59	10.70
15	Rayong	Muang	5.88	4.93	16.08

Beside the technical power potential, there are still many aspects to be considered in the offshore wind power development, e.g., the commissioning of the wind farms, geotechnical surveys for the design of the offshore foundations, environmental impact assessments, public acceptance and participation, and the economic aspects to assure the project viability.

The public policies to develop the offshore wind power potential of the Gulf of Thailand will also need to take into consideration the moderate offshore wind resource in the area. Therefore, feed-in-tariffs should be considered to facilitate the development of this renewable energy sector in Thailand.

Finally, while providing an initial overview of the technical power potential of a large area, wind resource maps none-the-less have uncertainties. Therefore, a measurement campaign, using either the installation of offshore met towers or fixed LIDAR on top of a platform of the Marine Meteorological Department in the Bay of Bangkok, is recommended. The field measurements should cover a period of at least one year to confirm the technical wind power potential and to confirm the feasibility of offshore wind farm project developments in the Gulf of Thailand.

CONCLUSIONS

This paper presents the offshore wind resource assessment of the Gulf of Thailand. Offshore wind atlas at current wind turbine generator hub heights, i.e., 100 m and 120 m heights a.g.l. are produced based on a coupled mesoscale atmospheric modeling and microscale wind flow modeling, using the NCEP/NCAR reanalysis database as input climate data. Results show that an interesting potential area covers the Bay of Bangkok, with a total area of 2,112 km^2. The 5,000 MW offshore wind power capacity could be theoretically developed, with annual production of 9.64 TWh/year of energy; the capacity factor of the potential wind power capacity is estimated to be 22%.

ACKNOWLEDGMENTS

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