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Technical note

High resolution wind atlas for Nakhon Si Thammarat and Songkhla provinces, Thailand

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A B S T R A C T

In this work, a high resolution wind atlas for Nakhon Si Thammarat and Songkhla provinces in southern Thailand was developed using combined mesoscale, MC2, and microscale, MsMicro, modeling techniques. The model inputs consist of long-term statistical climate data, i.e. the NCEP/NCAR database, high resolution topography and land cover data. The 200 m resolution wind resource maps were validated with observed mean wind speeds from 10 met stations located along the coastlines of the territory studied. These comparisons have shown that the wind atlas provides a good representation of the wind resource throughout the territory of Nakhon Si Thammarat and Songkhla provinces, Thailand. The technical power potential and potential annual energy production are then identified. Results from the technical power potential at 80 m above ground level show that a total of 1374 MW of wind farms, generating annually 3.6 TWh of electricity, could be installed; while 407 MW of small wind turbines (50 kW), generating annually 1.0 TWh of electricity, could be installed.

1. Introduction

Wind atlases are developed to determine the wind resource over a given area. By helping to identify sites with a good wind energy potential, they are an enabler for the development of wind energy in jurisdictions.

In Thailand, wind energy is still in its very early stages of development, where only a few demonstration turbines are installed. However, the Ministry of Energy of Thailand has recently launched a Renewable Energy Development Plan, where 20% of the electricity generation in the country will be from renewable sources by 2022, with an objective of 800 MW of wind energy installed capacity.

Nakhon Si Thammarat and Songkhla are two of the largest provinces of southern Thailand, in terms of size (9942 km^2 and 7394 km^2, respectively) and population (1,519,811 and 1,324,915 citizens, respectively). Located in southern Thailand, on the shore of the Gulf of Thailand, they are situated on the east side of the Malay Peninsula.

The Wind Energy Resource Atlas of Southeast Asia, developed by TrueWind Solutions LLC, covers four countries (Cambodia, Laos, Thailand and Vietnam) at 1 km resolution [1]. While this atlas shows the general distribution of the wind resource across the region, its resolution is too coarse for use in specific site evaluation studies for wind energy development. Other wind resource maps of Thailand have been produced, but these are at low resolution (5–10 km), thus limiting their utilization to identify potential sites for wind farm development and to influence wind energy public policies in the country.

In Canada, the Canadian Wind Energy Atlas was developed in 2004 by Environment Canada [2]. With the exception of the uttermost northern region of Canada, this atlas covers the entire country at 5 km resolution. In order to provide a more precise tool to facilitate the initial site survey for wind energy development, high resolution wind resource maps for specific regions have been produced and disseminated in the public domain [3–6]. While the main objective of wind resource maps is to document the wind regime over a specific territory, they have also influenced the development of public policies in regards to wind energy development [7,8].

The objective of this paper is to develop a wind atlas of Nakhon Si Thammarat and Songkhla provinces, Thailand, at a resolution of

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200 m, with the objective of documenting the wind resource over this territory, and to influence wind energy public policies in southern Thailand.

2. Methodology

The methodology used to develop the wind resource maps of Nakhon Si Thammarat and Songkhla provinces, Thailand, is based on the Anemoscope model [2]. The simulation process in Anemoscope is based on a state-of-the-art statistical–dynamical downscaling method [9] which 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 representation of atmospheric motion.

The first step in the simulation process, wind climate classification, consists of classifying the wind regimes such as to produce a climate state database. The NCAR/NCEP reanalysis database, which covers the entire globe with a 2.5° resolution, is included in Anemoscope. For each database grid point, or climatic station, the climatic states are defined and characterized by their frequency of occurrence. This information is necessary to initialize the mesoscale model.

The second step, mesoscale simulations, consists of producing simulations with the Mesoscale Compressible Community (MC2) model [10]. The MC2 model is a three-dimensional, non-hydrostatic, time variable model used to combine the terrain information and the climate information provided by the climate database into a series of mesoscale wind maps with a resolution of 1–5 km.

The next step, statistical post-processing, consists of using the statistical module WEStats, which combines the MC2 simulation results while considering the frequency of occurrence. From the WEStats module, a mesoscale wind map of the region is obtained

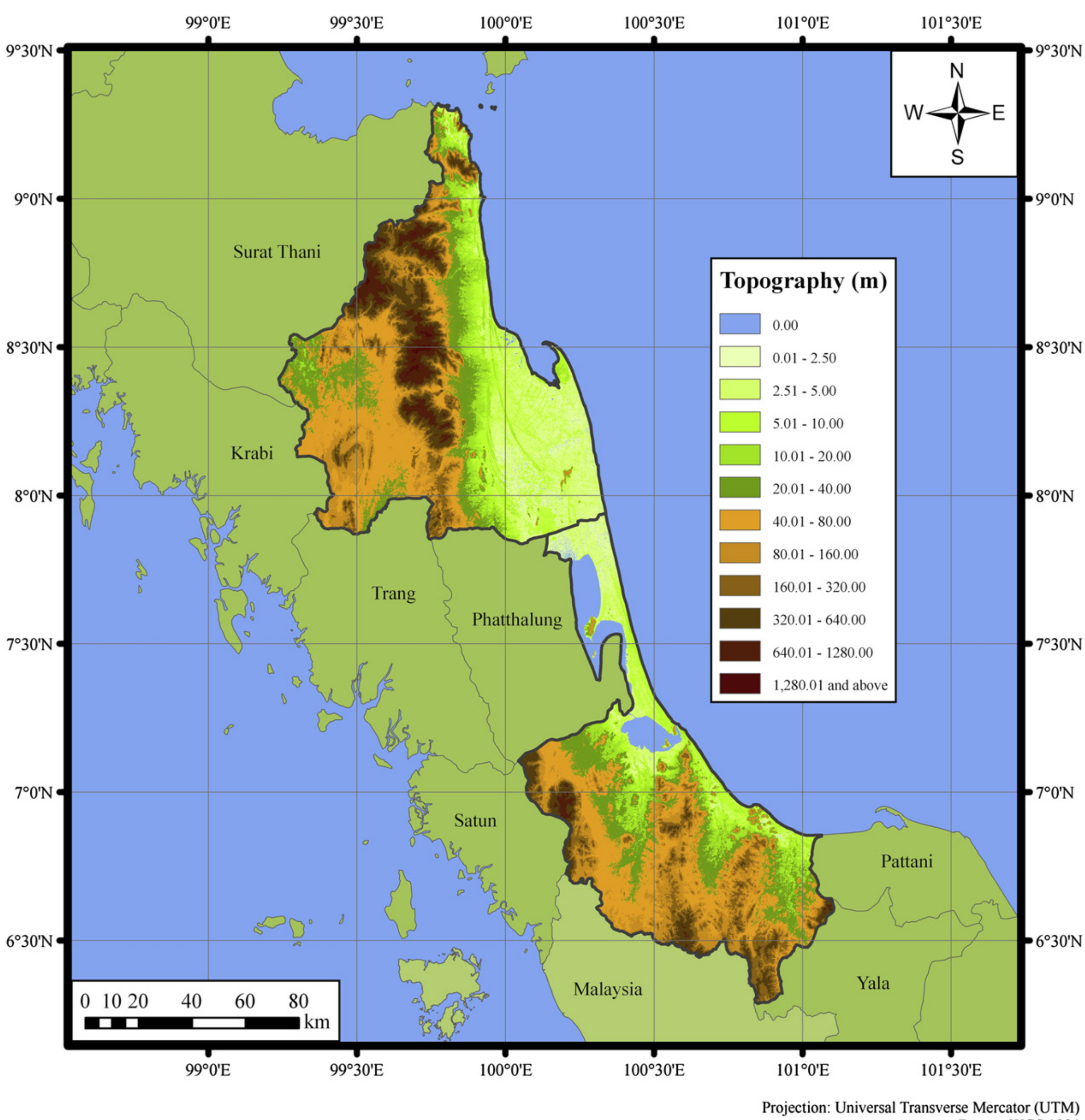

Fig. 1. Topography of Nakhon Si Thammarat and Songkhla provinces, Thailand.

with a 1–5 km resolution. The mesoscale wind map includes a complete set of the wind data necessary for the microscale simulations in the next step.

The last step, microscale modeling, consists of using the Meso-scale/Microscale Coupler (MMC) module which uses the wind energy statistics compiled at the previous step to determine the wind patterns for a subset of the area, i.e. the microscale region. The microscale region is composed of hundreds, or possibly thousands of tiles, depending on the resolution of the mesoscale grid. MMC uses the microscale wind model MsMicro [11], to determine the effects of wind flow across a single microscale tile in a particular direction. MMC then transforms the results from MsMicro and reassembles the results into a microscale wind map.

In terms of the limitations associated with the Anemoscope method used in this study, the MC2 mesoscale model used in Anemoscope has been proven to perform well in the finest mesoscales and more generally, to be as skilled as the most advanced mesoscale models [10,12]. Furthermore it has been applied successfully for large scale wind resource assessments [2,10,12,13]. For its part, the microscale model used in Anemoscope, MsMicro, a linear model, such as other models based on the Jackson and Hunt model [14] of flow over low hills, i.e. WAsP [15], requires a fraction of the computational cost compared to the advanced and more universal Computational Fluid Dynamics (CFD) models such as the Reynolds average Navier–Stokes (RANS) model [16–18] and have been proven to be as capable to reproduce the average neutral ABL velocity fields over gentle terrains, i.e. when the slope of the surface is lower than 0.3 (values at which separation of the flow becomes highly probable) [11,16–19].

In the development of the wind atlas, two 500 km by 500 km mesoscale grids with a 5 km resolution were used, each centered on the respective province. Furthermore, in order to completely cover

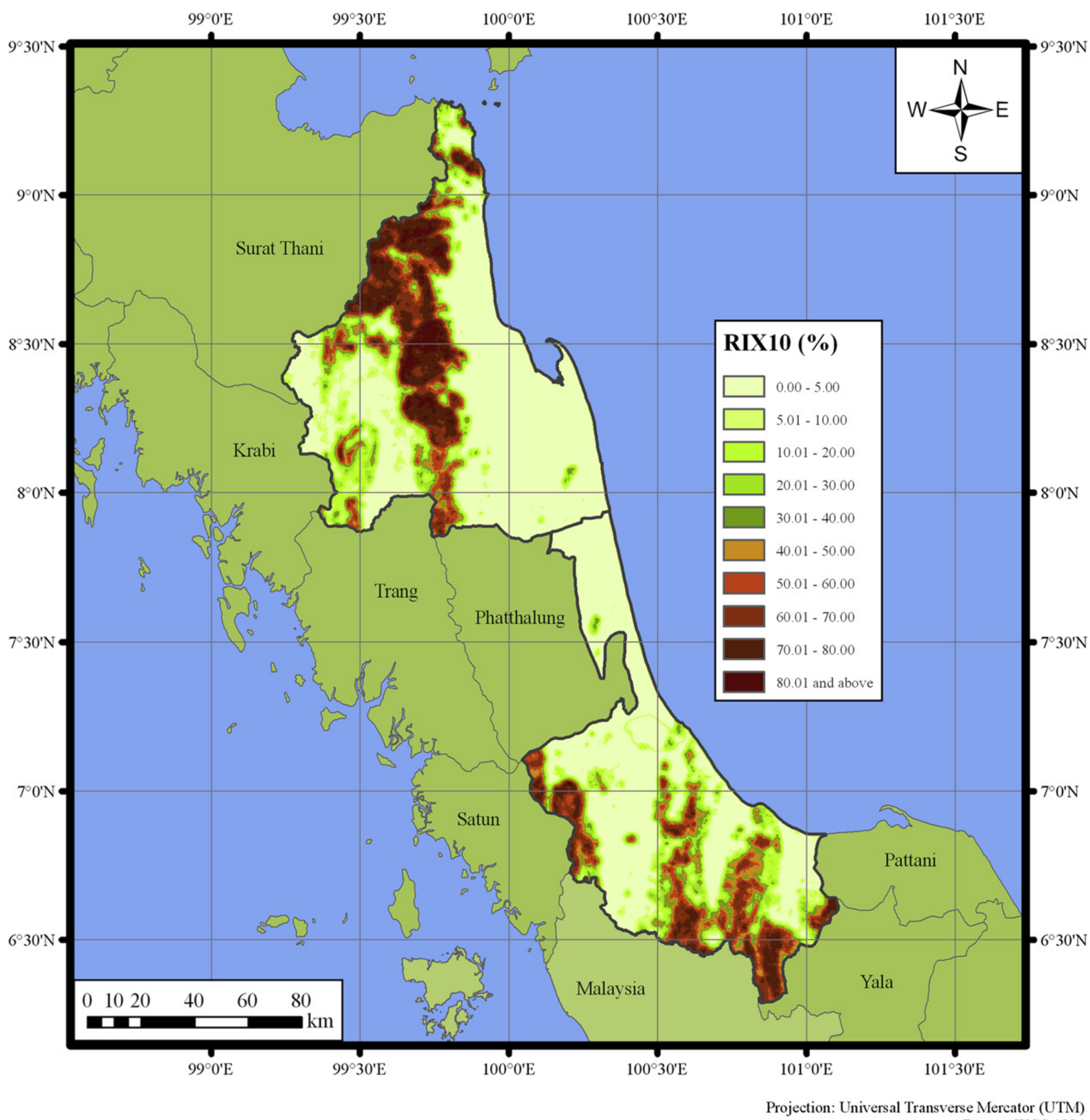

Fig. 2. Ruggedness index RIX_{10} of Nakhon Si Thammarat and Songkhla provinces, Thailand.

Table 1
Land cover and roughness heights.

Index	Description	Roughness height
1	Water	0.001
2	Ice	0.001
3	Inland lake	0.001
4	Evergreen needleleaf tree	1.5
5	Evergreen broadleaf tree	3.5
6	Deciduous needleleaf tree	1.0
7	Deciduous broadleaf tree	2.0
8	Tropical broadleaf tree	3.0
9	Drought deciduous tree	0.8
10	Evergreen broadleaf shrub	0.05
11	Deciduous shrub	0.15
12	Thorn shrub	0.15
13	Short grass and forbs	0.02
14	Long grass	0.08
15	Arable land	0.08
16	Rice field	0.08
17	Sugar cane field	0.35
18	Maize field	0.25
19	Cotton field	0.1
20	Irrigated crop	0.08
21	Urban area	1.35
22	Tundra	0.01
23	Swamp	0.05
24	Soil	0.05
25	Mixed wood forest	1.5
26	Transitional forest	0.05

both provinces, 20 microscale grids were superimposed; each being 160 km by 160 km with a 200 m resolution. In order to achieve the final wind resource maps for specific elevations, the microscale wind maps were stitched using the ArcGIS software into one large wind resource map covering the entire territory.

Inside the atmospheric boundary layer, the wind regime is influenced directly by the topography and the land cover. Thereby, in order to ensure continuity in the wind resource data, the topography and land use data of the following jurisdictions are incorporated in the model: the provinces of Nakhon Si Thammarat, Songkhla, Phatthalung, Trang, Krabi, Surat Thani, Satun, Pattani, Yala and Narathiwat, along with an adjacent section of Malaysia.

The topography data used to create the wind resource maps is taken from two different sources. Firstly, the topography data for the Thailand sections are taken from the database of the Land Development Department, Ministry of Natural Resources and Environment, Royal Thai Government [20]. The corresponding topography data consists of Digital Elevation Model (DEM) at a resolution of 30 m, where the ground elevations are recorded in metres relative to Mean Sea Level (MSL), based on the World Geodetic System (WGS) 1984 reference datum. Secondly, the topography data for the adjacent section of Malaysia is taken from the database of the Consortium for Spatial Information Consultative Group for International Agriculture Research (CGIAR-CSI) SRTM

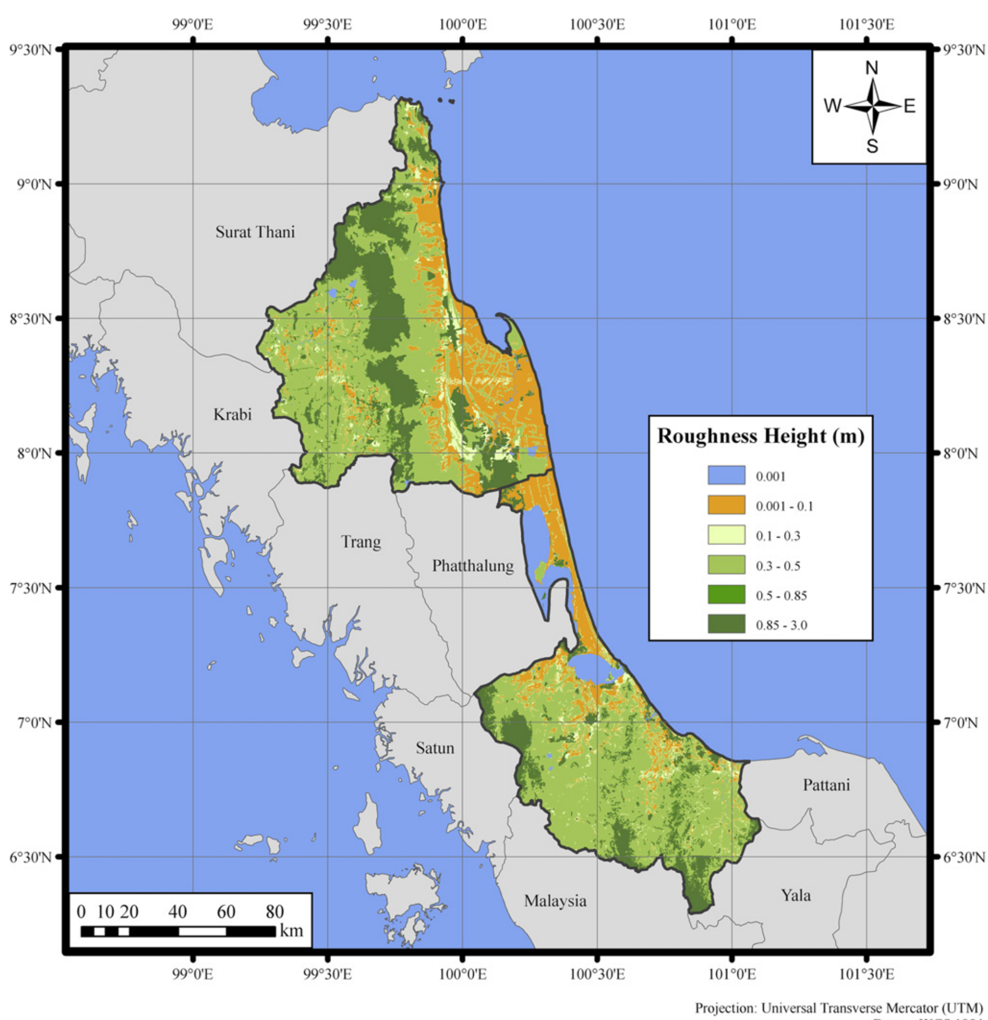

Fig. 3. Roughness height of Nakhon Si Thammarat and Songkhla provinces, Thailand.

[21]. The corresponding topography data consists of DEM at a resolution of 3 arc-seconds, where the ground elevations are recorded in metres relative to MSL, based on the WGS 1984 reference datum. Before using the topography data in the simulations, both databases are merged into one large raster file with 90 m by 90 m pixels encompassing the entire region studied.

Fig. 1 shows the topography of Nakhon Si Thammarat and Songkhla provinces after processing and ready for use in the simulation. The provinces are divided by the Phuket mountain range to the west and general lowlands to the east. The highest point in southern Thailand is Khao Luang mountain, located in the Nakhon Si Thammarat section of the Phuket mountain range at 1780 m above sea level. Songkhla province is also host to Songkhla lake, the largest natural lake in Thailand. The shallow lake covers an area of 1040 km^2 and has a north-south extent of 78 km.

For its part, Fig. 2 shows the ruggedness index RIX_{10} [22] for the entire study area. In the present study, it is to underline that, as it can be seen on Fig. 2, the ruggedness index RIX_{10} values of the provinces of Nakhon Si Thammarat and Songkhla, Thailand are generally low and RIX_{10} values higher than 10% are only observed in the mountainous regions of the study area. Thus, the use of the Anemoscope method (MC2 mesocale/MsMicro microscale models) appears generally to be well suited for the microscale wind resource evaluation of this study area; however, one should be careful in applying the simulation results in the mountainous regions of the study area.

The land use data needed to create the wind resource maps is taken from two different sources. For the Thailand land use, the data was obtained from the database of the Land Development Department, Ministry of Natural Resources and Environment, Royal

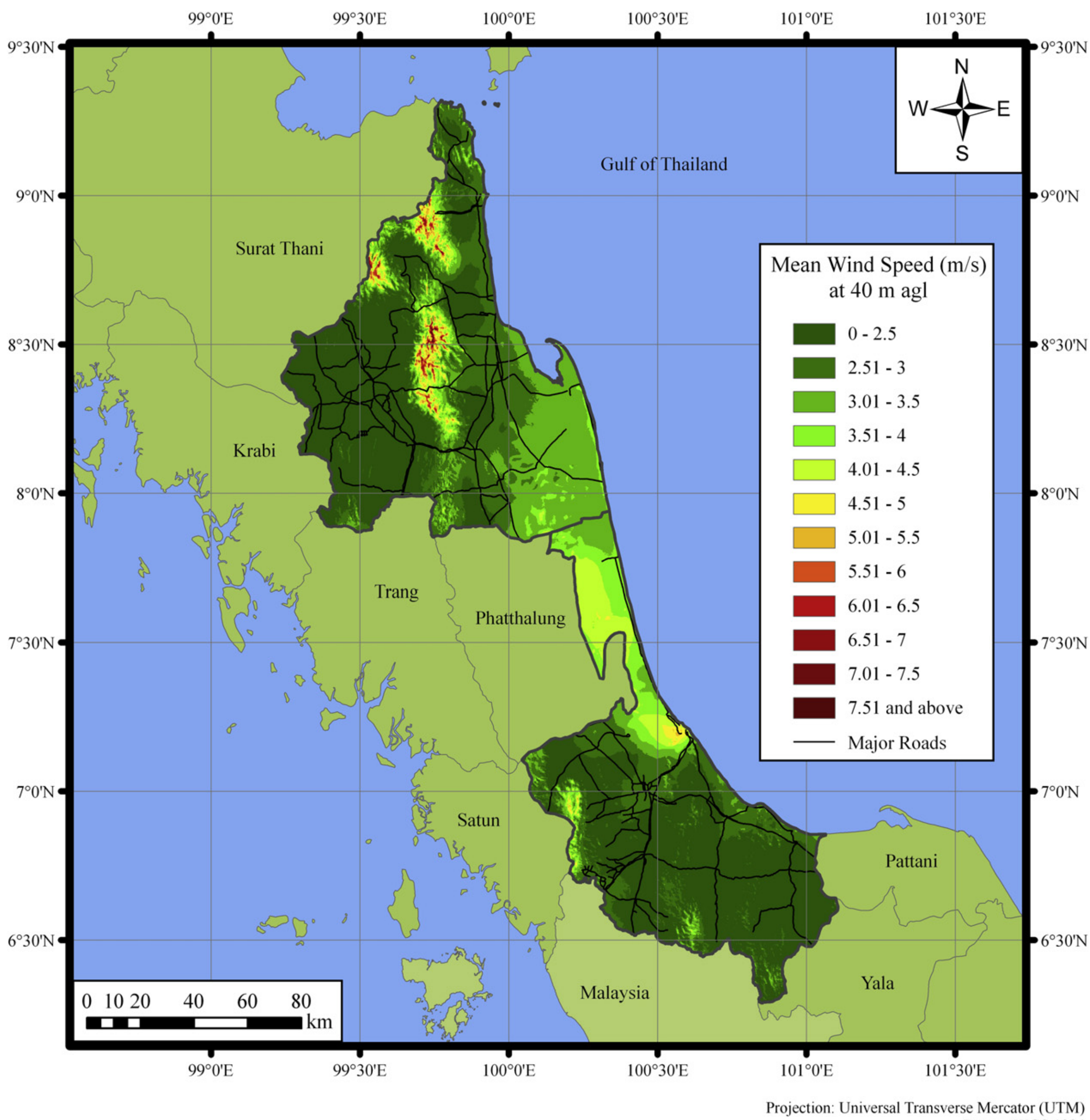

Fig. 4. High resolution wind resource map at 40 m agl for Nakhon Si Thammarat and Songkhla provinces, Thailand.

Thai Government [20], while the Malaysia land use data comes from the database of the European Commission Global Environment Monitoring (GEM) Program [23]. Both the Thailand and Malaysia land use mapping data are reclassified in ArcGIS with the Anemoscope vegetation cover classification index which is converted into corresponding roughness values during the simulations. The land use data is then merged into one large raster file with 90 m by 90 m pixels encompassing the entire region studied. Table 1 shows the Anemoscope vegetation cover classification index and the corresponding roughness height, as used in the computation of the wind resource maps.

Fig. 3 shows the roughness height data of Nakhon Si Thammarat and Songkhla provinces, as used in the computation of the wind resource maps. Most of the territory has a roughness height between 0.3 and 0.5, which corresponds to some sort of mixed forest and agricultural cover. Furthermore, there are significant forest areas where the roughness height is above 0.85. Finally, the eastern areas of the territory have a roughness height of 0.001–0.1, which corresponds to agriculture or aquaculture zones.

3. Results and discussion

The wind resource maps at 40 m, 65 m, 80 m, and 100 m elevations agl for Nakhon Si Thammarat and Songkhla provinces, Thailand, are shown on Figs. 4–7, respectively.

Results show that the region has a good wind regime along the Phuket mountain range and Songkhla lake, along with a moderate to low wind regime along the Gulf of Thailand coastline at 100 m agl. The wind regime in the other areas is generally low, even at 100 m agl.

In order to validate the wind resource maps, results of the simulation were compared to previous low resolution wind atlas

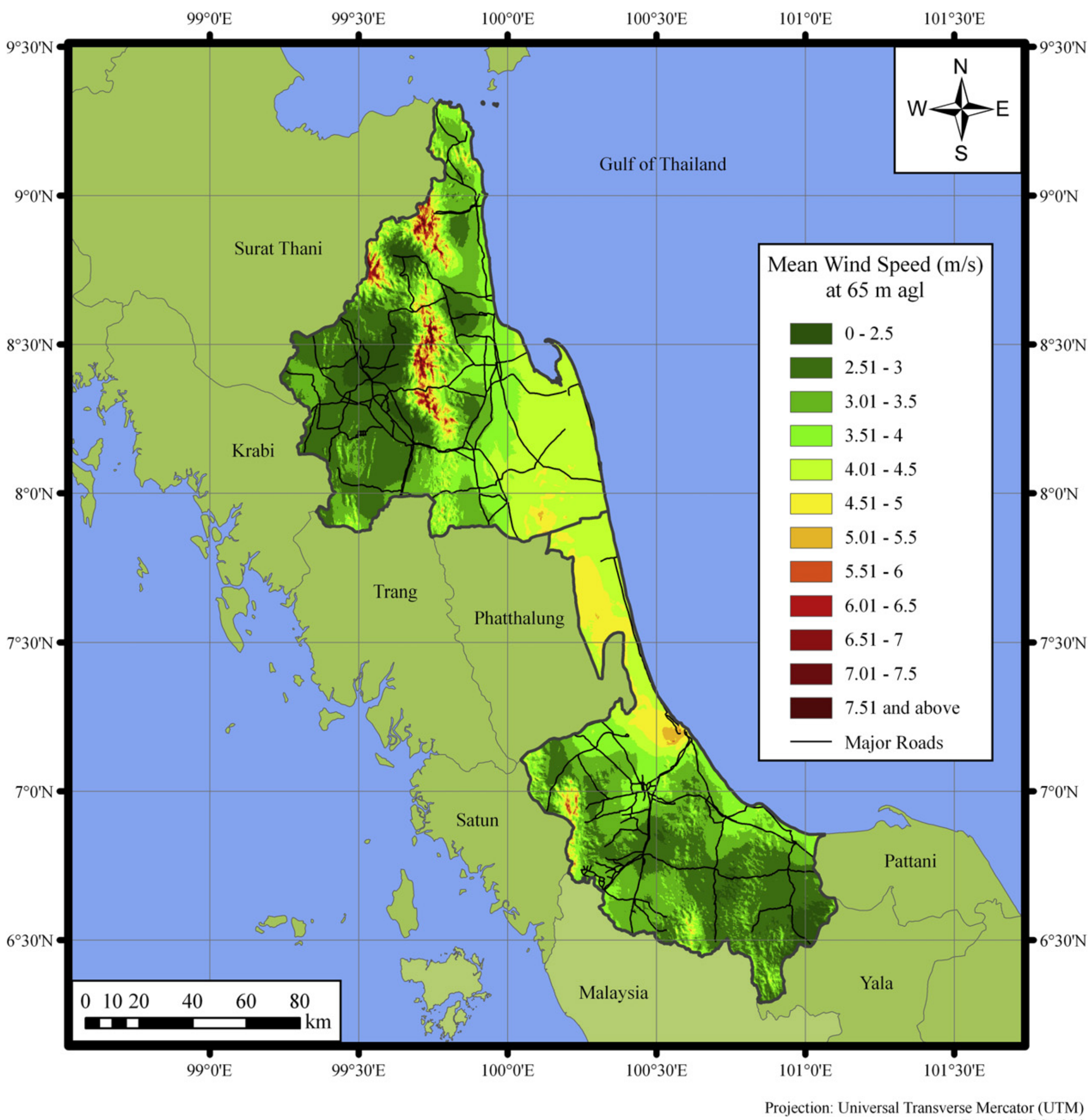

Fig. 5. High resolution wind resource map at 65 m agl for Nakhon Si Thammarat and Songkhla provinces, Thailand.

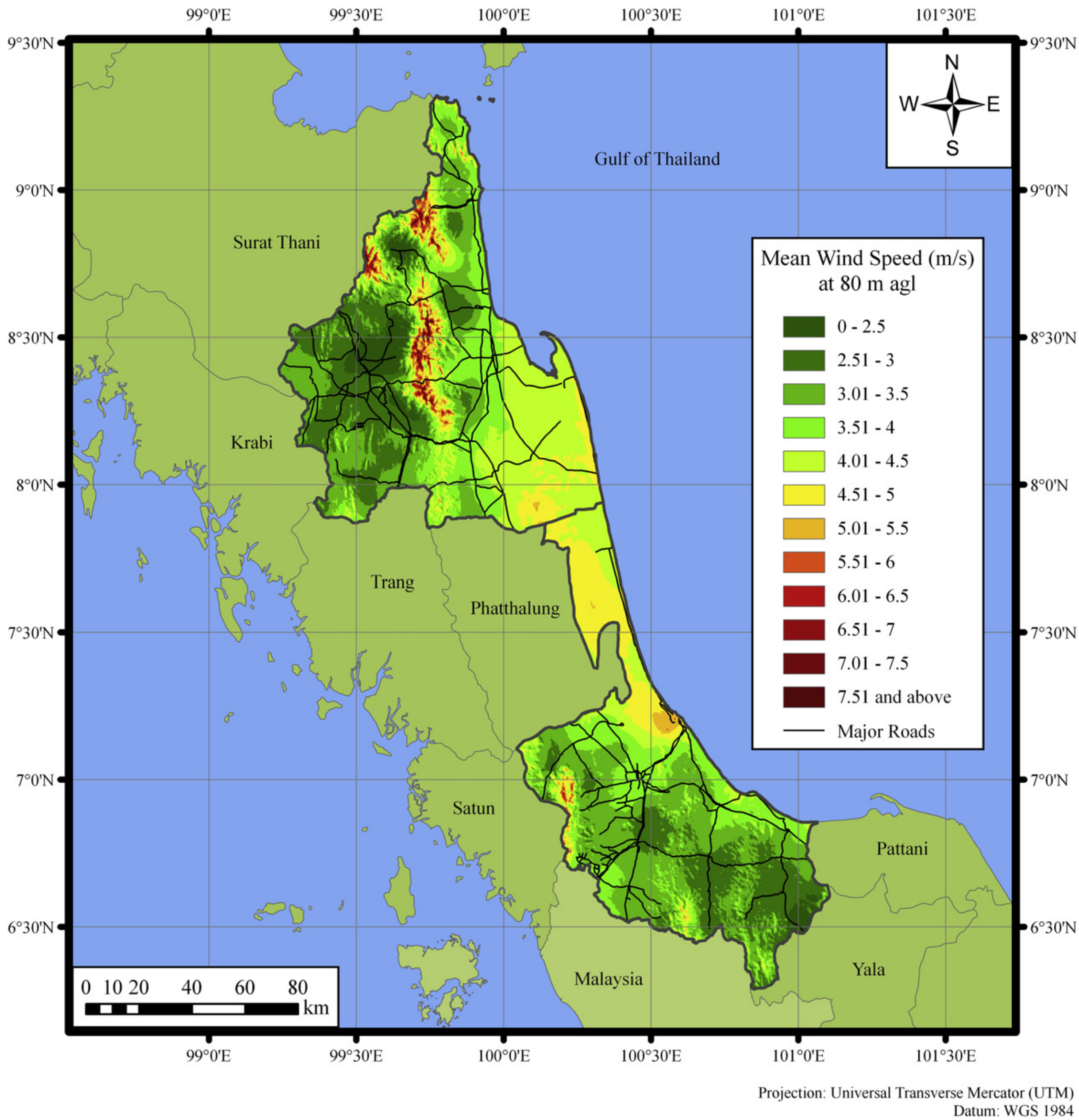

Fig. 6. High resolution wind resource map at 80 m agl for Nakhon Si Thammarat and Songkhla provinces, Thailand.

[24] and with available wind data distributed throughout the territory. To this end, the simulation results were compared to observational wind speeds at 40 m agl from 10 met stations, having a full two years of record, along the coast of both Nakhon Si Thammarat and Songkhla provinces. The geographical locations of the 10 met stations province are shown in Fig. 8.

The wind resource maps of Thailand were produced without any surface wind data. It is noteworthy that in this study, the primary purpose of the met station data is for the validation of the computed wind resource maps. As a result, uncertainty is critical since an error in met station data could lead to the interpretation of erroneous model error calculations. As a consequence, it was decided to be prudent with the comparison because of issues pertaining to the verification of the met station data and to the complexity of the terrain at the met station locations, i.e. coastal areas.

Table 2 shows the results of the comparison of the mean wind speeds observed at the 10 met stations, along with the wind speeds computed at these locations, at 40 m agl.

The comparisons of the computed wind speeds and the observed wind speeds at the met stations are reasonably good and thus confirm the validity of the wind resource maps. However, to mitigate these results, it is important to underline that there are only 10 stations and they are nearly all located on or close to the shore line on the coast of both provinces. Nevertheless, the comparisons of the computed wind speeds and the observed wind speeds show a relatively good agreement.

In terms of analysis of the wind resource throughout the territory studied, the technical power potential and potential annual energy production are identified. To this end, using GIS based analysis tools, economic constraints such as wind class, and assumptions such as the size of standard wind turbines, area per

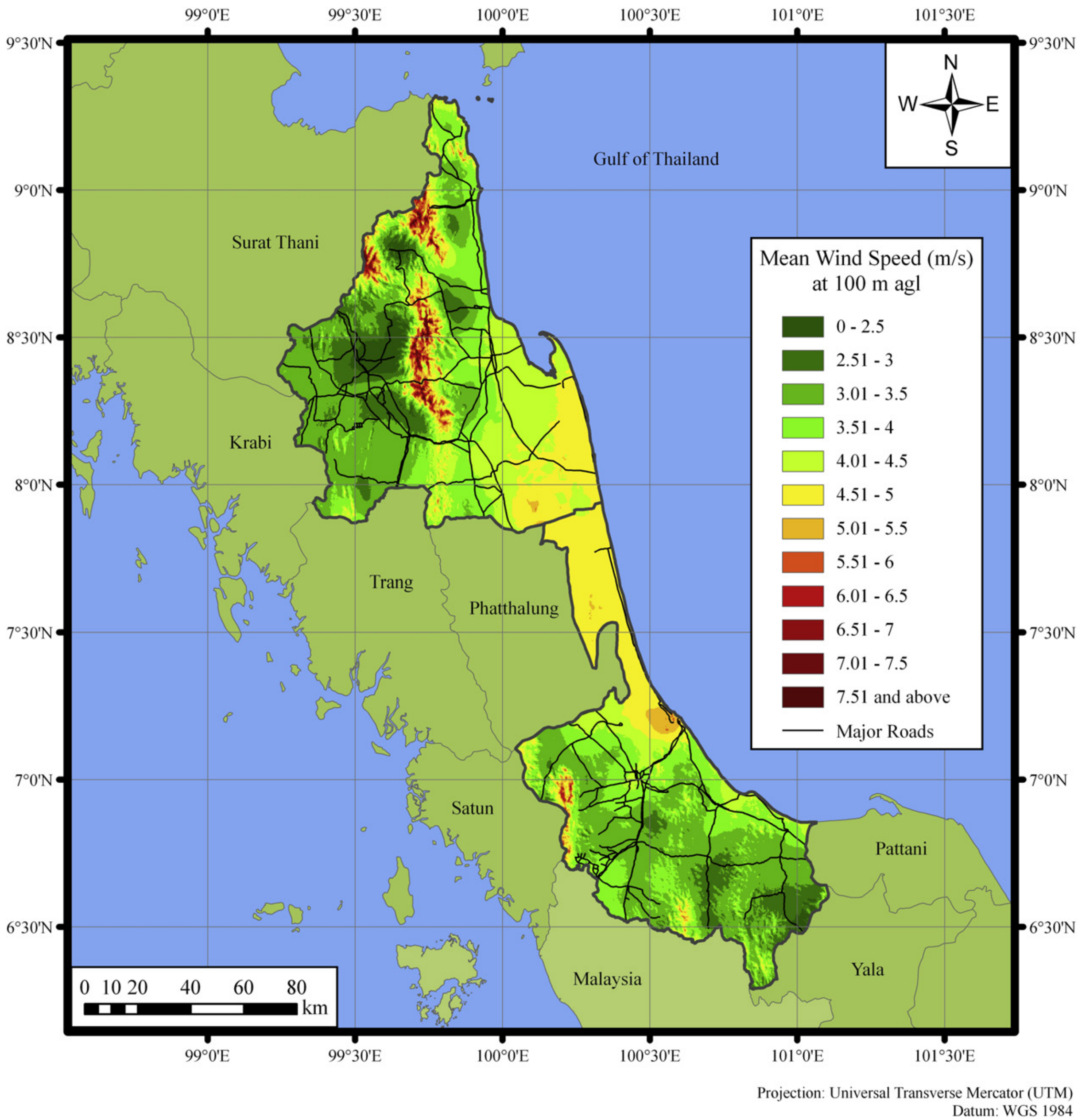

Fig. 7. High resolution wind resource map at 100 m agl for Nakhon Si Thammarat and Songkhla provinces, Thailand.

turbine, capacity factor by wind class, etc. are used to make a projection on the technical power potential and the potential annual energy production for two scenarios: (i) at 80 m above ground level, which corresponds to wind farms with multi-MW wind turbines having hub heights of 80 m, and (ii) at 40 m above ground level, which typically corresponds to single installations of small wind turbine having hub heights of 30 m–40 m.

For both scenarios, no provision is made with regards to landscape conservation, migratory corridors for birds, constraints due to access to roads and distance to electricity transmission lines, and to land that could be the subject of claims, nor does it differ between public and private land. In the 80 m scenario, the nominal power of the virtual wind turbine is 3 MW, while the area occupied by one turbine is 0.33 km^2. In the 40 m scenario, the nominal power of the virtual wind turbine is 50 kW, while the area occupied by one turbine is 2.25×10^{-4} km^2. In both scenarios, the respective capacity factor of a wind class is based on a Weibull distribution with a k factor of 2.0 and a wind shear exponent of 0.14.

Table 3 shows results from the technical power potential at 80 m, where a total of 1374 MW of wind farms could be installed on parcels of land covering 151 km^2 throughout the territory studied; this corresponds to approximately 1% of the land area of both provinces. Further, these wind farms could generate approximately 3.6 TWh in total annual energy production.

For its part, Table 4 shows results from the technical power potential at 40 m, where a total of 407 MW of wind turbines, each having an installed capacity of 50 kW, could be installed on parcels of land covering 46 km^2 throughout the territory studied; this corresponds to approximately 0.3% of the land area of both provinces. Further, these wind turbines could generate approximately 1.0 TWh in total annual energy production.

Fig. 8. The geographical distribution of the 10 met stations used to validate the wind resource maps.

Table 2
Comparison of observed wind speeds at the met stations and computed wind speeds at 40 m agl.

No.	Station name	Observed mean wind speed (m/s)	Computed wind speed (m/s)	Relative difference (%)
1.	Khanom	3.26	3.02	7.4
2.	Sichon	2.33	2.60	−11.5
3.	Thasala	3.44	2.91	15.4
4.	Pakphanang	3.81	3.57	6.3
5.	Huasai	3.91	3.46	11.5
6.	Ranot	3.49	3.53	−1.2
7.	Sathingphra1	3.10	3.78	−22.0
8.	Sathingphra2	3.62	3.93	−8.7
9.	Singhanakhon	4.28	3.56	16.8
10.	Chana	4.16	2.99	28.0

Table 3
Technical power potential at 80 m agl.

Wind speed (m/s)	Area (km^2)	Technical power potential (MW)	Capacity factor	Potential annual energy production (TWh)
<6.0	17,497	–	–	–
6.0–7.0	112	1020	28.1	2.5
7.0–8.0	35	321	35.6	1.0
8.0–9.0	3	33	42.1	0.1
>9.0	0	0	47.4	0
Total exploitable (>6.0 m/s)	151	1374	–	3.6

Table 4
Technical power potential at 40 m agl.

Wind speed (m/s)	Area (km^2)	Technical power potential (MW)	Capacity factor	Potential annual energy production (TWh)
<6.0	17,603	–	–	–
6.0–7.0	39	346	25.9	0.8
7.0–8.0	6	56	34.2	0.2
8.0–9.0	1	5	41.7	0.0
>9.0	0	0	47.9	0
Total exploitable (>6.0 m/s)	46	407	–	1.0

4. Conclusion

In this work, a high resolution wind atlas for Nakhon Si Thammarat and Songkhla provinces in southern Thailand was developed using combined mesoscale, MC2, and microscale, MsMicro, modeling techniques. The model inputs consist of long-term statistical climate data, i.e. the NCEP/NCAR database, high resolution topography and land cover data. The 200 m resolution wind resource maps were validated with observed mean speeds from 10 met stations located along the coastlines of both Nakhon Si Thammarat and Songkhla Provinces. These comparisons of the measured and computed wind speeds at 40 m agl have shown that the wind atlas provides a good representation of the wind resource throughout the territory studied.

The technical power potential and potential annual energy production for both Nakhon Si Thammarat and Songkhla provinces are identified. Results from the technical power potential at 80 m agl show that a total of 1374 MW of wind farms, generating annually a total of 3.6 TWh of energy, could be installed throughout the territory of Nakhon Si Thammarat and Songkhla provinces. On the other hand, a total of 407 MW of small wind turbines (50 kW) could be installed over the territory, corresponding to an annual energy production of 1 TWh.

It is anticipated that this work will stimulate the development of wind energy policies in Thailand, which should lead to the installation of wind farms in the country.

Future work includes performing the wind resource map for other regions of Thailand, with the objective to eventually have a high resolution wind atlas of the whole country.

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