

Wind energy resources in yemen

Eng: Khaled Faisal Gaafar Bin Taleb
Aden University/ Faculty of Engineer - Electrical
Engineer/Power& Contrall

4

Abstract:

The study aims to develop a wind resource map using wind resource calculations and available data to estimate the technical potential of wind energy. Using the Vestas V52 energy curve, the study identifies technically and economically attractive locations, providing the initial step to encourage investment in wind energy.

The wind resource map is the primary indicator of economically feasible locations for wind farms to generate energy. This is preceded by the establishment of monitoring stations to measure the energy expected to be produced by each field. These measurements are used to develop economic feasibility studies, technical specifications, construction work, and financial returns for each project.

1) Introduction

A wind resource map was developed using a wind resource calculation using three-dimensional meso-scale atmospheric model Klima Model Mainz (KLIMM) based on available data from Global Upper Air Climatic Atlas and Civil Aviation & Meteorology Authority (CAMA) *Ref. [3]&[5]*. The available meteorological wind observation data as well as the data from the ongoing wind measurement campaign within the scope of the Wind Resource Assessment and Demonstration Project at Al Hodeidah and Al-Mocha were also used as input in the resource calculation.

Based on the wind resource map *Ref. [4]*, the technical potential for wind power was calculated. The technical potential was estimated using a class II wind energy converter and the power curve of Vestas V52 with a hub height of 50 meters and rotor diameter of 52 meters was used. Also mountainous areas with more than 30% slope have been excluded *Ref.[6]*.

Technically attractive sites in Yemen are those that could generate more than 3000 full load hours (FLH) or a capacity factor (CF) higher than 35 percent. Assuming that around 40 percent of the potential shown in the technical map can be used, preliminary estimates show that around 14,214 MW can be developed at these sites.

Economically attractive sites are however those with more than 3500 full load hours (FLH) or a capacity factor (CF) of about 40 percent. A capacity of about 2,507 MW could be developed at these sites which could generate around 8,293 GWh of electricity per year. These results are however preliminary due to limited availability of long-term data.

Areas with high power concentration, e.g. high capacity factors and high full load hours, are located in the coastal plains, from the south of Hodiedah Governorate to Taiz, Lahej, Aden, and some part of Abyan, as well as mountain areas in Saadah and Amran, north of Sana a, Dhamar, Al-Beida, and Al-Dhale e. The coastal plains from central Hodiedah up to

northern tip of Hajjah as well as Abyan and Shabwa have also good potential for wind power development *Ref.*[4].

2) Wind Resource Assessment Methodology

2.1 Meso-scale Atmospheric Model

Wind resource assessment was undertaken in this study using the Klima Model Mainz (KLIMM) *Ref.*[7], a three dimensional numerical meso-scale model of the atmosphere. The model can simulate wind situations at any point in the atmosphere. With this model, an analysis of typical weather situations as well as locally measured wind resource data, the long-term annual wind speed for any location can be calculated.

Figure 1 shows the general simulation approach of KLIMM. As shown in the figure, KLIMM is a top-down model. Starting from the distribution of the upper air geostrophic wind, the model calculates the wind direction and the wind velocity for each grid cell within the three-dimensional terrain.

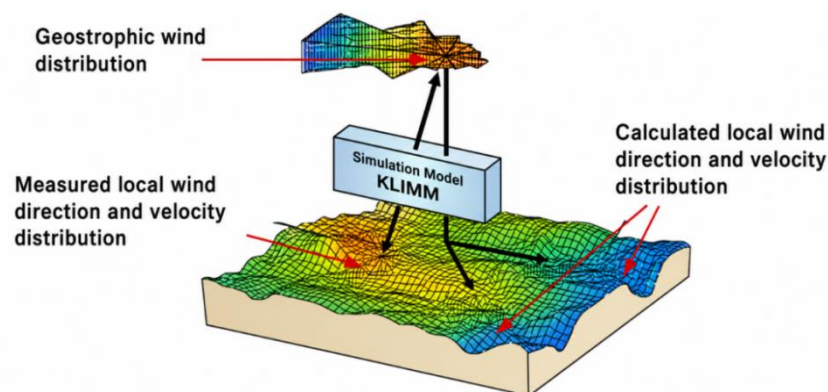


Figure 1: Simulation method of the Klima Model Mainz (KLIMM) *Ref.*[7].

Data used in the model simulations are the following: i) geodetic height data (digital terrain model) *Ref.*[1]; ii) data of land-use (digital raster data) *Ref.*[8]; iii) information on the geostrophic wind conditions and air temperature stratification *Ref.*[5]; iv) measured wind velocities at several wind measurement stations *Ref.*[4].

2.2 Topography and Land-Use Data

The Republic of Yemen is situated in the Middle East, bordering the Arabian Sea, Gulf of Aden and Red Sea between Oman and Saudi Arabia.

Yemen covers an area of approximately 527,970 km² and is located between 42.53 degree to 52.98 degree East and 12.50 degree to 18.95 degree North and its area is cover by mountains and coastal plain in the western part, respectively (Figure 2)Ref.[1].

Topographic data of Yemen used in the study were obtained from the NASA Shuttle Radar Topography mission in 2004 (3 arc second data) and from the gtopo 30 arc second data model from the U.S Geological Survey. A software module was developed (top_use_edit) to enable the huge data amount to be processed for the complete area of Yemen. The wind map developed in the study is based on 3 arc second data with an approximate resolution of 250 m per topographic grid cell.

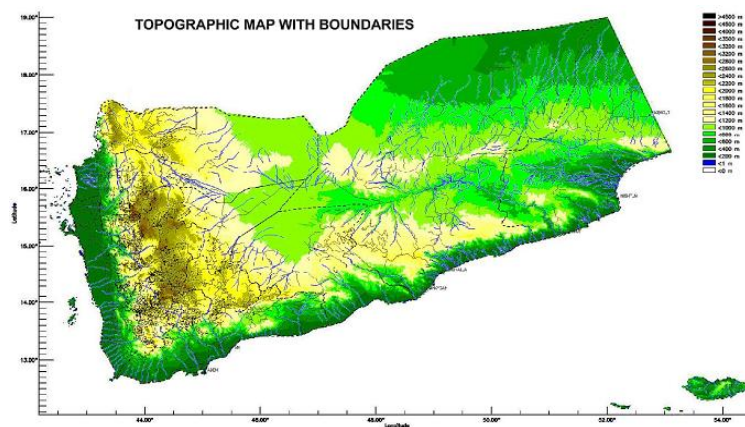


Figure 2: Digital elevation model (DEM) of Yemen Ref.[1].

Land use data of Yemen from the NASA TERRA/MODIS HDF-EOS MOD12Q1 V004 products with a resolution of approximately 900 m per land use grid cell (30 arc second). Classification is available according to the classes shown in Table 1 and the land-use model for Yemen is shown in Table 3.

Table1: Land use classification.

0 - Water	9 - Savannas
1 - Evergreen needle leaf forest	10 - Grasslands
2 - Evergreen broadleaf forest	11 - Permanent wetlands
3 - Deciduous needle leaf forest	12 - Croplands
4 - Deciduous broadleaf forest	13 - Urban and Built Up
5 - Mixed forests	14 - Cropland/Natural Vegetation Mosaic
6 - Closed shrubland	15 - Snow and Ice
7 - Open shrubland	16 - Barren or sparsely vegetated
8 - Woody savannas	

2.3 Upper Air Wind Data of Climatic Atlas

With regard to the wind direction and wind speed distributions to be expected in the investigation area, the upper air wind directions and wind speeds at a height of approximately 6,000 meters were taken from the Global Upper Air Climatic Atlas (Ver.16.3.0, Nov. 2022). The data base, which was subject to this investigation, comprises a record period of 7 years with data from 2000 to 2007 and a period of 6 years from 2015 to 2021.

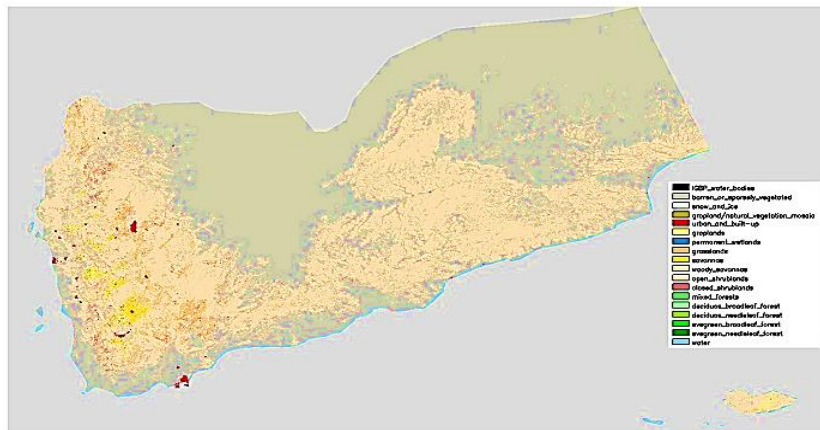


Figure 3: Digital land use model of Yemen

The average long term representative upper air flow characteristic is shown in Table 2. The most frequent flow directions are represented by winds coming from north- eastern and eastern directions (> 50%/year). The same direction sectors are decisive for the higher wind velocities from the upper air.

2.4 Upper Air Temperature Profile of Climatic Atlas

For the assessment of the wind characteristics in the investigation area, apart from the upper air wind statistics, information on the atmospheric temperature stratification are also required. The temperature stratification describes the strong influence of atmospheric stability on the local flow pattern. For instance, in a stable stratification of the atmosphere (represented by cold air near ground covered by warmer air in the upper layers) the vertical mixing of air masses and the transportation of upper air wind speeds towards the ground is very much suppressed compared to an atmosphere with unstable stratification (represented by air near ground warmer than above), which facilitates vertical mixing *Ref.[5]*.

As a consequence wind speeds at a certain location near ground can differ with atmospheric temperature stratification, although the upper air wind speed is the same. Data are reported in the Global

Table 2: Mean upper air wind data *Ref.[2]*.

Sector	N	NE	E	SE	S	SW	W	NW
15.0 N 42.5 E, (Hodida) 500 mbar – approximately 5800 m								
[m/s]	5.7	6.1	6.7	5.1	4.5	4.4	5.6	5.3
[%]	6.7	24.4	24.7	9.0	5.6	7.9	13.4	7.9
15.0 N 45.0 E, (Sana'a) 500 mbar – approximately 5800 m								
[m/s]	5.9	6.4	6.9	4.7	3.9	4.0	5.8	5.8
[%]	12.0	28.5	19.2	7.3	4.5	6.6	12.9	8.5
15.0 N 47.5 E, (shabwa) 500 mbar – approximately 5800 m								
[m/s]	6.3	6.7	6.7	5.1	3.9	4.6	6.0	5.9
[%]	13.7	27.3	19.4	6.8	4.1	6.7	12.5	8.3
15.0 N 50.0 E, (Mukalla) 500 mbar – approximately 5800 m								
[m/s]	6.2	7.0	7.0	5.5	3.6	4.8	5.8	6.1
[%]	13.7	28.4	20.3	6.1	3.7	6.7	12.2	8.7
15.0 N 52.5 E, (Mahra, Hufe) 500 mbar – approximately 5800 m								
[m/s]	6.0	7.3	7.2	5.2	4.4	5.1	6.4	6.2
[%]	12.1	27.9	20.9	6.3	3.7	9.1	12.3	9.7
17.5 N 50.0 E, (Sayoun) 500 mbar – approximately 5800 m								
[m/s]	6.6	6.8	6.4	4.7	4.4	5.6	7.5	7.2
[%]	12.6	23.5	15.3	4.6	3.7	9.1	19.9	11.1
17.5 N 52.5 E, (Mahra, Shihen) 500 mbar – approximately 5800 m								
[m/s]	6.4	6.8	6.2	4.8	4.5	6.1	7.3	6.9
[%]	10.8	23.7	17.5	4.2	3.9	8.3	18.8	12.2
12.5 N 42.5 E, (Bab, Almundab) 500 mbar – approximately 5800 m								
[m/s]	5.5	6.4	7.6	6.0	4.5	4.3	4.2	4.6
[%]	7.5	27.3	34.3	10.5	4.2	4.6	6.2	5.0
12.5 N 45.0 E, (Aden) 500 mbar – approximately 5800 m								
[m/s]	5.5	6.8	7.7	5.5	3.9	3.9	4.6	4.7
[%]	10.4	32.3	28.3	8.3	3.6	3.6	6.5	6.2

* Prevailing frequency components are marked (italic)

Table 3: Mean values of upper air temperature data of climatic atlas

Pressure [mbar]/	Approximate Height [m]	15.0 N 42.5 E	Gradient [oC/100m]
500	5800	-5.9	-0.63
700	3100	11.8	-0.65
850	1500	22.9	-0.66
1000	70	30.2	-0.51

Upper Air Climatic Atlas (Ver.2.0, April 2000)[5], providing extrapolated temperature profiles. Table 3 shows the long-term average temperature gradients for different height layers of the atmosphere.

2.5 Surface Measurement Data

Surface measurement data were taken from Civil Aviation and Meteorological Authority (CAMA) stations. Table 4 contains priority ranking of 5 available surface measurement stations for average wind velocity values measured at 10 m above ground *Ref*[3]. Table 5 shows the measured data from CAMA s Aden and Hodeidah stations.

All stations contain gaps in measurement series and the detailed environmental conditions (e.g. obstacles, roughness structure, condition of monitoring, exact location) are not known. The data are only available at 10 m measurement height and an observation interval of 1 hour. The stations of WMO and CAMA indicate different measurement results at 10 m hub height in the same area. Consequently the data indicate only a first estimate of the wind potential at local sites *Ref*.[3].

Ranking	Station	E	N	Estimated Elevation [m.a.s.l.]	Mean wind [m/s]
	10 m above ground velocity				
1	Hodeidah (CAMA/WMO)	45° 02'	12° 50'	12	9.2 / 7.0
2	Taiz	44° 08'	13° 41'	1385	6.6
3	Aden (CAMA/WMO)	45° 02'	12° 50'	3	6.5 / 7.2
4	Sana'a	44° 11'	15° 31'	2190	3.7
5	Ibb	44° 20'	14° 00'	1929	1.5

meters above ground level.)

Table 4: Priority ranking of surface measurement stations (measuring height 10 meters above ground level.)

Table 5: Frequency distribution of Aden and Hodeidah station (A,k weibull parameter)

Aden (E 45° 02', N 12° 50', 10 m height, mean: 7.2 m/s, A: 8.1 m/s, k: 2.8)

Degree	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
v [m/s]	7.2	5.3	6.9	7.4	7.4	7.5	7.3	7.9	8.1	6.4	6.2	5.3
f [%]	3.8	3.8	7.5	30.2	18.9	7.5	9.4	3.8	3.8	3.8	3.8	3.8
A [m/s]	8.1	6.0	7.7	8.3	8.2	8.4	8.2	8.9	9.1	7.3	7.0	5.9
k	2.8	2.2	2.6	3.1	3.1	3.1	2.5	2.3	2.7	2.0	2.2	1.6

Hodeidah (E 45° 02', N 12° 50', 10 m height, mean: 7.0 m/s, A: 7.9 m/s, k: 2.1)

Parameters	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
v [m/s]	4.4	-	4.5	6.4	6.4	6.2	8.2	7.2	6.0	6.1	7.0	6.7
f [%]	4.0	-	4.0	4.0	4.0	4.0	33.0	13.0	7.0	18.0	4.0	4.0
A [m/s]	5.0	-	5.1	7.1	7.2	7.0	9.3	8.2	6.7	6.9	7.9	6.0
k	2.6	-	2.2	1.5	2.9	2.7	2.2	2.3	2.6	2.3	2.5	2.7

2.6 Re-analyses Wind Data at 2.5 Degree Grid Nodes

To improve the accuracy of the calculation, the study reanalyzed the data of the World Wind Atlas at 50 meters height above the ground at the 2.5° - grid nodes covering Yemen to provide estimations of average wind

velocity distributions in a series of grid nodes and improve the accuracy of the calculation. The results are shown in Table 6.

Table 6: NCEP / NCAR reanalyzed data *Ref.[4]*.

WA1, E 50 N 17.5, 50 m height, mean: 5.5 m/s, A: 6.2 m/s, k: 2.4

Degree	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
v [m/s]	5.3	5.1	4.7	4.3	4.6	5.5	6.6	6.3	5.1	4.1	3.9	4.5
f [%]	4.4	6.5	6.7	6.4	6.8	11.2	22.8	17.4	7.5	3.7	3.0	3.4

WA2, E 47.5 N 17.5, 50 m height, mean: 6.0 m/s, A: 6.7 m/s, k: 2.7

Degree	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
v [m/s]	4.7	6.6	6.1	5.5	5.6	6.1	6.7	6.9	5.5	4.7	4.4	4.1
f [%]	2.8	8.0	11.7	11.0	9.5	10.3	13.1	18.2	7.8	3.4	2.4	1.9

WA3, E 45.0 N 17.5, 50 m height, mean: 5.1 m/s, A: 5.6 m/s, k: 2.5

Degree	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
v [m/s]	4.4	5.0	5.5	5.0	5.0	5.1	5.0	5.2	5.2	5.4	4.9	4.4
f [%]	3.2	5.4	9.3	9.7	10.1	10.7	12.4	12.5	10.8	7.3	4.9	4.0

WA4, E 42.5 N 17.5, 50 m height, mean: 6.1 m/s, A: 6.8 m/s, k: 2.2

Degree	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
v [m/s]	3.9	3.4	3.8	4.6	5.7	6.1	4.8	5.6	6.1	7.5	7.5	5.1
f [%]	4.6	3.3	3.2	5.1	7.5	8.1	4.6	6.9	10.1	19.6	19.7	7.5

WA5, E 50.0 N 15.0, 50 m height, mean: 6.4 m/s, A: 7.1 m/s, k: 2.3

Degree	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
v [m/s]	4.4	6.2	5.8	5.4	5.2	5.9	6.3	8.3	7.6	4.3	3.3	3.4
f [%]	1.0	2.3	5.3	9.1	13.7	17.2	15.9	21.3	10.4	2.4	1.0	0.6

WA6, E 47.5 N 15.0, 50 m height, mean: 6.2 m/s, A: 6.9 m/s, k: 2.8

Degree	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
v [m/s]	4.0	4.9	5.3	5.7	6.1	6.4	5.7	6.7	7.0	5.8	3.9	3.2
f [%]	0.8	1.7	3.4	7.3	18.1	24.7	13.5	12.6	11.9	4.2	1.0	0.7

WA7, E 45.0 N 15.0, 50 m height, mean: 5.5 m/s, A: 6.1 m/s, k: 2.8

Degree	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
v [m/s]	3.1	2.8	4.8	5.2	5.6	6.0	5.4	5.3	5.7	5.4	5.0	4.2
f [%]	1.0	0.8	2.0	9.0	20.2	19.3	10.7	9.5	12.4	8.6	4.9	1.7

WA8, E 42.5 N 15.0, 50 m height, mean: 5.7 m/s, A: 6.4 m/s, k: 2.2

Degree	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
v [m/s]	4.3	3.2	3.3	3.7	6.4	6.5	5.6	4.0	4.2	5.5	6.9	5.5
f [%]	2.9	1.8	1.5	2.3	9.9	17.9	12.7	7.2	7.4	13.1	16.5	6.9

WA9, E 50.0 N 12.5, 50 m height, mean: 6.6 m/s, A: 7.2 m/s, k: 2.2

Degree	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
v [m/s]	3.4	5.5	6.5	5.9	4.8	4.5	5.8	8.8	9.3	5.3	3.3	3.0
f [%]	1.1	4.6	26.4	21.9	8.3	4.7	5.7	14.6	10.3	1.3	0.6	0.6

WA10, E 47.5 N 12.5, 50 m height, mean: 7.2 m/s, A: 8.0 m/s, k: 2.6

Degree	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
v [m/s]	3.2	4.6	7.4	6.9	5.0	4.0	4.1	7.6	9.5	6.6	3.8	2.6
f [%]	0.5	1.2	23.6	33.8	7.4	2.4	1.8	7.4	18.2	2.8	0.6	0.4

WA11, E 45.0 N 12.5, 50 m height, mean: 7.0 m/s, A: 7.8 m/s, k: 3.2

Degree	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
v [m/s]	2.9	3.7	6.8	7.8	6.0	3.9	4.4	7.1	7.8	6.0	3.9	3.3
f [%]	0.6	0.9	5.6	43.4	12.5	2.7	3.1	10.2	14.8	4.3	1.2	0.7

WA12, E 42.5 N 12.5, 50 m height, mean: 4.9 m/s, A: 5.4 m/s, k: 2.4

Degree	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
v [m/s]	3.9	3.5	3.7	5.8	6.0	4.6	3.6	3.6	3.7	4.1	4.3	4.5
f [%]	2.7	2.2	2.7	13.6	31.1	13.1	6.3	6.0	6.7	6.8	5.0	3.8

2.7 Wind Map Calculation Procedure

With topography, land use, geostrophic wind distribution and the temperature stratification of the atmosphere the numerical model for the

KLIMM flow simulations is well defined. For the defined model area, KLIMM runs are performed for totally 12 individual meteorological situations. Each individual flow simulation is carried out with the respective characteristic meteorological boundary conditions.

During the numerical calculation boundary conditions are kept fixed, while the three-dimensional flow pattern after a certain iteration time adapts itself within the complex terrain. The numerical iteration is proceeded until the wind speed alterations within one incremental time step under-runs a given limit value. The three-dimensional flow adjustments result in the occurrence of the characteristic flow patterns, such as channeling along valleys, speed-ups while traversing mountain ridges, weakening at the lee side of mountains and the large-scale passing of the major topographic structures.

For the preparation of the wind map the following working steps have been performed subsequently: i) data collection and pre-processing of input data for the KLIMM model, ii) performance of the flow simulations with the KLIMM model for totally 12 individual meteorological situations, iii) superposition of single results according to their individual frequency to give the complete representative annual wind pattern, iv) fine-adjustment of the long-term annual wind speeds through correlation with wind measurement data at locations within the investigation area; v) terrain following extraction of wind speeds for a fixed height above ground and preparation of wind map.

2.8 Model Area

The model area comprises a horizontal extension from 42.53 degree East to 52.98 degree East and 12.50 degree North to 18.95 degree north, covering an area of approximately 527,970 km² with a grid resolution of approximately 250 to 1000 meters for the wind map.

3 Wind Energy Potential

3.1 Mean Wind Speeds and Power Density

The spatial distribution of the annual mean wind speed at the height of 50 meters within the whole area of Yemen is shown in Figure 4. Excellent wind conditions (wind speeds of above 7.5 m/s) are found in the coastal plains, from the south of Hodiedah Governorate to Taiz, Lahej, Aden, and some part of Abyan, as well as mountain areas in Saadah and Amran, north of Sana'a, Dhamar, Al-Beida, and Al-Dhale'e. The coastal plains from central Hodiedah up to northern tip of Hajjah as well as Abyan and Shabwa have also very good wind resources (between 6.2-7.5 m/s). Power densities of the wind energy resource are shown in Figure 5. Regions mentioned earlier with very good to excellent wind conditions have power densities higher than 200 W/m². Power densities above this level are considered to be suitable for power development. Figure 5 clearly indicates the regions where wind resources could be potentially exploited for power development.

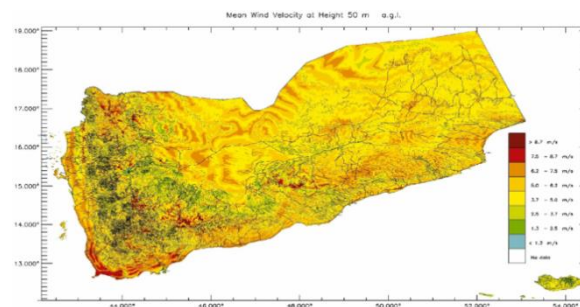


Figure 4: Average wind speed in Yemen (50 m above ground level)

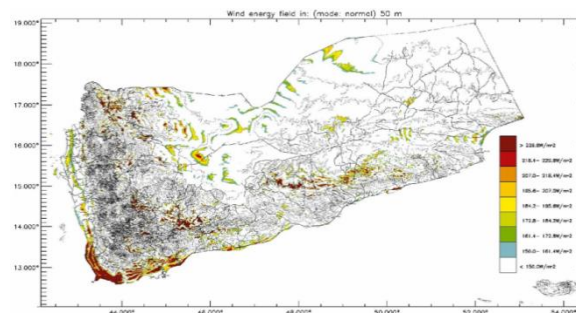


Figure 5: Wind power density (50 meters above ground level)

3.2 Technical and Economic Potential

The wind power technical potential was estimated in the study with the following assumptions:

- The calculation is based on a Class II wind energy converter: 52 meter rotor diameter, nominal rated power of 850 kW, and 50 meter hub height.
- The power curve of Vestas V52 turbine was used.
- The minimum theoretical power density considered is 150 W/m².
- Spacing of the wind energy converter is 10D 5D, e.g. in main wind direction, the distance between the units is 10 x the rotor diameter D, and in cross wind direction, 5 x D.
- Mountainous areas with more than 30% of slope have been excluded
- No other exclusion areas (like settlements, infrastructure, reserves, etc have been factored out.

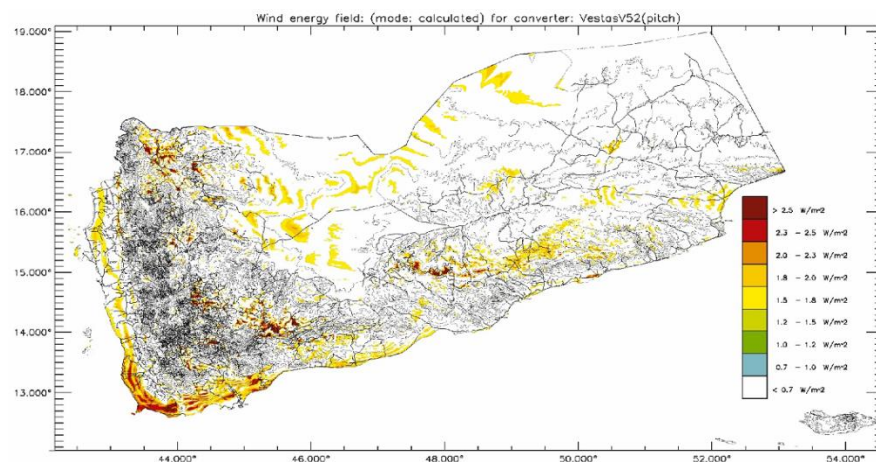


Figure 6: Technical wind energy potential

Figure 6 shows the spatial distribution of calculated power potential based on the above assumptions. It also presents regions with high power concentration, e.g. high capacity factors and full load hours. These include the coastal areas of southwest and southern part of Yemen, some specific locations in Sadaah, Sana a, Dhamar, Al-Beidah, Taiz, and

Hadramout. Calculated power densities in these areas are higher than 2.0 W/m². Areas with high power densities in the coastal plains could be easily.

identified and developed while those in the highlands with complex terrain needs further investigation and may require additional measurements. The technical power density, W/m², represents the harvestable power in a given land area by a specified wind energy converter. Since turbines have constant spacing, this relates directly to the capacity factor and the number of full load hours (FLH) of operation per year. The relationship among these parameters is shown in Table 7.

Table 7: Relation between harvestable average power, CF and FLH

W/m²	CF	FLH
≤ 1.3	≤ 25%	2200
≤ 1.4	≤ 27%	2340
≤ 1.5	≤ 29%	2510
≤ 1.6	≤ 31%	2690
≤ 1.7	≤ 33%	2860
≤ 1.8	≤ 35%	3030
≤ 1.9	≤ 37%	3210
≤ 2.0	≤ 39%	3380
> 2.0	> 40%	3470

From Figure 6, assuming that only 40 percent of the potential can be used due to shading losses, settlement and exclusion areas, and considering only areas with capacity factors higher than 25 percent, one finds the total technical potential of 15,200 MW (Table 8). Taking into account best sites with capacity factors above 35 percent, the technical potential sums up to around 14,200 MW providing about 42,300 GWh of electricity per year.

Economically attractive areas are those with capacity factors of around 40 percent and full load hours of more than 3500 hours per year. This corresponds to more than 2500 MW of installed capacity with an average yearly electricity generation of around 8300 GWh.

As shown also in Figure 6, most of these economically attractive areas are situated in the coastal plains of Hodeidah (southern part), Taiz, Lahej, Aden and Abyan. Wind power development is also favourable in these areas due their proximity to the national grid.

Table 8: Wind power potential

FLH	MW installed	GWh/year
≤ 2200	115992	255183
2340	13	31
2510	0	0
2690	1024	2754
2860	8570	24511
3030	3137	9504
3210	1286	4129
3380	787	2662
> 3470	433	1503
Total (> 2200)	15237	43559
Total (> 3030)	14214	42308
Total (> 3470)	2507	8293

CONCLUSIONS

In summary, the seasonal wind movement, captured by satellite, indicates an excellent source of wind energy in Yemen, particularly in the governorates of Taiz, Lahj, Aden, Abyan, Hadhramaut, and Shabwa. This foretells a promising future for wind energy investment or government energy projects in this field.

To complement the wind inventory and assessment program, monitoring stations must be established to collect, process, and analyze actual data and prepare it for wind energy projects.

REFERENCES

1. National Aeronautics and Space Administration. (2004). *Shuttle Radar Topography Mission (SRTM) 3 arc-second global dataset*. U.S. Geological Survey.
2. National Oceanic and Atmospheric Administration. (2022). *Fleet Numerical Meteorology and Oceanography Detachment dataset*. Fleet Numerical Meteorology and Oceanography Detachment, U.S. Navy; National Climatic Data Center.
3. Civil Aviation and Meteorological Authority. (n.d.). *Surface meteorological observation data for Yemen stations (Aden, Hodeidah, Taiz, Sana'a, and Ibb)*. Meteorological Department, Republic of Yemen.
4. National Centers for Environmental Prediction, & National Center for Atmospheric Research. (n.d.). *NCEP/NCAR weather reanalysis data at 2.5-degree grid nodes for Yemen*. World Wind Atlas.
5. Global Upper Air Climatic Atlas. (n.d.). *Global Upper Air Climatic Atlas (GUACA) (Version 2.0)*.
6. MKWIND. (n.d.). *V52-850 kWh generation specification*. <https://mkwind.pl/uploads/filemanager/PDF/V52-850kWh%20Gen%20Spec-1-1.pdf>
7. KLIMM. (n.d.). *Technical reference guide of KLIMM*.
8. National Aeronautics and Space Administration Earth Observatory. (2004). *Terra/MODIS HDF-EOS land cover product (MOD12Q1 V004)*. NASA Land Processes Distributed Active Archive Center.