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Published in:
The world directory of renewable energy suppliers and services 1996

Publication date:
1996

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Mortensen, N. G., & Said Said, U. (1996). Wind energy in the desert. The case of the Gulf of Suez. In B. Cross (Ed.), The world directory of renewable energy suppliers and services 1996 (pp. 192-208). London: James & James Science Publishers Ltd..

WIND ENERGY IN THE DESERT

THE CASE OF THE GULF OF SUEZ

ARTICLE

Niels G. Mortensen and Usama Said Said

Deserts are often thought of merely as wastes of arid land of little or no use to man or beast . . . There may be an occasional oil well or a quarry – and almost certainly some spectacular scenery – but basically these huge land areas are very sparsely populated and the human activity per square kilometre is extremely low. This characteristic of desert regions makes them almost ideal for wind energy applications: the pressure on the land is low, access is easy, and construction work relatively simple. Furthermore, the surface roughness tends to be low and uniform, so siting of wind turbines can be done primarily with the optimization of energy production – and the minimization of cost – in mind.

Desert regions could therefore provide space for large-scale utilization of wind energy, provided they are favoured by a healthy wind climate and situated not too far from places where power is in demand. Unfortunately, as in many other sparsely populated regions, the meteorological network is very coarse and the wind climate is therefore not known in any detail at present. In addition, the general circulation and associated wind climates in these dry regions with high solar insolation and little or no vegetation are quite different from those of, say, the temperate regions – where most of the models and techniques for wind resource estimation and siting were developed and tested.[1] Possible wind energy projects thus face a basic lack of knowledge of the wind resource as well as a larger than usual uncertainty in the siting process.

The major deserts of the earth are situated around the Tropics of Cancer and Capricorn – that is, roughly between 20 and 30 degrees north and south respectively. At these latitudes, large areas are dominated by so-called dynamic anticyclones (high pressure systems) with widespread subsidence of the atmosphere. Caused by the differential heating of the earth's surface by the sun, as well as by the earth's rotation, these anticyclones effectively suppress the formation of extensive cloud systems, leading to clear skies and little or no rainfall. The tropics, on the other hand, are characterized by relatively low pressure, and winds on the equatorial sides of the subtropical anticyclones are therefore northerly in the northern hemisphere and southerly in the southern hemisphere. The trade winds, noted for their constancy in speed and direction, are examples of this type of flow – these, however, are found mainly over the sea. Over land, in the deserts, the winds are mostly expected to be rather weak.[2]

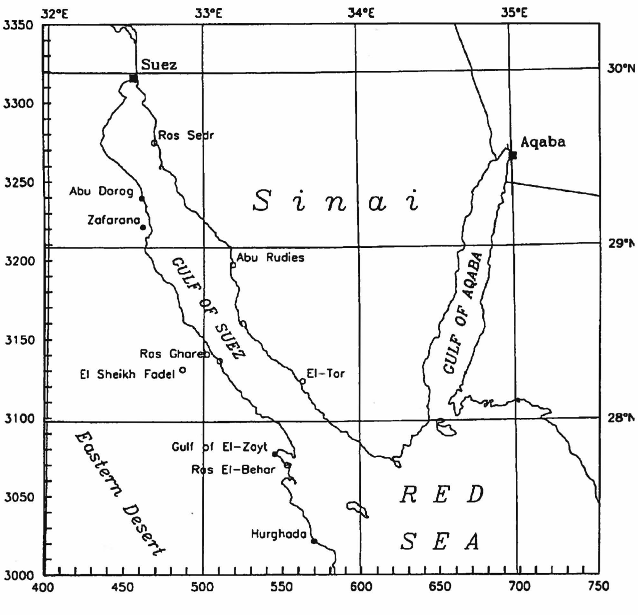


__Figure 1.__ Overview map of the study area with the Gulf of Suez, the northern Red Sea, the Gulf of Aqaba and the Sinai Peninsula. The four main wind atlas stations, as well as several auxiliary stations, are shown on both sides of the Gulf of Suez

Even though the wind resources of the deserts in general are not expected – from our knowledge of the general circulation – to be extremely favourable for wind energy utilization, there exist large desert regions with a very promising wind potential. In this article, we will take a closer look at one such region: the Gulf of Suez and the northern Red Sea – between the Eastern Desert and the Sinai Peninsula in Egypt (Figure1).

PREVIOUS INVESTIGATIONS

It has long been recognized that the wind energy potential along the Gulf of Suez and the Red Sea is markedly higher than in other parts of Egypt – and most other parts of the North African deserts as well. However, early estimates of the mean wind speed (such as those of Griffiths and Soliman[3]) – based on the existing network of meteorological stations in Egypt – range from only about 4m/s in the northern part of the Gulf of Suez to about 6m/s in the northern Red Sea – values which we now know to be far too low.

In the 1970s and 1980s a number of wind resource assessment studies were carried out in Egypt, including the erection of several wind-monitoring stations. These activities were summarized a decade ago by Renne et al.,[4] who also published a map showing the distribution of seven wind power classes over Egypt. Renne et al. reanalysed the existing wind data obtained at stations run by the Egyptian Meteorological Authority and then verified and detailed these resource estimates through additional wind measurements at key locations, in particular along the Gulf of Suez and the Mediterranean coast. They further used climatological data on winds aloft and maps of pressure patterns and air flow, as well as topographical maps, in estimating the wind resources of the data-sparse areas. The resource estimates were calculated from measured distributions of mean wind speed or, in cases where only average wind speeds were available, by assuming that the wind speeds are distributed according to the Rayleigh distribution. The wind resource estimates were referred to 10m above ground level over 'areas free of local obstructions to the wind and to terrain features that are well exposed to the wind, such as open plains, plateaus, and hilltops'.

***Table 1.** Overall summary 1991–95 of wind observations 24.5m above ground level at the four wind atlas stations: data recovery rate, Weibull A- and k-parameters, mean wind speed, mean energy density, and direction and magnitude of the mean wind vector. The occurrence of calms at the stations is less than 0.1%*

Station	R [%]	A [ms^{-1}]	k	U [ms^{-1}]	E [Wm^{-2}]	Du [deg]	U [ms^{-1}]
Abu Darag	75.7	10.3	3.75	9.0	627	358	7.8
Zafarana	77.0	10.4	3.42	9.1	652	001	7.3
Gulf of El-Zay t*	97.7	12.2	3.84	10.6	1016	327	9.8
Hurghada	67.3	7.8	2.36	6.9	333	339	5.3

* Data for 1995 only

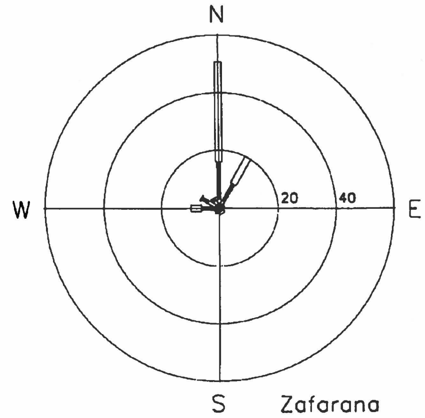
The mean wind speeds in the Gulf of Suez were found to range from class 3 (5.1–5.6m/s) in the northernmost part of the Gulf, to class 6 (6.4–7.0m/s), covering the southernmost three quarters of the Gulf. At one station the data even indicated class 7 (7.0–9.4m/s), but this was attributed to the location of the station on a well-exposed ridge,[4] and may not be representative of the terrain of the region in general.

A NEW WIND RESOURCE ASSESSMENT PROGRAMME

The methods for wind resource assessment and siting developed rapidly during the 1980s, and with the publication of the *European Wind Atlas*,[5] many of these techniques and models became widely available. The existing wind data for the Gulf of Suez were therefore reanalysed in 1990 by the New and Renewable Energy Authority in Egypt and Risø National Laboratory, Denmark – in the framework of the *European Wind Atlas* methodology. Based on the findings of this study it was decided to conduct a new wind resource assessment programme with the primary purpose of establishing reliable and accurate wind atlas data sets for the Gulf of Suez and northern Red Sea. Naturally, a secondary purpose was to evaluate the applicability of contemporary wind resource estimation and siting tools – in particular the *European Wind Atlas* methodology – to the extreme climatic conditions found in the desert.

At the time of writing, almost five years' worth of wind data have been collected at four meteorological masts along a 250km stretch of the Gulf of Suez and the northern Red Sea (see Table 1).

The wind data have further been analysed using the Wind Atlas Analysis and Application Program (WAsP) (see Petersen et al.[6]). The accuracy of the wind speed measurements have been secured by careful calibration of the cup anemometers used, both before and after the period covered by the study. The roughness of the terrain has been assessed from topographical maps and aerial photographs, as well as during site visits. In addition, the aerodynamic roughness lengths of the desert surfaces have been estimated from wind profile analysis. The height variations of the terrain are described in digital terrain models, obtained by digitization of topographical maps. The study finally employs the results of previous investigations,[4] as well as satellite imagery obtained from NOAA-11 AVHRR data, in an effort to validate the magnitude and areal distribution of the wind resource. A report, entitled *Wind Atlas for the Gulf of Suez, Measurements and Modelling 1991–95*, is in the final stages of preparation and is expected to be published by the end of 1995. Some preliminary results of this new wind resource assessment programme are given below.



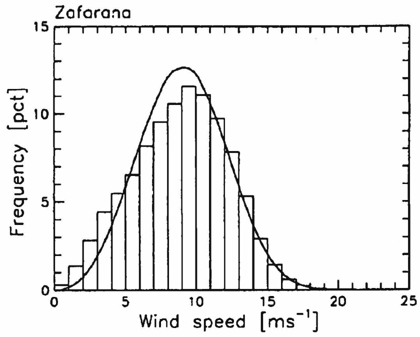


Figure 2. *Wind rose and distribution of wind speeds at Zafarana. More than 50% of the time the wind is in the 30 degree sector centred on north. A Weibull distribution function has been fitted to the wind speed distribution (see Table 1)*

THE WIND RESOURCES OF THE GULF OF SUEZ

As might be expected from our knowledge of the general circulation, the winds in the Gulf of Suez are predominantly northerly (see Figure 2). At Zafarana, the wind blows from the north more than half of the time; at Abu Darag this fraction increases to almost two-thirds. This strongly preferred direction, however, is not only due to the general pressure gradient from north to south, but is also caused by a channelling of the wind flow between the mountain ranges that border the Gulf of Suez on both sides and reach heights of 1000m or more above sea level. The topography is further responsible for the generally high mean wind speeds measured at the three northernmost wind atlas stations. As the flow enters the Red Sea the terrain opens up, the wind loses momentum, and the mean wind speed immediately decreases by about 20%.

When comparing the measured wind climates at the four stations, it should be borne in mind that these may not be representative of a larger area since the measurements are also influenced by the local topography found around the masts. The wind atlas analysis therefore allows us to estimate the wind climates corresponding to certain standard conditions. As an example, we have calculated the mean wind speeds and mean energy densities at the four stations for five standard heights over an infinite water surface; these are given in Table 2.

The terrain is relatively simple (that is, homogeneous and flat) in the immediate surroundings of all four wind atlas stations, so in this case the overall picture of the magnitude and distribution of the wind resource in the Gulf of Suez remains basically unchanged. However, these generalized data can be compared directly with similar data obtained at other stations in

***Table 2.** Estimated profiles of mean wind speed and energy density over roughness class 0 (water) at the four main wind atlas stations*

z	Abu Darag		Zafarana		Gulf of El-Zayt		Hurghada	
m	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}
10	9.4	689	9.5	738	11.5	1200	7.1	333
25	10.2	890	10.4	952	12.5	1544	7.8	430
50	10.9	1079	11.1	1153	13.4	1860	8.3	.527
100	11.8	1362	12.0	1447	14.3	2285	9.0	681
200	12.9	1805	13.1	1903	15.4	2893	10.0	945

different parts of the world. Figure 3 shows corresponding values of mean wind speed and mean energy density for the four stations together with similar data from the Danish stations given in the *European Wind Atlas*. With mean wind speeds and energy densities of 10–12.5m/s and 900–1500W/m^2, respectively, at a height of 25m over roughness class 0 (water), the wind resource in the Gulf of Suez is comparable to that of the most favourable regions in north-west Europe.[5]

Most importantly, though, the wind atlas methodology makes it possible to predict the wind climate at any site (and height) around the stations, as long as the overall wind climate can be assumed to be basically the same as that of the station(s) used for the prediction.[6] In the case of the Gulf of Suez, this means that most of the near-coastal land areas along the Gulf are covered by our wind atlas data, whereas the predictions become increasingly uncertain with increasing distance from the coastline. In the mountains, and further away, we would not expect the wind atlas and models to give accurate predictions, since the wind climate there is most probably completely different from that along the Gulf.

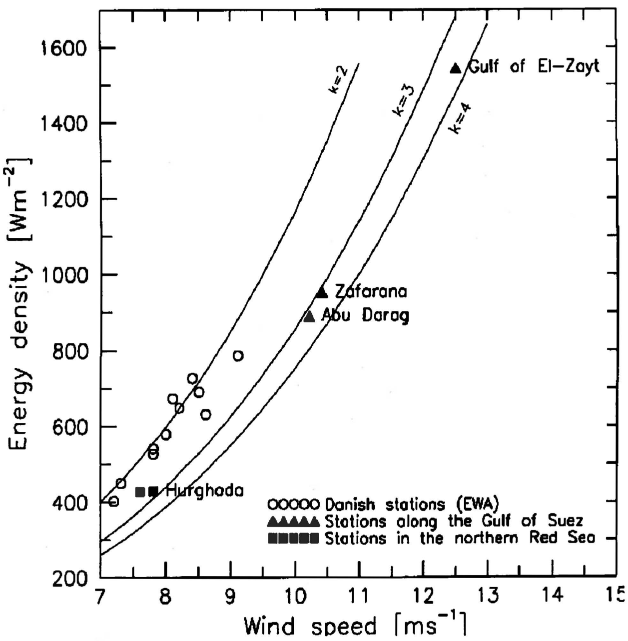


***Figure 3.** Mean wind speeds and energy densities 50 m above ground level over roughness class 0 (water) for the four stations along the Gulf of Suez and the northern Red Sea. For comparison, the Danish stations of the European Wind Atlas are also shown. The differences in corresponding mean wind speed and energy density values are related to the different Weibull k-parameters of the wind speed distributions*

The wind atlas predictions provide estimates of the sector-wise distribution of the wind direction as well as the distribution of the wind speeds within each sector. Given the power curve of a specific wind turbine we are therefore able to estimate the actual energy production of this turbine at different sites. This is illustrated in Figure 4, where the yearly energy production of a 450kW wind turbine is shown as a function of distance to the coastline in the Gulf of Suez. The production is calculated along a 20km-long profile, from 10km inland to 10km offshore, using wind atlas data from Zafarana and the actual topography in the modelling. The profile is then roughly perpendicular to the coastline and to the prevailing wind direction. For comparison, calculations for a similar 20km profile near Vindeby, Denmark, are also shown. The world's first offshore wind farm was constructed here in 1990–91 and the Vindeby profile is also roughly perpendicular to the local coastline and prevailing wind direction.

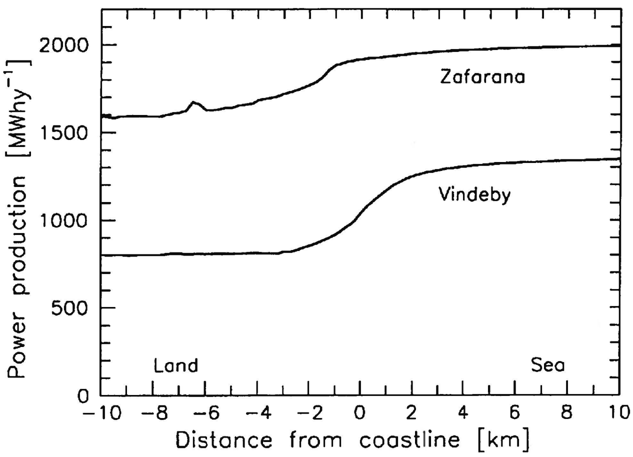
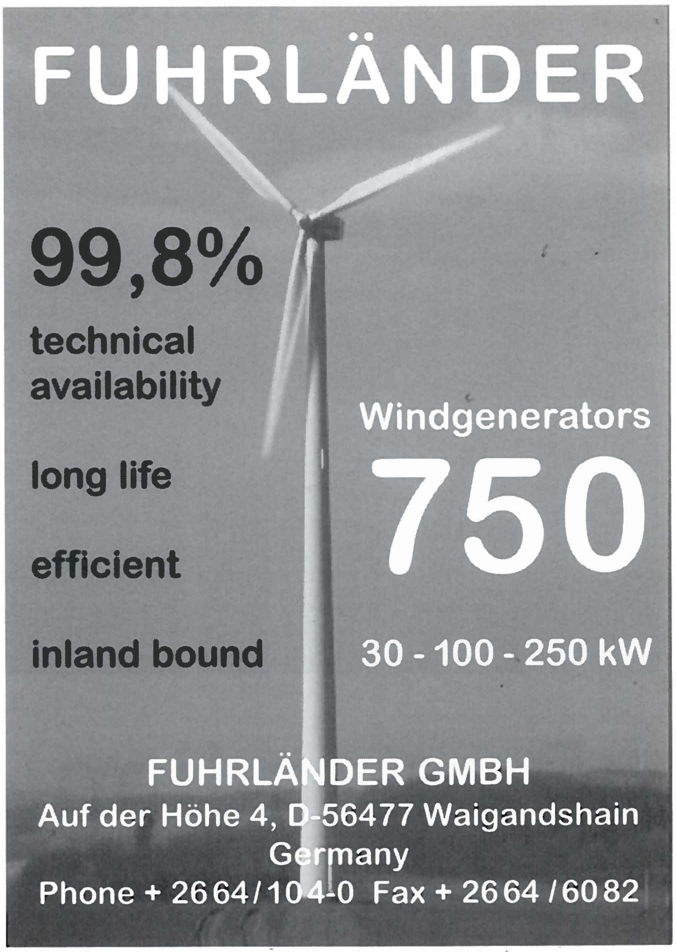


Figure 4*. Estimated mean energy production of a 450kW wind turbine in the Gulf of Suez and in Denmark. The energy productions are calculated at 250m intervals along a 20km-long profile perpendicular to the coastline. The profiles are situated close to Zafarana and Vindeby, respectively*

The wind resource in the Gulf of Suez becomes even more impressive when seen through the rotor of a wind turbine (Figure 4). Over sea, the production in the Gulf is estimated to be around 50% higher than for a similar offshore site in Denmark. Over land, the production in the Gulf decreases to about 80% of the offshore value, whereas the energy production in the Danish example falls to about 60% of the corresponding Danish offshore value. The inland potential in the Gulf of Suez is therefore twice as high as the inland potential close to Vindeby. The different ratios of inland-to-offshore potential are mainly due to the different surface roughnesses of the Egyptian desert and open Danish farmland, the desert being much smoother to the wind flow.

OTHER CLIMATE STATISTICS

In addition to a more reliable and accurate picture of the wind climate and wind resources along the Gulf of Suez, the wind resource assessment programme has also provided valuable information on other climate statistics, some of which may be important for the design and implementation of future wind energy projects in this area. The investigation therefore contains



information on barometric pressure, air temperature, vertical air temperature gradient, land and sea surface temperatures, atmospheric stability, wind speed profiles, aerodynamic roughness lengths, observed and estimated extreme wind speeds, and gustiness of the wind.

CONCLUDING REMARKS

The wind resource assessment programme described above documents in detail the existence of a widespread and large wind resource in and along the Gulf of Suez – a resource even larger than was hitherto assumed. It further establishes the meteorological basis for utilization of wind energy in this region, and includes the information necessary for the siting of wind turbines and for the estimation of their annual energy production. To what extent this huge wind resource is going to be exploited in the future will of course depend on a number of other factors – related to technology, economics and infrastructure, for example – which are beyond the scope of this brief article.

From a wind-prospecting point of view it is worth noting that the existence of a very healthy wind climate in the Gulf of Suez is only partly resolved by the existing meteorological network – and with much less accuracy and detail than would be required for most wind resource assessment studies. This highlights the need for more detailed analyses, as well as additional wind measurements, in other parts of the deserts – and indeed in many other parts of the world.

The wind atlas methodology, originally developed for wind resource assessment and siting in Europe, has proven very useful in the extreme climatic conditions of the desert. Applied with care, it can provide accurate predictions of the wind climate at candidate sites for wind turbines along the Gulf of Suez – and the experience obtained can be used in other places with a similar climatology.

ACKNOWLEDGEMENTS

The Wind Resource Assessment Programme in the Gulf of Suez is funded by the Danish Ministry of Foreign Affairs through DANIDA, and by the Egyptian Ministry for Electricity and Energy through the New and Renewable Energy Authority (NREA).

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