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Evaluation and Zoning of Wind Power in Hormozgan Province, Iran

Sohrab Ghaedi*

Shahid Chamran University of Ahvaz, Iran

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Abstract
Limited resources of fossil energies and climate change have encouraged countries to use renewable energies like wind energy. Although Iran has enormous natural resources of fossil fuels, environmental considerations and the depletion of these resources in the future have increased interest in renewable energies. In this paper, the magnitude and power of wind in Hormozgan province, southern Iran were investigated and classified. The long coastlines and several islands of this province have provided suitable conditions for exploiting wind energy. Collecting data related to speed and direction of the wind, the magnitude and power of zonal and meridional winds were calculated. A cluster analysis on wind magnitude showed the central regions of the province has less productive energy potentials than other regions. From central to the surrounding areas, there is an increased amount of energy potential. Wind power was estimated by the different rotor radius of turbines in the province. In islands, wind magnitude was more than 1/5$m.s^{-1}$, which increases energy potential production in the cold months. In eastern regions, up to 68000 $w.m^{-2}$ power could be produced.

Keywords: wind power, zonal and meridional wind, air density, rotor radius, Hormozgan province.

Introduction

Interest has recently risen in renewable energy sources especially wind energy for electricity generation in many countries. Many countries have tried to find solutions for wind energy generation design parameters (Mostafaeipour et. al, 2013). Utilization of renewable energy resources like wind is a viable way towards having a clean environment, and a sustainable and secure energy future in the world (Nedaei et al, 2014) and in addition, wind energy is one of the more low-cost electricity productions among renewable energy resources (Ramachandra et al, 2005). Wind power experienced a record in year 2015, with more than 63 GW added – a 22% increase over the 2014 market – for a global total of around 433 GW. More than half of the world's wind power capacity has been added over the past five years (Renewable energy policy network, 2017). In 2015, the percentage of global electricity demand provided by wind power was 2.5 % (International Energy Agency, 2015).

There is a potential capacity of 60000 MW of wind power in Iran of which only 160 MW is exploited, making Iran's share of wind energy be less than %0.4 of the total electricity production (Renewable energy organization of Iran, 2015). Iran has abundant oil and gas

* Corresponding author E-mail: s.ghaedi@scu.ac.ir

resources, and this has made fossil fuels to be cheaper than other resources of energy. The area of Iran, its location in the middle latitudes region, its height difference which is up to 5700 m, and having more than 2400 km coastlines in south and north have all caused this country to have suitable conditions for the use of other energies, especially wind energy (Bagheri Moghaddam, 2011). Hormozgan province in southern Iran has several islands and about 900 km coastlines. The population density and commercial and industrial activities in this region need a large amount of energy.

The purpose of this research is to evaluate and classify wind energy potential in Hormozgan province. The study is organized as follows: First, the zonal and meridional wind components are calculated. Next, wind power is estimated and classified. Finally using rotor with different radius, wind power is evaluated.

The previous studies on wind energy in Iran

Mostafaeipour and Abarghooei (2008) analyzed wind energy harnessing at Manjil area in the north of Iran. They stated this region is one of the best locations in the world for establishing wind farms. Keyhani et al. (2010) surveyed wind energy potential in Tehran and found that the wind potential of the region can be adequate for non-grid connected electrical and mechanical applications, such as wind generators for local consumption, battery charging, and water pumping. Mostafaeipour (2010) studied Iran's offshore wind turbine installation and compared with that of the world. He concluded there are many countries like Iran with offshore wind potential, but there has not been serious effort in this regard. Bagheri Moghaddam (2011) evaluated the wind energy status of Iran in terms of the technological capability in manufacturing wind turbines and believed despite high potential in Iran for renewable energy, the oil-bearing characteristic is one of the most important reasons for underdevelopment in using renewable energies in Iran. Mostafaeipour et al. (2011) investigated wind energy in Shahrbabak (Kerman province) and with attention to energy potential recommended to install small size wind turbines for electricity supply of public and public buildings and private houses. By using Weibull parameters, Saeidi et al. (2011) analyzed the wind data during a short period of time in two provinces, namely Northern and Southern Khorasan. This research presents the wind energy potential at four zones in these provinces, Bojnourd, Esfarayen of North Khorasan province and Nehbandan, and Fadashk of South Khorasan province. Mirhosseini, et al. (2011) evaluated the wind energy potential in five counties in Semnan province using the Weibull model. They used the power law for extrapolation of 10 and calculated Extractable annual energy from five wind turbines that showed the possibility of producing higher than 2000 MWh energy with larger one only during the year 2007. By using the Weibull distribution, Emami and Behbahani-nia (2012), according to world classification of wind power, estimated wind data in the Firouzkouh region located in the third class of wind power. They concluded the yearly average wind power density value at 50 m is 329.95 $W.m^{-1}$, which shows this particular site corresponds to the wind power class of 3, since the density value is fairy good for grid connected applications. Alamdari et al. (2012) surveyed wind speed data for 68 stations during one year at different heights in Iran using the Weibull distribution. They found that the eastern and northwestern regions of Iran have a good potential for wind energy. Nedaei (2012) by evaluation wind reverse in Abadan showed that the studied site has good potential for Installation of large and commercial wind turbines at height of 80 m or higher. nedaei (2012) by assessment wind energy in Chalus County concluded that the wind potential of studied site is not capable for using wind energy in order to produce electricity but is probably capable for mechanical applications such as water pumping. Mostafaeipour et al. (2013) analyzed hourly wind data in Binalood region to determine the potential of wind power generation. Their study showed that Binalood has great wind energy potential available. Mohammadi and

Mostafaeipour (2013) studied wind turbine utilization in Zarrineh. They believed this area does not have an available potential for large turbines, but has sufficient wind for small scale wind turbines for different purposes. Biglari et al. (2013) evaluated of wind resource in the Port of Chabahar in southeast of Iran and found that monthly wind speeds in the region are more than 5/6 $m.s^{-1}$ and has fairly good conditions for development of wind power plants. Mostafaeipour et al. (2014) studied wind energy potential in Zahedan and recommended to install Proven 2.5 kW model wind turbine in the region which is the most cost efficient option. The assessment of wind energy potential and economy in Tabriz and Ardabil cities by Fazelpour et al. (2015) indicated that the monthly mean price of electricity generated from the 25 kW wind turbine in Tabriz and Ardabil, for most of the months of the year, are less than or approximately equivalent to the current purchase tariff of renewable energy in Iran. Mohammadi (2015) studied wind power in Kurdistan province and observed that Zarineh Aobato and surrounding areas are the most appropriate place to install wind turbines. The evaluation of wind energy potential in Bushehr province by Dabbaghiyan et al. (2016) indicated that Bordkhun has better potential for using wind energy than the other areas in the province and the annual mean wind power density for this location was found to be about 265$W.m^{-1}$ for winds at a height of 40 m.

The study region

In this study, Hormozgan province was selected as the study region. Hormozgan province, one of the 31 provinces in Iran, is located in the south of Iran with a long coastline along the Persian Gulf and Oman Sea about 900 km (Figure 1). Bandar Abbas is the capital of the province, and its 13 counties are: Abu Musa, Bastak, Bandar-e-Lengeh, Jask, Haji Abad, Rudan, Qeshm, Parsian, Minab, Khamir and Bashagerd. This province is situated between 25° 24′ –28° 57′ N latitude and 53° 41′ – E59° 15′ E longitude. The province of Hormozgan neighbors Bushehr province to the west, Kerman and Fars provinces to the north, Sistan and Baluchistan province to the east, and the Persian Gulf to the south. The Zagros Mountains are located in the north of province, thus there is an increase in height from south to north. The plains extend along the coast of the Persian Gulf and Oman Sea.

Material and Methods

The wind speed and direction data were measured every 3 hours by the Meteorology Organization for the 18 stations studied in this research. In addition, air temperature and pressure were used for calculating air density. The list of stations is presented in Table 1 and the geographical locations of these stations are shown in Figure 1. All measurements at all wind observation stations are recorded at 10 m height above the ground level. Stations with more than 10 years statistics were selected. In addition to the stations of the province data from adjacent provinces was used to calculate wind variability and zoning. Station distribution is from east to west of the province. The longest period is related to Bandar Abbas station (1957 -2014).

First, According to wind speed and direction data, zonal and meridional wind component was calculated as follows:

$$\mathrm{U} = -\,\mathrm{S} \times \sin(\mathrm{D}\ \times 3.1416/180) \quad (1)$$

$$\mathrm{V} = -\mathrm{S} \times \cos(\mathrm{D}\ \times 3.1416\ /180 \quad (2)$$

where U and V are wind zonal and meridional components, respectively, S is wind speed and D is wind direction.

Table 1. Studied stations in Hormozgan province and adjacent station

Station	Latitude (N)	Longitude (E)	Height(m)	Statistical period
Jask	25° 38	57° 46	5	1968 - 2014
Minab	27° 6	57° 5	30	1985-2014
Rudan	27° 27	57° 11	190	2003 - 2014
Bandar Abbas	27° 13	56° 22	10	1957-2014
Qeshm	26° 55	55° 55	6	1996-2014
Haji Abad	28° 19	55° 55	931	1998-2014
Abu Musa	25° 50	54° 50	6.6	1984-2014
Bandar Lengeh	26° 32	54° 50	22.7	1966-2014
Kish	26° 30	53° 59	30	1976-2014
Siri	25° 53	54° 29	4.4	1983-2014
Lavan	26° 48	53° 23	22	2004-2014
Lamerd	27° 18	53° 7	411	1995-2014
Lar	27° 41	54° 17	792	1989-2014
Darab	28° 47	54° 17	1080	1995-2014
Sirjan	29° 28	55° 41	1740	1985-2014
Baft	29° 14	56° 35	2280	1989-2014
Kahnouj	27° 58	57° 42	470	1989-2014
Chahbahar	25° 17	60° 37	8	1963- 2014

Source: Iran Meteorological Organization

Figure1. The study region

To calculate the monthly and annual average zonal and meridional wind components, the following equation was used:

$$\overline{U}_{ltm} = \frac{\sum_{n=1}^{k} f_i U_i}{n} \quad (3)$$

$$\overline{V}_{ltm} = \frac{\sum_{n=1}^{k} f_i V_i}{n} \quad (4)$$

where f_i is occurrence frequency and n is the number of data.
Wind magnitude is calculated by the following equation (Stull, :

$$M = (U^2 + V^2)^{1/2} \quad (5)$$

In addition to wind magnitude, wind power is influenced by air density and the rotor radius of wind turbine. Turbine power is generated from the conversion of wind power to torque (vortex power). This power affects the rotor and finally changes into electricity power. Therefore the amount of energy which wind can transfer to rotor depends on air density, the area of rotor and wind magnitude. Wind power is estimated by the following:

$$P = \frac{1}{2}\,\rho\,(\pi\, r^2) m^3 \quad (6)$$

where P is wind power (watt), ρ is air density ($kg\,.m^{-3}$), π is 3.1416, and r is rotor radius (m). Rotor diameter of wind turbines is classified in 3 groups: small those having a diameter less than 20 m, medium between 20 to 45 m and large more than 50 m (German wind energy association, 1991). In this study, wind power was estimated for turbines having rotor radiuses of 10, 15 and 25 m (rotors diameter 20, 30 and 50 m).

Air density can be determined in varying degrees of accuracy using the following methods (Hughes, 2000):

$$\rho = 1.225\, kg. \quad (7)$$

(Constant value based on U.S. Std. Atmosphere, at sea level)

$$\rho = 1.225 - (1.194 \times 10^{-4}) \times z \quad (8)$$

(z= the location's elevation above sea level in m.)

And based on pressure and temperature data:

$$\rho = P\,/RT \quad (Kg\,.m^{-3} \quad (9)$$

where P is air pressure (in units of Pascal or Newton /m, R is the specific gas constant (287 J kg) and T is air temperature in degrees Kelvin (deg. C + 273). In this paper, this equation was used to calculate wind density.

Result and discussion

A cluster analysis on wind magnitude showed four regions in the province (Figure 1). The first region is a small region in the center of the province which includes Minab station. Table 2 shows the first region only covering 1.7% of all province. The average wind magnitude is 0.91 $m.s^{-1}$ and the deviation from the average is very low (.058) which gradually increases in other regions. Most wind magnitudes are mainly related to the eastern regions that include Jask station; Northeast and west of province, there are small regions which are considered Region 4. The vastest region was Region 3 that covers more than 48% of the whole province. Average wind magnitude in this region is 1.76. Broadly speaking, wind magnitude increases from the center to the margins. Wind magnitude is higher in the coastlines of Oman Sea than in other regions, which is probably due to larger area and low friction.

Table 2. The statistical characteristics of wind magnitude classes

	Region 1	**Region 2**	**Region 3**	**Region 4**
Area %	1.7	21.7	48.4	28.2
Average wind magnitude	.91	1.37	1.76	2.33
Average deviation	0.058	0.08	.11	.17

Source: Research findings

Measurement of wind power correlated with wind magnitude and the rotor radios of turbines. Rotor radius can be very different in any country. In this paper, wind power was calculated by rotor radiuses of 10, 15 and 25 meter. The larger the rotor radius, the more wind power. If the rotor radius is selected 10 m., wind turbine can produce up to 11,000 watts per square meter of energy. This amount of potential energy was related to the east of the province with 10% area (Figure 3). Table 3 shows with a 10 m rotor radius, less than 2500 $w.m^{-2}$ wind energy can be produced in about 41% of the province, from 2500 to 5000 $w.m^{-2}$ in 31.5% and up to 8000 $w.m^{-2}$in 17.7%.

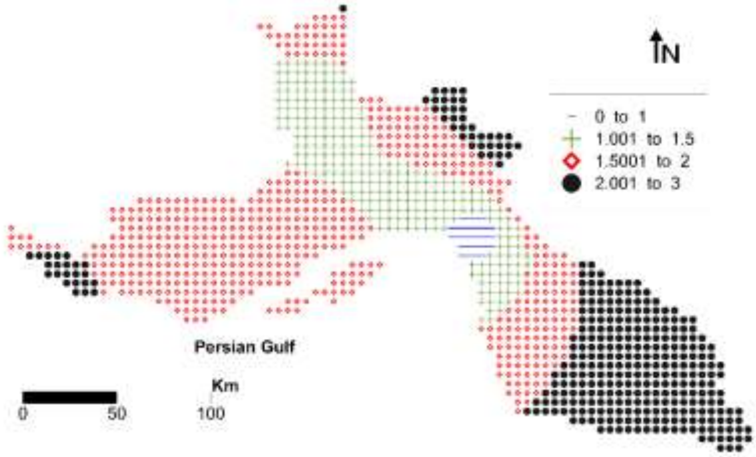

Figure 2. The zoning of wind magnitude in Hormozgan province

Table 3. The statistical characteristics of wind power with 10 m rotor radius

	Region 1	**Region 2**	**Region 3**	**Region 4**
Area %	40.8	31.5	17.7	10
mean	1645	3423	6492	8824
Average deviation	467	556	751	417

Source: Research findings

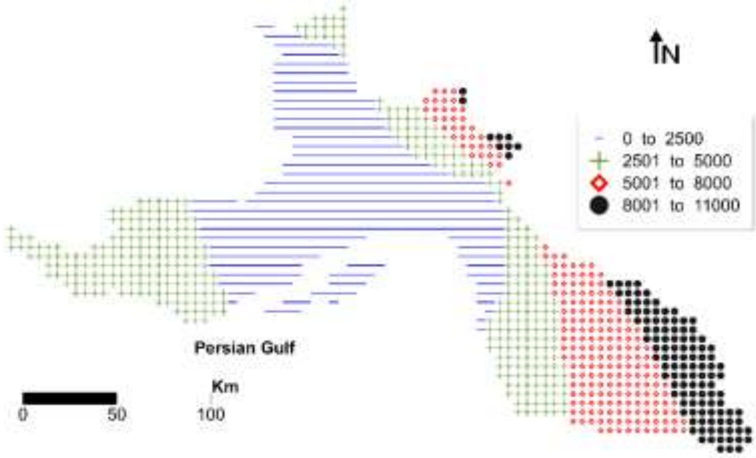

Figure 3. Zoning of wind power with 10 m rotor radius

The zoning of wind power with 15 m. rotor radius is shown in Figure 4. As in previous classifications, the eastern province has highest wind power of up to $24610 w.m^{-2}$. Table 4 shows statistical characteristics of wind power with 15 m. rotor radius. The vastest area is Region 1 with 44% whose average wind power is $3854 w.m^{-2}$.

Table 4. The statistical characteristics of wind power with 15 m rotor radius

	Region 1	**Region 2**	**Region 3**	**Region 4**
Area %	44	30.5	15.5	10
mean	3854	8193	15038	19855
Average deviation	1121	1408	1473	939

Source: Research findings

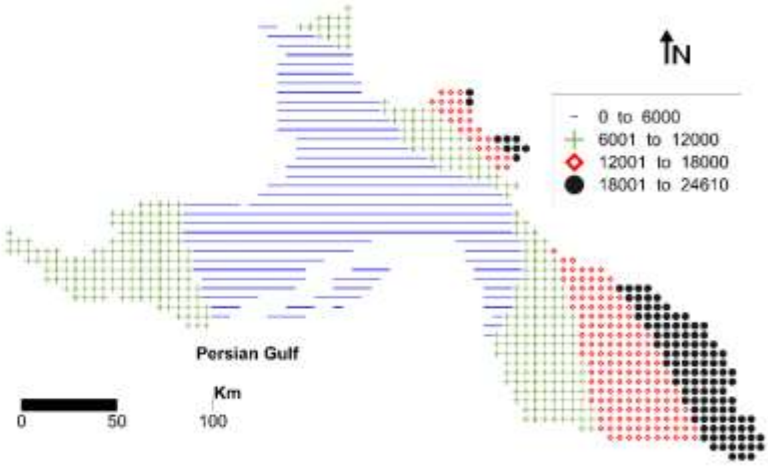

Figure 4. Zoning of wind power with 15 m rotor radius

The wind power potential increases up to 68350 $w.m^{-2}$ when using turbines with 25 m rotor radius in the eastern regions of province (Table 5 and Figure 5). Although increasing rotor radius increases wind power, the extent of the area with maximum wind power decreases compared to the previous cases. Therefore, the area of region 4 decreases in favor of region 1.

Table 5. The statistical characteristics of wind power with 25 m rotor radius

	Region 1	**Region 2**	**Region 3**	**Region 4**
Area %	45.4	29.5	15.8	9.2
mean	10910	23249	42487	55583
Average deviation	3209	3986	4195	2435

Source: Research findings

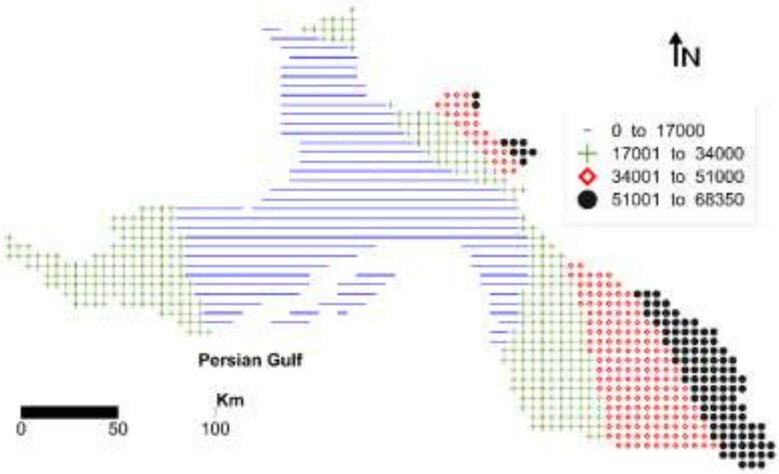

Figure 5. Zoning of wind power with 25 m rotor radius

According to figure 6, the prevailing wind direction is mainly from south to west (180° to 270°), although in Qeshm and Bandar Length it leads to south east.

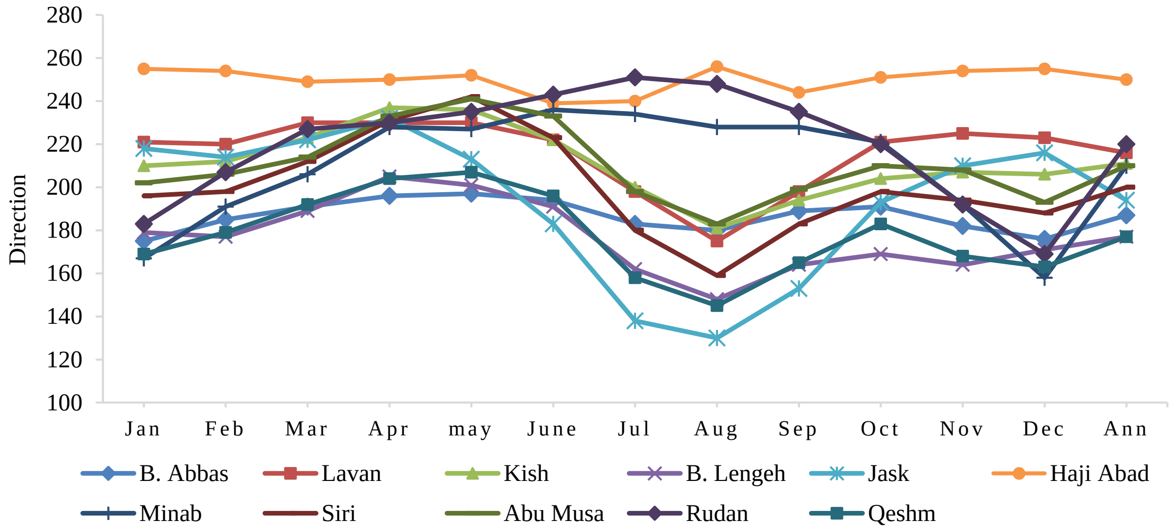

Figure 6. Wind direction in stations

Although the province has 14 islands, only the five islands Siri, Lavan, Abu Musa, Qeshm and Kish have wind statistics in a large period of time. Since Qeshm Island has the largest area (the largest island in the Persian Gulf), its wind properties are presented on the map, but those of other islands are presented in charts due to the small scale of the map. According to figure 7, wind magnitude in islands is between 1.5 and 2.7$m.s^{-1}$. Although wind magnitude in islands is not much different, its maximum and minimum could be seen in Lavan Island and Abu Musa respectively. Due to the fact that the prevailing wind is from south to north, wind magnitude increases in the northern part of the Persian Gulf by reducing the friction. Pressure gradient is more in cold months which leads to increased wind magnitude compared to the warm months.

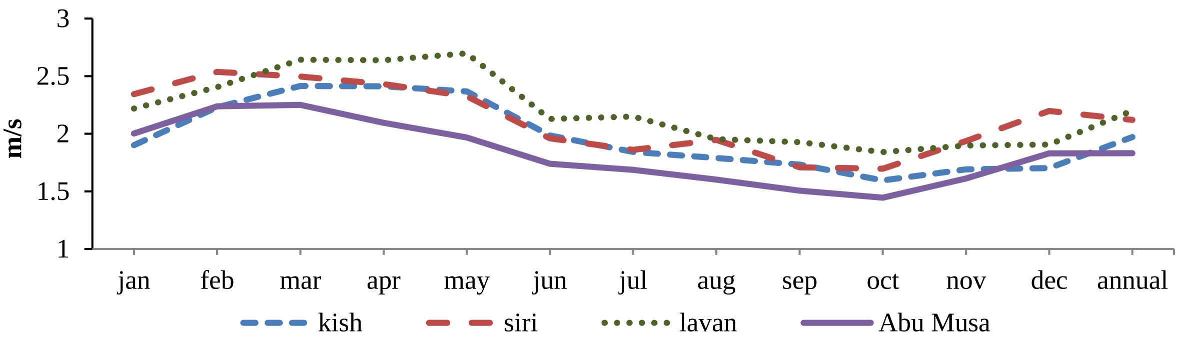

Figure 7. Wind magnitude in islands of Hormozgan province

Figures 8 to 10 present wind power in islands based on rotor radiuses of 10, 15 and 25 m respectively. As in wind magnitude, the maximum and minimum of wind power are in Lavan and Abu Musa respectively. The greater the rotor radius, the greater the difference between clod and warm months. By using turbines with 10 m rotor radius, up to 4700 $w.m^{-2}$ power can be produced in Lavan. This value decreases in Abu Musa down to 2700 $w.m^{-2}$. These values show the maximum and minimum amount of energy produced, respectively. Also the same is true in 15 m rotor radius (figure 9) and 25 m rotor radius, but there is an increase in the difference between cold and warm months. Wind power potential with 10 m rotor radius is variable between 6000 (Abu Musa) and 10500 $w.m^{-2}$(Lavan). The maximum wind power by using 25 m rotor radius is 29300 $w.m^{-2}$ (Lavan) and its minimum is about 17000 $w.m^{-2}$ (Abu Musa).

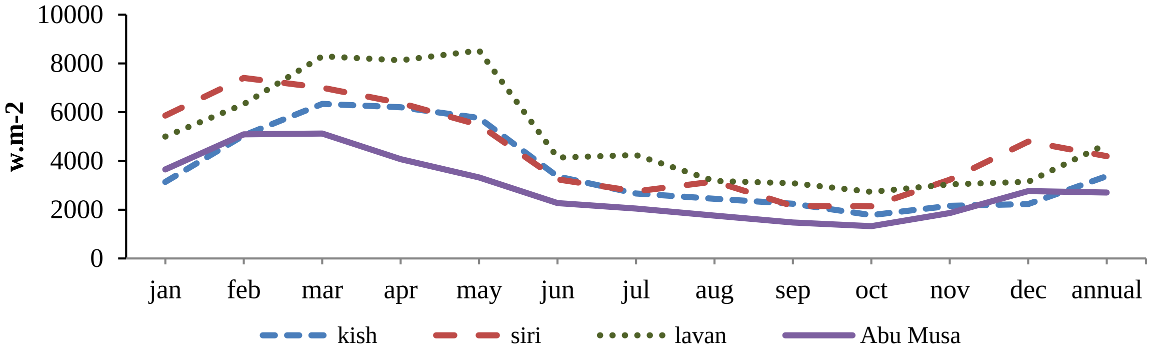

Figure 8. Wind power in islands with 10 m radius rotor

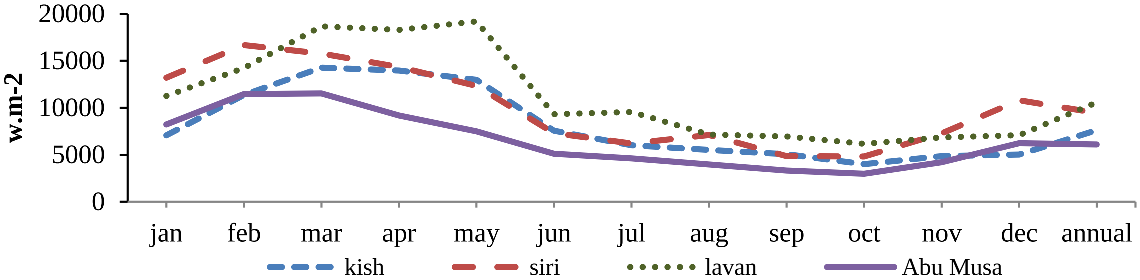

Figure 9. Wind power in islands with 15 m radius rotor

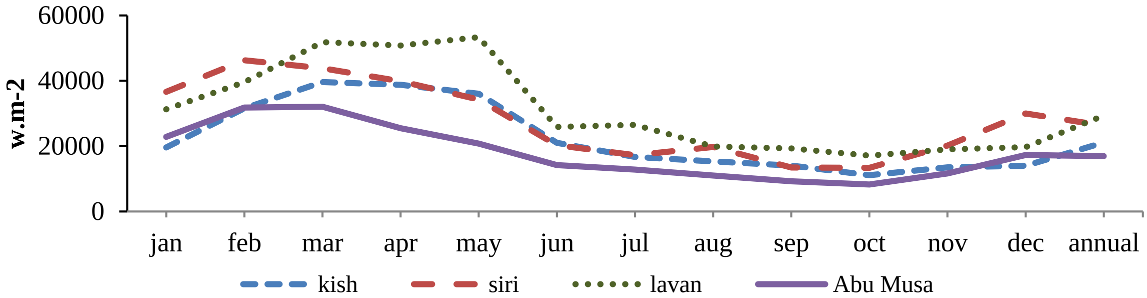

Figure 10. Wind power in islands with 25 m radius rotor

Conclusions

A cluster analysis on wind magnitude in Hormozgan province showed an increase in wind magnitude from the center to the margins. Magnitude and wind power in eastern regions is more than those in other regions. This shows that wind speed on the Oman Sea coastline is more than that on the Persian Gulf coastlines which is probably due to the wide area of Oman Sea and the more pressure gradient between land and sea. Wind power was calculated with rotor radiuses of 10, 15 and 25 meter. If the rotor radius is selected 10 m., wind turbine can produce up to 11,000 watts per square meter of energy. This amount of potential energy was related to the east of the province with 10% area. Calculates show with a 10 m rotor radius, less than 2500 $w.m^{-2}$ wind energy can be produced in about 41% of the province, from 2500 to 5000 $w.m^{-2}$ in 31.5% and up to 8000 $w.m^{-2}$in 17.7%. With 15 m. rotor radius, the eastern province has highest wind power of up to 24610$w.m^{-2}$; but in the vastest area of province (44%) average wind power is 3854$w.m^{-2}$. The wind power potential increases up to 68350 $w.m^{-2}$ when using turbines with 25 m rotor radius in the eastern regions of province. The prevailing wind direction changes from west to southwest in all parts of the province. It seems that wind power is an appropriate for Hormozgan province and can provide an important part of energy demand. Broadly speaking, in compared with other regions and according to world classification of wind power, Hormozgan province has a mean potential for wind energy production. Due to the long shores and vast lands with different height, there is the capability to produce wind energy in the province. It seems that Jask and surrounding regions are the most appropriate place to install wind turbines.

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