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-RESEARCH ARTICLE-

The Investigation of The Wind Energy Potential of The Belen Region and The Comparison of The Wind Turbine with the Production Values

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Abstract

In this study, the potential of wind energy has been investigated in Belen region of Hatay province between 2013-2016. As a result of the study, it was aimed to compare the real field conditions with the predicted values and to enlighten the error analysis of the pre-feasibility reports of the investors who will invest in the region. In the research area, the annual production values are based on a known reference wind turbine. This wind turbine, which is already installed, has been analyzed with computer aided software considering environmental factors. Wind speed, temperature and pressure data were obtained from Belen Meteorology station, which is very close to the area where the turbine is located. The topographical data of the turbine and meteorological station were evaluated by using the WaSP (Wind Atlas Analysis and Application) program using the vector elevation maps of Hatay region. A wind atlas map of the region was created with the WaSP program. Considering the classification requirements of the European Wind Energy Association, it was evaluated that, Belen region could be included in the classes rated as good and very good.

Keywords: WAsP, Belen, Wind, Energy, Weibull Distribution

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Introduction

Increasing population in the world, developments in technology enhance the need of energy day by day. The current depletion of fossil fuels used in the near future, price fluctuations, carbon emissions and transport problems have led countries to different sources of energy. As an alternative to fossil fuels, renewable energy sources are of great importance (Bilgili at al., 2010). Among renewable energy sources, wind energy is considered to be a good alternative to fossil fuels. The number of wind power plants (WPP) in the world is increasing in recent years. In 2017, 52.6 GW wind power plants were established and total installed capacity reached 539 GW by January 2018. As of June 2018, the installed wind power plant in Europe is 182 GW. The 165 GW of these are onshore power plant and 16.9 GW are offshore power plant. As of January 2018, the total installed capacity is 6.98 GW in Turkey. In terms of installed capacity Turkey is the 12th largest country in the World and 6th in Europe (WWEA, 2017; WEEO, 2018).

Due to enhanced energy demand, Turkey's high wind energy potential and investment are increasing in importance. Energy imports, which is one of the biggest obstacles to the development of the country, increases the dependency on foreigners and becomes one of the most important items of the current account deficit. Turkey is trying to supply its energy needs with own resources and investments made in recent years. Turkey plans to invest about 3.3 GW of wind power by 2022 (WEEO, 2022). With these investments, it is planned to reduce the emission of fossil fuels and to reduce the carbon emissions and thus to increase the employment. In 2015, with the energy generated from wind turbines, natural gas imports decreased by $ 574 million and carbon emissions decreased by 5.88 million tons. In addition, approximately 15,000 people were employed in these plants (Tureb, 2018, a). Hatay has an important position among the cities in Turkey with high wind energy potential and the 4th largest city with 364.50 MW of installed capacity of wind power plant in Turkey. With the completion of the ongoing wind energy sources MWs construction, the existing installed power will be 410 MW, while 144.3 MW of this installed power is in Belen region (Tureb, 2018, b). Wind energy potentials in Belen and other regions of Turkey have been studied (Bilgili et al., 2004; Bilgili et al., 2015; Mert et al., 2014; Mert et al., 2016; Tanç et al., 2014).

When investments are completed, the area where the WPP will be installed is of great importance. Most of the costs of the WPP are paid during the installation phase. However, the climatic and topographic structures of the area where the WPP will be installed affect the repayment period of the investment costs. False investments negatively affect repayment periods and therefore profitability (Tureb, 2018, a). In this study, four-year wind data were studied between 2013-2016 by using WAsP program. A detailed wind atlas of 2016 was prepared. The results are compared with the net energy produced by a wind turbine in the region for four years.

Material and Methods

Wind Atlas Analysis and Application Program (WAsP)

The Wind Atlas Analysis and Application Program (WAsP), developed by the Danish Technical University (DTU) Risø National Laboratory, allows for many analyzes such as wind turbine evaluation, wind turbines and location detection for wind power stations, and energy efficiency at these locations. The program is able to perform energy efficiency analysis for both on-shore and off-shore WPP. In the program database, wind turbine models produced by the world's leading wind turbine manufacturers and the technical information of these models contain. The WAsp program needs the following data when modelling (WASP, 2018; MGM, 2018).

- Wind speed and direction
- Region location information and vector map
- Area roughness
- Near obstacles

In WAsP, point analysis of a single turbine can be performed or analysis can be done for large WPP. Gross and net electricity generated by turbines, power density of the turbine in the rotor center, power density maps of the region, average wind speed at different heights (10m - 25m - 50m - 100m - 200m), frequency of wind formation, prevailing wind directions many sectors such as speed, energy and power density can be obtained by dividing into sectors. The Wasp program performs wind frequency modelling in accordance with the two-parameter Weibull distribution. General expression of two-parameter Weibull distribution for wind speed,

$$f_w(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \quad (1)$$

where f_w (v) is the probability function of the measured wind speed v. k and c are Weibull parameters. k is the shape parameter and c is the scale parameter (Mert et al., 2014; Mert et al., 2015).

The wind power potential of a wind turbine with a wing sweep area A at v speed,

$$P(v) = \frac{1}{2}\rho A v^3 \quad (2)$$

where, ρ is the density of the air (kg / m³). The WAsP program calculates by varying the density of air at different temperature and heights. The average power density for the Weibull distribution is calculated as follows.

$$P(v) = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \quad (3)$$

Database

Wind Speed and Direction

The wind speed data used in this study was obtained from meteorological data information sales and presentation system (MEVBIS) of the General Directorate of Meteorology. The data are recorded on an hourly basis by the meteorological station located in the district of Belen, Hatay, between 2013-2016.

Region Location Information and Vector Map

The map of Hatay used in the study is the SRTM (Shuttle Radar Topography Mission) map created by NASA (National Aeronautics and Space Administration). Map of Hatay region are created using Global Mapper program and digitized so that WAsP program can be read. Map of Hatay Region is given in Figure 1. The altitude of the measuring station is 603 meters and the measuring pole is 10 m above the ground level (Mevbis, 2018). Location Information of Belen Meteorology Station is given in Table 1. The turbine center height of the wind turbine, located at an altitude of 724 m, is 80 m from the ground. Reference Wind Turbine Position is given in Table 2.

Table 1. Belen Meteorology Station Location Information

Station Nr	Station	Latitude	Longitude	Altitude	Anemometer Height
18057	Belen	36.4889°	36.2172°	603 m	10 m

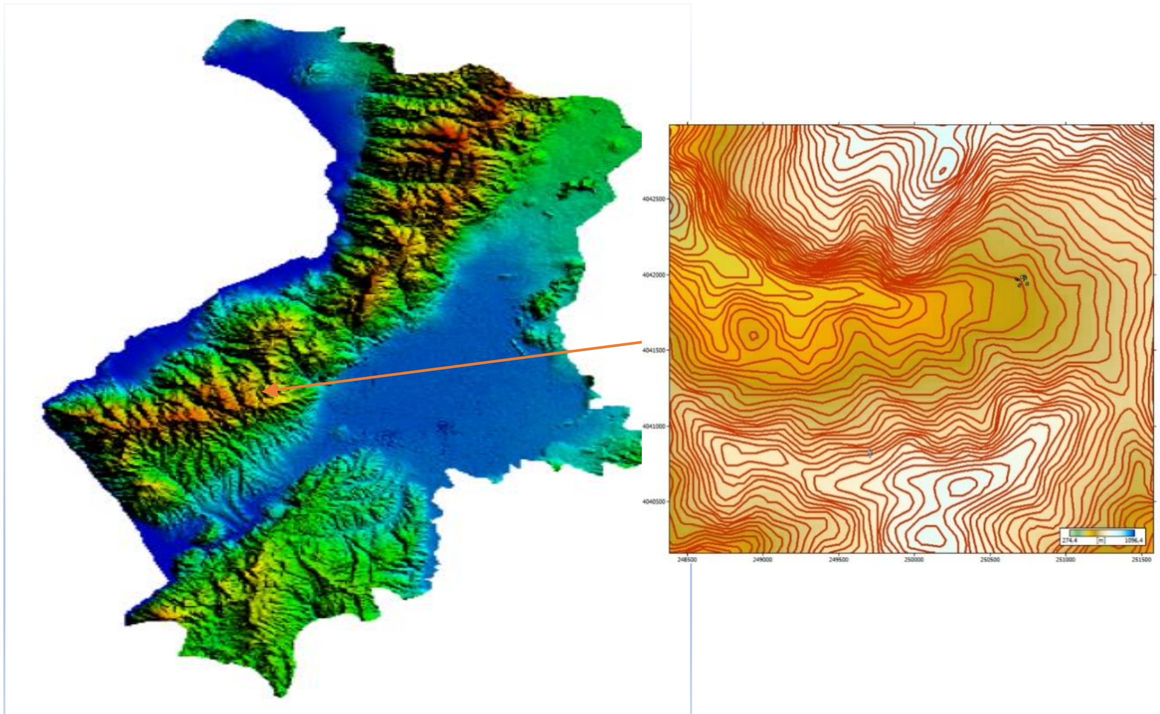

Figure 1. Map of Hatay Region

Table 2. Reference Wind Turbine Position

Turbine Nr	Turbine	Latitude (°)	Longitude (°)	Altitude (m)	Turbine Central Height (m)	Wing Diameter (m)
T01	Vestas V90	36.4781	36.2061	724	80	90

Roughness

Each region has a roughness value. The map is divided into areas according to these roughness values defined by z0. The roughness length gives information about the terrain structure, vegetation and building structures of the region. Roughness values are expressed in meters. The roughness value of the water is 0.0 m. A small value of roughness means a clear and flat land (snow, sand, bare earth, etc.). The roughness lengths of the lands are given in Table 3. These roughness values can also be taken from pre-digitized maps (CORINE, ESA CCI, etc.). The WAsP program cannot read these maps in raw form. Therefore, with the help of Global Mapper and similar programs, the fields and roughness values in the maps are digitized and processed on the elevation map so that the WAsP program can read (Pusat, 2017; Mortensen N. G., 2016).

Table 3. Roughness Length (15)

Roughness Type	**Length (m)**
City	1
Forest	0.8
Open Fields	0.01
Sea	0.0001

Obstacle

Anemometer, turbine or any obstacles around the point to be taken on the area and to be analyzed are processed into the WAsP program as it will change the wind flow.

Wind Turbine

The turbine used as a reference for the theoretical study is the Vestas V90-3.0 MW VCS 50 Hz model. The rotor diameter of the turbine is 90 m and the hub height is 80 m. Reference turbine characteristics are given in Table 4. Vestas V90 the 3 MW VCS 50 Hz wind turbine has a minimum operating speed of 4 m/s and a maximum operating speed of 25 m/s. The power curve graph of the turbine is given in Figure 2.

Table 4. Reference Turbine Features (Vestas, 2018)

General	
Model	Vestas V90 3MW
Capasity	3,000 kW
Hub Height	80 m
Working Speeds	
Minimum Speed	4 m/s
Maksimum Speed	25 m/s
Nominal Speed	15 m/s
Rotor	
Diameter	90 m
Sweeping Area	6,362 m^2
Number of Wings	3
Wing Length	44 m
Speed range	8.6-18.4 rpm
Rated Speed	16.1 rpm

v (m/s)	P [kW]
4	77
5	190
6	353
7	581
8	886
9	1273
10	1710
11	2145
12	2544
13	2837
14	2965
15	2995
16	3000
17	3000
18	3000
19	3000
20	3000
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22	3000
23	3000
24	3000
25	3000

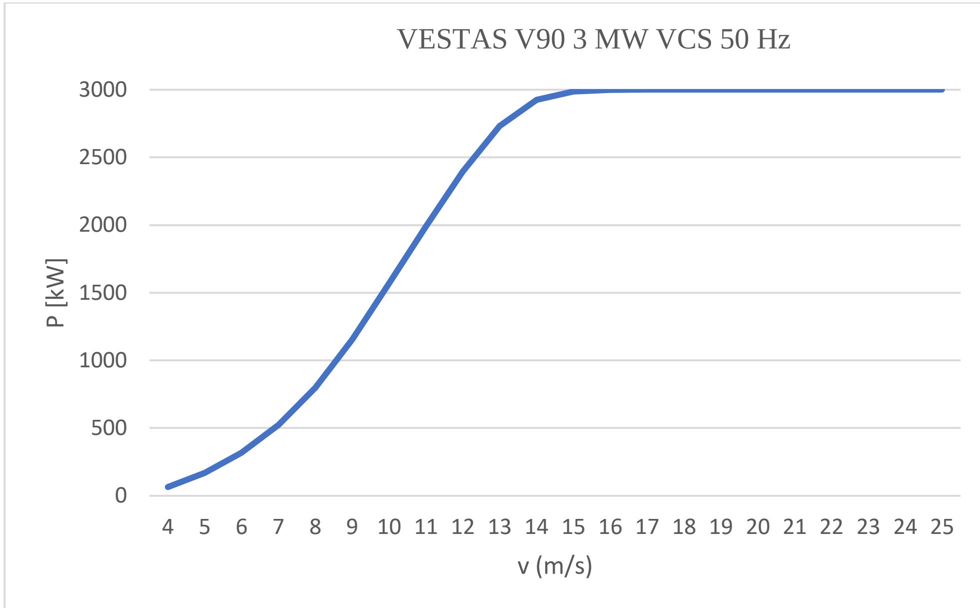
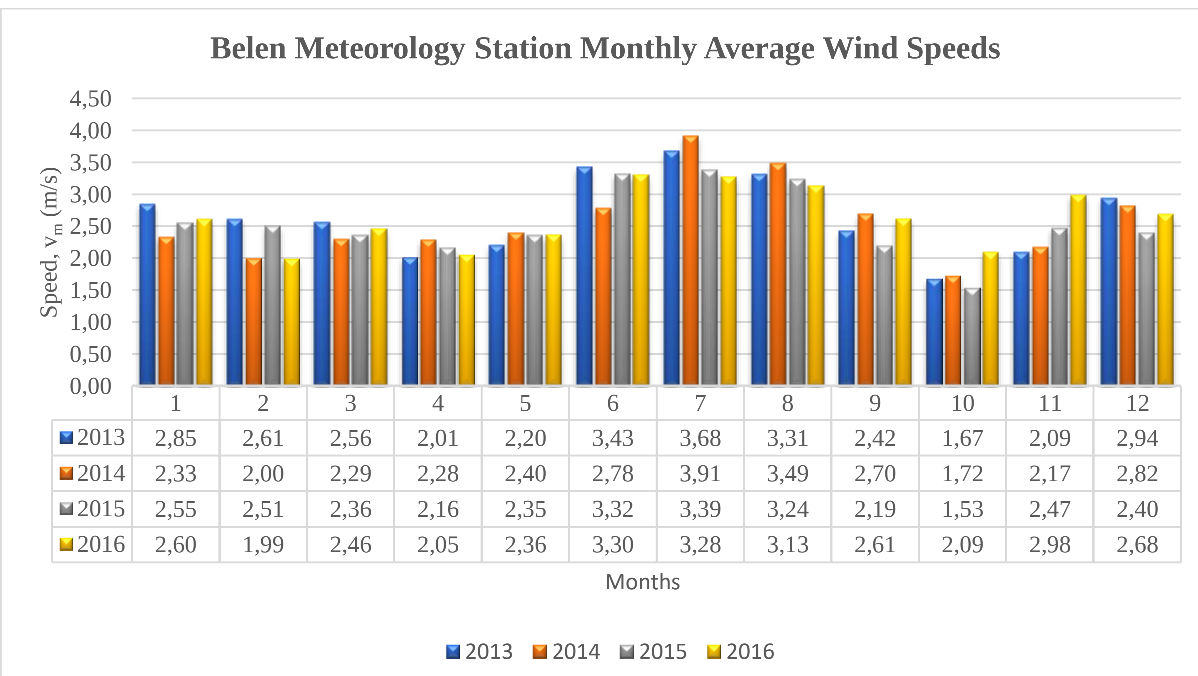


Figure 2. Vestas V90 3 MW VCS 50 Hz wind turbine power curve graph

Results and Discussion

In the study, wind data from Belen Meteorology station were analyzed by the WAsP program as hourly, daily, monthly and yearly. The reference temperature of the station was 17.4 ° C, the air density was 1.129 kg / m³, the average pressure was 96,409 Pa and the relative humidity was 72.02%. Monthly average wind speeds according to the years measured in the station are given in Figure 3. The highest wind speed average was 3.93 m/s in July 2014 and the lowest wind speed average was 1.53 m/s in October 2015.



	1	2	3	4	5	6	7	8	9	10	11	12
2013	2,85	2,61	2,56	2,01	2,20	3,43	3,68	3,31	2,42	1,67	2,09	2,94
2014	2,33	2,00	2,29	2,28	2,40	2,78	3,91	3,49	2,70	1,72	2,17	2,82
2015	2,55	2,51	2,36	2,16	2,35	3,32	3,39	3,24	2,19	1,53	2,47	2,40
2016	2,60	1,99	2,46	2,05	2,36	3,30	3,28	3,13	2,61	2,09	2,98	2,68

Figure 3. Monthly wind speed averages over Belen region

The wind speed and direction are measured by the wind climate analysis (Wasp Climate Analyst) program at 10 m were calculated as raw meteorology data. The wind direction is divided into 30° intervals and is composed of 12 sectors between 0° and 360° The program calculates the prevailing wind direction and frequency (f) separately for each year. The average speed and frequency of frequencies calculated in 2016 are given in Table 5. The dominant wind direction is the sector 11 and it is in the North-West direction. The wind-blown directions and the frequency-wind speed graph are given in Figure 4.

Table 5. Belen meteorology station average wind speed and frequency by sectors (Year 2016)

Sector	1	2	3	4	5	6	7	8	9	10	11	12
F (%)	0.80	0.20	0.80	6.50	18.20	13.70	1.00	1.00	2.20	8.10	27.00	20.40
U [m/s]	1.97	0.77	1.60	2.69	2.12	3.08	0.86	1.04	1.55	2.24	2.70	2.99

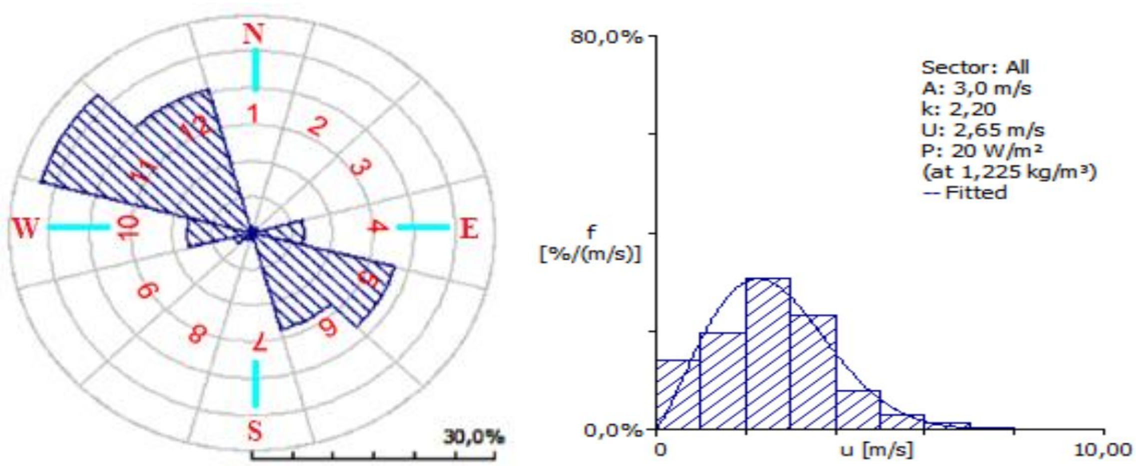


Figure 4. Belen meteorology station wind blow direction and wind speed frequency chart

The average wind speeds, frequencies, Weibull parameters, power densities of the four-year (2013-2016) and sectors of the reference turbine are given in Table 6. Frequency value is the highest in the 12th sector with 20% when the working period is taken into consideration. According to the frequency of all sectors, the highest wind speed average was 8.12 m/s in 2013 and the lowest was 7.93 m/s in 2016. Average power density values were 517 W/m² for 2016 and 544 W/m² for 2013. In the classification made by the European Wind Energy Association, the energy potential of turbine hub heights is close to 100-300 W/m², good between 300-700 W/m² and very good if it is higher than 700 W/m² (Bilgili et al., 2010). The power density at the reference turbine position is in the range of 500-550 W/m² and the energy potential is considered to be good.

Table 6. WAsP Annual wind characteristic analysis by sector a) Year 2013 (80 m)

Sector		Wind Statistics			2013	P (ρ=1,109)
Nr	**Angle [°]**	**Frequency [%]**	**Weibull-c [m/s]**	**Weibull-K**	**Speed [m/s]**	**Power [W/m²]**
1	0	11.50	14.80	4.11	13.39	1,629
2	30	1.50	7.90	1.24	7.33	818
3	60	4.00	9.30	2.21	8.20	532
4	90	5.50	6.90	1.96	6.09	244
5	120	8.90	5.90	1.62	5.29	200
6	150	13.60	8.40	1.96	7.42	441
7	180	8.80	11.10	2.23	9.79	899
8	210	2.40	5.40	2.15	4.74	105
9	240	4.10	6.10	3.30	5.49	123
10	270	6.50	6.30	3.86	5.69	128
11	300	13.20	7.60	4.57	6.90	215
12	330	20.00	10.20	3.93	9.24	543
All sectors		100.00			8.12	544

b) Year 2014 (80 m)

Sector		Wind Statistics			2014	P (ρ=1,109)
Nr	**Angle [°]**	**Frequency [%]**	**Weibull-c [m/s]**	**Weibull-k**	**Speed [m/s]**	**Power [W/m²]**
1	0	12.60	15.00	3.76	13.56	1,748
2	30	1.30	6.60	1.31	6.07	421
3	60	3.60	7.40	1.99	6.57	301
4	90	5.30	6.00	2.06	5.35	158
5	120	9.00	6.30	1.99	5.58	185
6	150	12.60	8.30	2.27	7.33	372
7	180	7.70	10.50	2.47	9.33	715
8	210	2.80	5.70	2.00	5.07	138
9	240	4.90	6.20	3.21	5.59	131
10	270	6.90	6.10	3.76	5.51	117
11	300	12.80	7.20	4.21	6.58	192
12	330	20.50	10.30	3.45	9.22	569
All Sectors		100.00			7.98	523

c) Year 2015 (80 m)

Sector		Wind Statistics			2015	P (ρ=1.109)
Nr	**Angle [°]**	**Frequency [%]**	**Weibull-c [m/s]**	**Weibull-k**	**Speed [m/s]**	**Power [W/m²]**
1	0	13.70	14.60	3.83	13.23	1,613
2	30	1.40	6.40	1.80	5.69	218
3	60	3.60	7.20	2.12	6.35	256

4	90	5.40	5.90	1.99	5.21	151
5	120	9.40	6.00	1.71	5.36	194
6	150	13.50	8.40	2.01	7.43	431
7	180	8.50	11.00	2.27	9.72	868
8	210	2.80	5.90	2.10	5.25	146
9	240	5.00	6.60	3.59	5.96	151
10	270	6.40	6.10	4.01	5.53	115
11	300	10.80	7.00	4.10	6.37	176
12	330	19.50	10.10	3.39	9.06	545
All Sectors		100.00			7.99	536

d) Year 2016 (80 m)

Sector		Wind Statistics			2016	P (ρ=1.109)
Nr	Angle [°]	Frequency [%]	Weibull-c [m/s]	Weibull-k	Speed [m/s]	Power [W/m²]
1	0	11.80	13.90	3.69	12.55	1,394
2	30	1.20	6.90	1.33	6.32	462
3	60	3.20	7.50	1.87	6.66	337
4	90	5.00	5.90	1.79	5.26	174
5	120	9.10	6.00	1.63	5.34	204
6	150	13.60	9.20	2.08	8.14	550
7	180	8.60	12.40	2.42	11.01	1.198
8	210	2.60	6.40	2.76	5.69	150
9	240	4.50	6.50	3.47	5.87	147
10	270	6.80	6.10	4.14	5.51	113
11	300	13.30	7.00	4.43	6.35	169
12	330	20.30	9.40	3.47	8.49	444
All sectors		100.00			7.93	517

In the Wasp program, wind atlas of each year were created separately. With this wind atlas, calculations can be made for the desired height and different surface roughness values. Table 7 shows the wind atlas data for the analysis region in 2016.

Table 7. Wind Atlas of 2016

2016	Height [m]	0.00 m	0.03 m	0.10 m	0.40 m	1.50 m
	Weibull-c[m/s]	6.52	4.71	4.13	3.26	2.18
10.0	Weibull-k	1.97	1.80	1.83	1.87	1.92
	Wind [m/s]	5.78	4.19	3.67	2.90	1.94
	Weibull-c[m/s]	7.15	5.64	5.09	4.29	3.30
25.0	Weibull-k	2.02	1.90	1.93	1.96	2.00
	Wind [m/s]	6.34	5.00	4.52	3.81	2.93
	Weibull-c[m/s]	7.70	6.51	5.96	5.18	4.24
50.0	Weibull-k	2.10	2.06	2.07	2.09	2.12
	Wind [m/s]	6.82	5.77	5.28	4.59	3.75

	Weibull-c[m/s]	8.35	7.67	7.07	6.25	5.31
100.0	Weibull-k	2.13	2.25	2.25	2.24	2.22
	Wind [m/s]	7.39	6.80	6.26	5.54	4.70
	Weibull-c[m/s]	9.16	9.32	8.58	7.65	6.63
200.0	Weibull-k	2.08	2.23	2.22	2.20	2.17
	Wind [m/s]	8.11	8.25	7.60	6.77	5.87

After the wind atlas has been formed, the energy potential map of the region and the average wind speed map are extracted in the light of this information. These maps make it easier to decide which locations turbines can be placed on. Calculations are performed at the height of the selected wind turbine. In the study, the hub height of the reference turbine is 80 m. The average wind speed atlas of the Belen region in 2016 is given in Figure 5 and the wind energy potential atlas is given in Figure 6. The highest power density in the analyzed region is calculated as 1092 W/m² and the lowest power density is 126 W/m². Average wind speeds vary between 5.09 m/s and 10.12 m/s.

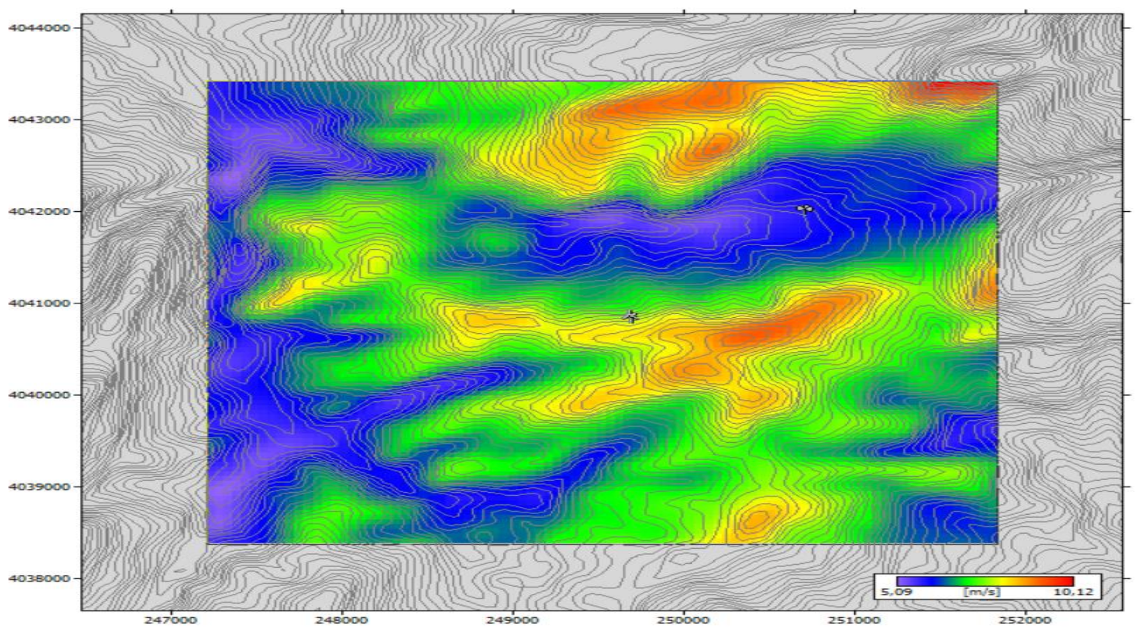


Figure 5. Wind speed atlas of Belen region in 2016 (80 m)

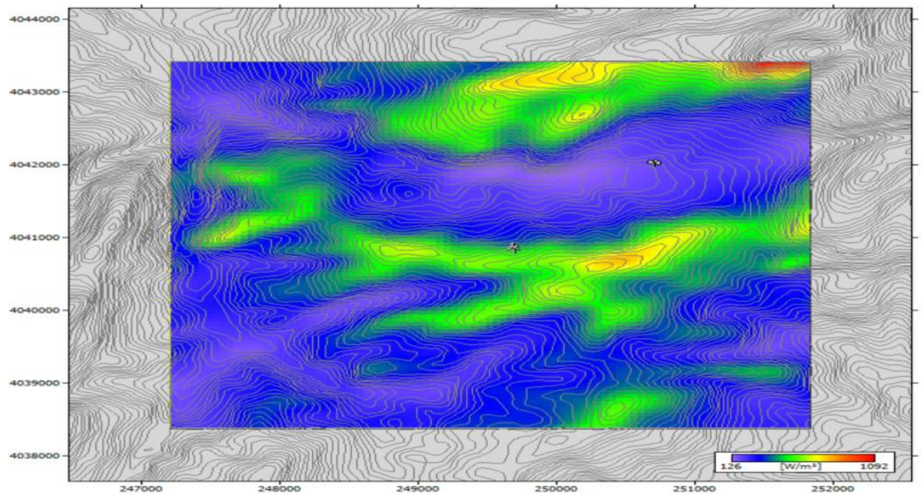


Figure 6. The wind energy potential atlas of Belen region in 2016 (80 m)

Wind power plants record unintentional stops (maintenance, malfunction, periodic checks, etc.). The ratio of the total time of these stops to the whole working time is called at involuntary waiting coefficient (IWC). The energy is produced yearly by the subject turbine that is divided into the IWC so this way prevents the effect of the unintentional stops on the theoretical study. The actual values of the turbine are divided into these values and are calculated by assuming that there is no involuntary stand. The region of the subject turbine was analyzed and the total annual energy produced in the turbine was calculated for four years. The actual energy produced in the turbine and the theoretical value calculated by the WAsP program were compared. The theoretical energy production values of the subject turbines calculated with WAsP program and the actual energy production values are given in Figure 7. The annual wind energy production values calculated in the WAsP program are considered to be very close to the actual values. The deviation between the real and estimated values was realized in 2013 by 7.11%. The closest value to real production was in 2016 with deviation of 0.82%. The differences between the values are given in Table 8.

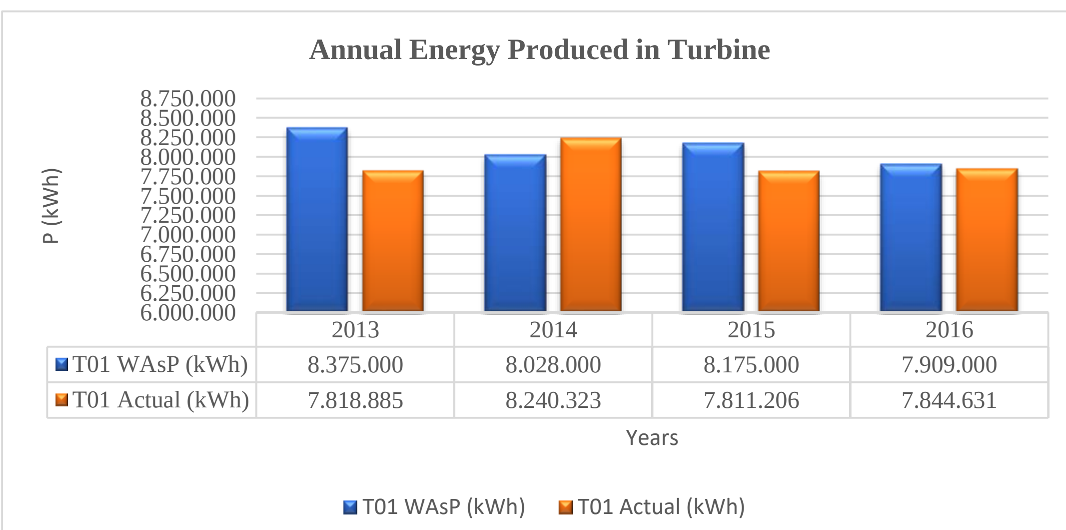


Figure 7. Actual energy production values of the subject turbines and theoretical energy production values calculated with the help of WAsP program

Table 8. Comparison of actual power generation values and WAsP theoretical power generation values

T01	T01 WAsP (kWh)	T01 Actual (kWh)	Difference (kWh)	Difference (%)
2013	8,375,000	7,818,885	-556,115	-7.11%
2014	8,028,000	8,240,323	212,323	2.58%
2015	8,175,000	7,811,206	-363,794	-4.66%
2016	7,909,000	7,844,631	-64,369	-0.82%

Conclusions

In this study, wind energy potential of Belen in district of Hatay was investigated between 2013-2016. WAsP program and Vestas V90-3.0 MW VCS 50 Hz model values were used for the analysis. As a result of the calculations, the difference between the reference turbine and the theoretical study was the highest deviation in 2013 with a rate of 7.11%. The closest result to real production was obtained in 2016 with a deviation of 0.82%. However, according to the classification conditions of the European Wind Energy Association, it is assumed that the Belen region has good - very good rated areas.

Symbols

A : Area [m^2]

c : Weibull scale parameter [m/s]

fW(v) : Weibull distribution function

Γ() : Gamma function

k : Weibull shape parameter

WPP : Wind power plant

WAsP : Wind Atlas Analysis and Application

NASA :National Aeronautics and Space Administration

SRTM : Shuttle Radar Topography Mission

PW : Average power density for the Weibull distribution [W/m^2]

Mevbis : : Meteorological data information sales and presentation system

P(v) : Average wind power potential [W]

R : Correlation coefficient

ρ : Air density [kg/m^3]

σ : Standard deviation [m/s]

v : Wind speed [m/s]

vm : Average wind speed [m/s]

References

Bilgili, M., Şahin, B., & Kahraman, A. (2004). Wind energy potential in Antakya and Iskenderun regions, Turkey. *Renewable Energy*, 29(10), 1733-1745.

Bilgili, M., Şahin, B., & Şimşek, E. (2010). Turkey, South, Southwest and Wind Energy Potential in the Western Region. *Journal of Heat Science and Technology*, 30 (1), 1-12.

Bilgili, M., Simsek, E., Sahin, B., Yasar, A., & Ozbek, A. (2015). Estimation of human heat loss in five Mediterranean regions. *Physiology & behavior*, 149, 61-68.

Mert, İ., Karakuş, C., & Peker, F. (2014). Antakya bölgesi rüzgar karakteristiğinin incelenmesi. *DÜ Mühendislik Dergisi*, 5(1), 13-22.

Mert, İ., Karakuş, C., & Üneş, F. (2016). Estimating the energy production of the wind turbine using artificial neural network. *Neural Computing and Applications*, 27(5), 1231-1244.

MGM. (2018), Meteoroloji Genel Müdürlüğü, available at: https://www.mgm.gov.tr/genel/ruzgar-atlasi.aspx (10/2018).

MEVBIS Data order information No. 201710025E41 of the General Directorate of Meteorology (10/2018).

Mortensen, N. G. (2016). *Wind resource assessment using the WAsP software (DTU Wind Energy E-0135)*. Technical University of Denmark (DTU). DTU Wind Energy E, No. 0135

Pusat, Ş. (2017). A study of wind energy potential for Sakarya University. *Pamukkale University Journal of Engineering Sciences*, 23 (4), 352-357.

Tanç B., Mert, İ., Arat, H. T., Karakuş, C., & Baltacıoğlu, E. (2014). Estimation of wind energy potential using WAsP in Hatay Airport region. *International Journal*, 2(2), 2311-2484.

Tureb, (2018a). Tureb rüzgar enerjisi ve etrkileşim Raporu, available at: https://www.tureb.com.tr/files/yayinlar/tureb_ruzgar_enerjisi_ve_etkilesim_raporu.pdf (10/2018).

Tureb, (2018b). Türkiye rüzgar enerjisi istatistik raporu Ocak 2018, available at: https://www.tureb.com.tr/files/tureb_sayfa/duyurular/2018/03/turkiye_ruzgar_enerjisi_istatistik_raporu_ocak_2018.pdf (10/2018).

Vestas. (2018), Vestas V90 3MW 50 Hz Product Brochure. Available at: http://arquivo.pt/wayback/20090706121351/ (10/2018).

Wasp. (2018), Wind resource assessment, siting & energy yield calculations Available at6: http://www.wasp.dk/wasp (10/2018).

WEEO (2018). Wind energy in Europe: Outlook to 2022. Available at: https://windeurope.org/members-area/files/protected/market-intelligence/reports/Wind-energy-in-Europe-Outlook-to-2022.pdf (10/2018).

WWEA. (2018), World Wind Energy Association 2017 Statistic available at: https://wwindea.org/blog/2018/02/12/2017-statistics/ (10/2018)