

Investigation of Wind Characteristics for Bergama in Terms of Wind Energy

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ABSTRACT: Wind energy has been growing tendency in our country, especially in recent years. To satisfy growing demand, the wind farm that will be established which needs to be studied very well. In this study, for selected coordinate (Latitude: 38.99588, Longitude: 27.1375) in Bergama District of İzmir, long term wind speed (80 meter) and wind direction (80 meter) data has used to analyse the wind energy potential of the region. The data were taken from 3TIER site, and the form of the data is MERRA (The Modern Era Retrospective-analysis for research and Applications) type. Our study covers the years between 1981-2014. For the 34 year period, annual, monthly, daily and hourly wind speed analysis were carried out. After then, boxplot, scattering diagram, wind rose, histogram, etc. were investigated. According to preliminary results obtained, the selected area is appropriate for the establishment of wind farm because of mean wind speed is 8.37 m/s (there is not much extreme wind speed and low wind speed).

KEYWORDS: Wind energy, Wind farm, Merra data.

I. INTRODUCTION

After major oil crisis in 1973, all the world experienced a great fear and parallel to this, renewable energy sources have gained a great importance. By the mid-1980's, despite the dissolution of the oil crisis, which has created "energy security" concept was permanent. In this context, wind energy which is one of the renewable energy sources, also maintain an increasing demand in popularity (YEGM, t.y.).

In Turkey, as well as all over the world, there is a increasing investment trend in wind energy area. In this regard, one of the most important problem that seen in our country is to find suitable areas to build the wind farms. There are many criteria about this but the most important one is mean wind speed of the selected area.

Referring to the literature, there are many studies about the wind farm site selection. Haaren and Fthenakis found that a novel method of site selection for wind turbine farms. They especially work on optimization and built an algorithm for selection of the best area. In another work, a table (Table 1) has been established for the selection of the best wind farm (Patel, 2013).

Table 1. Wind resources are classified based on annual mean wind speed (Patel, 2013).

Wind Power Class	Wind Speed (m/s)	Wind Power Density (W/m ²)	Resource Potential
1	< 4	0 - 100	Poor
2	4 - 6,4	100 - 300	Poor
3	6,4 - 7	300 - 400	Fair
4	7 - 7,5	400 - 500	Good
5	7,5 - 8	500 - 600	Excellent
6	8 - 8,8	600 - 800	Outstanding
7	8,8 - 11,1	800 - 1000	Super

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In this study, mean wind speeds, extreme wind speeds, wind directions were evaluated for the years between 1981-2014. Firstly, annually, monthly, daily and hourly analysis were made. After then, wind rose, boxplot, scatter diagram, many statistical tests were applied. R Programming Language, Windographer and EasyFit programs were used in this study.

II. MATERIALS AND METHODS

In this study, Modern Era Retrospective-analysis for research and Applications (MERRA) data were used. The MERRA is the system that integrate a diversity of observing systems with numerical methods to produce a spatially and temporally logical synthesis of observations and analyses of variables which is not easily observed. The MERRA time interval covers the modern era of remotely sensed data which is from 1979 through the present. Also it focus on the atmospheric assimilation which is the hydrological cycle. (NASA, 2015). For selected coordinate (Latitude: 38.99588, Longitude: 27.1375), the analysis made for the years between 1981 and 2014.

The statistical analysis were made by using R Program, Windographer and EasyFit. For wind energy sector, especially, Windographer program is widely used. EasyFit program is generally used for data analysis and it allows to manually or automatically fit a large number of distributions (Mathwave, 2015). R program is a strongly functional language statistical program (The R Project, 2015).

III. ANALYSIS RESULTS

For the years between 1981 and 2014, hourly wind speed analysis made in the Figure 1. It prepared by using R program.

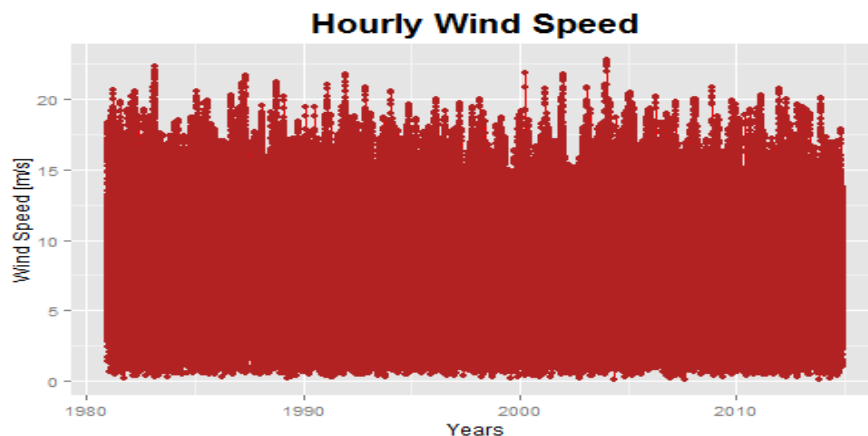


Fig. 1 Hourly wind speed data for the years between 1981 and 2014

As shown in the figure, there is not extreme wind speed values (>25 m/s). The maximum wind speed is about 20 m/s. But we can not see the average and low values of wind speed data in here. To see the average values and low values, selected period (34 years) is divided into four (Figure 2).

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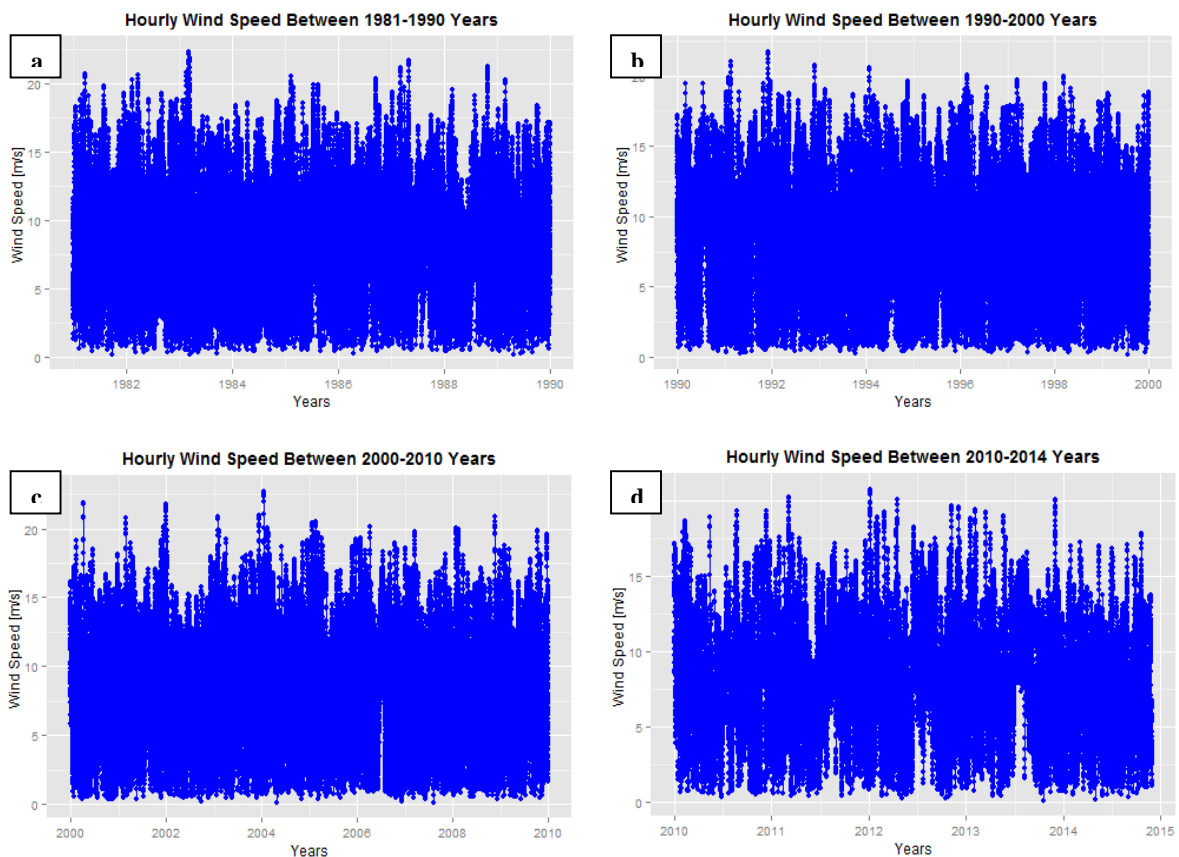


Fig. 2 Hourly wind speed data for the years between 1981 and 2014; a)1981-1990; b)1990-2000; c)2000-2010; d)2010-2014.

As can be seen in the figures above, from 1981 to 1990, 14 – 22 m/s wind speeds are not seen too much. Same trend seen in 1990 to 2000 and 2000 to 2010 periods. But in 2010 to 2014 period, there is too low high speeds seen. High speed wind speed values decrease to 9 m/s in 2011. Generally, we can say there is a declining trend in maximum wind speed values from past to present. In order to see general trend of the wind speed distribution, we can look at the histogram in Figure 3.

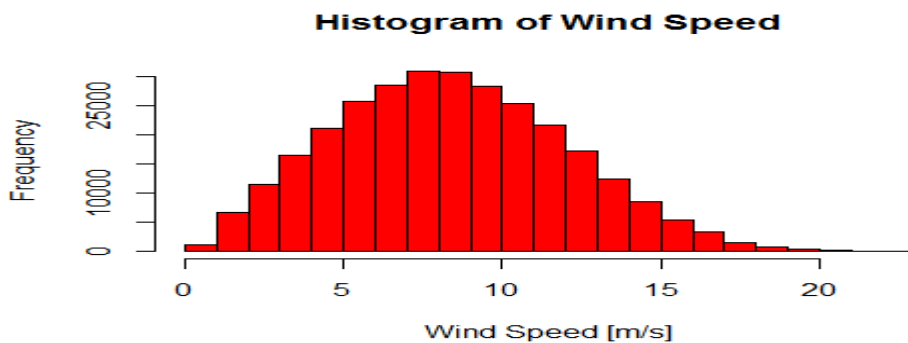


Fig. 3 Histogram of wind speed between the years 1981 and 2014.

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When we look at the histogram, firstly we can say that it fits normal distribution. Also average wind speed is about 8 m/s. There is not minimum and maximum wind speed values, and it is the best condition for wind energy area. In Figure 4, wind direction histogram has been shown.

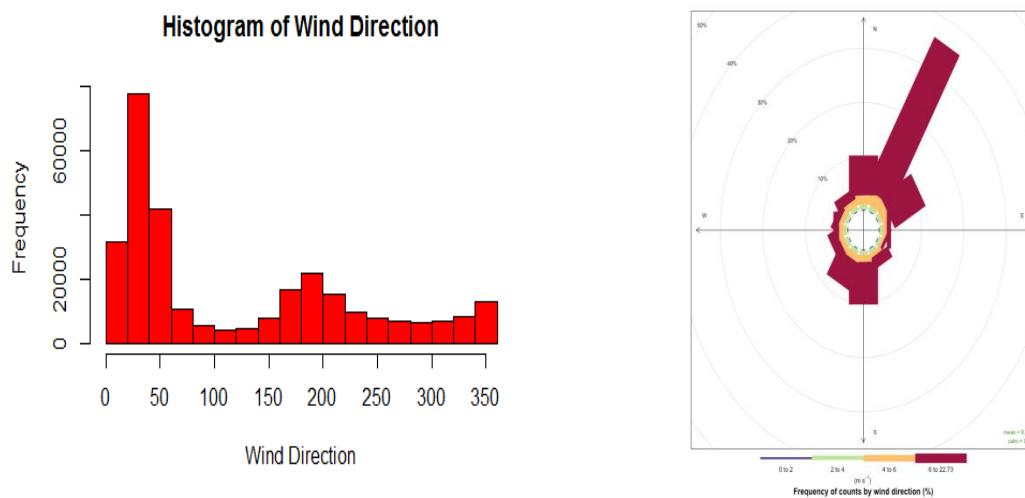


Fig. 4 Histogram and wind rose of wind direction between the years 1981 and 2014.

By looking at the histogram and wind rose, we can say the dominant wind direction is about 20° to 60°. For 34 years period, North and Northeast winds often seen in the selected area.

Average Wind Speed

In our data set, average wind speed is mostly seen about 8-9 m/s for the selected period. It shown in the Figure 5.

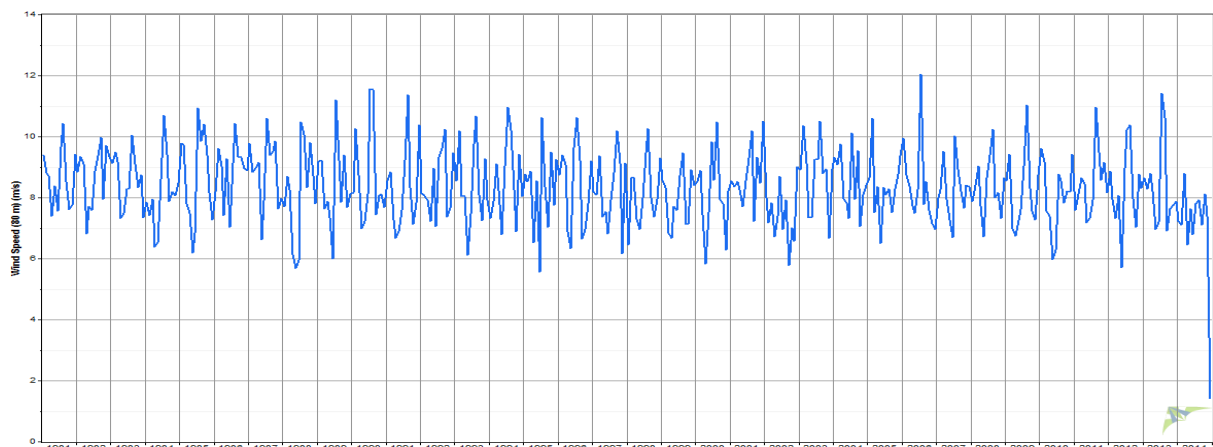


Fig. 5 Average wind speed values between the years 1981 and 2014.

From 1981 to 2014, average wind speed values show a similar oscillation and it is between 8 m/s and 10 m/s. These values are highly suitable for the building wind energy sector.

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Extreme Wind Speed

For 34 years data, there is not too much extreme wind speed values. Looking subjectively, our data set fits with Normal Distribution. But if we take into account the extreme wind speeds, selected data set fits with Gumbel Distribution with extreme wind speeds (Figure 6).

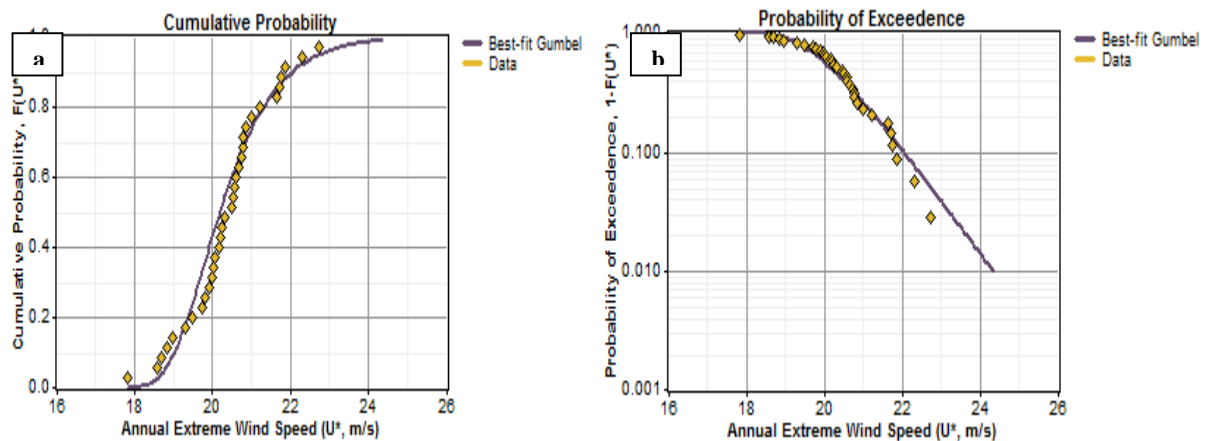


Fig. 6 Extreme wind speed values between the years 1981 and 2014; a) Cumulative Probability Function; b) Probability of Exceedence Function.

As shown in the Figure 6a, the probability of seen 22 m/s and higher wind speed values are very low. It is also corrected by Figure 6b. Both of the figures show that extreme wind speed values best fit with Gumbel Distribution. Also annually detailed description shown in Table 2.

Tab. 1 Wind resources are classified based on annual mean wind speed (Patel, 2013).

Year	60-min Mean Wind Speed			Gusts Max (m/s)	Year	60-min Mean Wind Speed			Gusts Max (m/s)
	Possible Records	Valid Records	Recovery Rate (%)			Possible Records	Valid Records	Recovery Rate (%)	
1981	8,760	8,760	100	20.68	1998	8,760	8,760	100	20
1982	8,760	8,760	100	20.58	1999	8,760	8,760	100	18.84
1983	8,760	8,760	100	22.3	2000	8,784	8,784	100	21.88
1984	8,784	8,784	100	18.69	2001	8,760	8,760	100	20.77
1985	8,760	8,760	100	20.52	2002	8,760	8,760	100	21.76
1986	8,760	8,760	100	20.31	2003	8,760	8,760	100	21.01
1987	8,760	8,760	100	21.64	2004	8,784	8,784	100	22.73
1988	8,784	8,784	100	21.21	2005	8,760	8,760	100	20.49
1989	8,760	8,760	100	20.2	2006	8,760	8,760	100	20.19
1990	8,760	8,760	100	19.47	2007	8,760	8,760	100	19.79
1991	8,760	8,760	100	21.73	2008	8,784	8,784	100	20.86
1992	8,784	8,784	100	20.79	2009	8,760	8,760	100	19.91
1993	8,760	8,760	100	18.98	2010	8,760	8,760	100	19.31
1994	8,760	8,760	100	20.59	2011	8,760	8,760	100	20.25
1995	8,760	8,760	100	18.58	2012	8,784	8,784	100	20.74
1996	8,784	8,784	100	20.02	2013	8,760	8,760	100	20.07
1997	8,760	8,760	100	19.73	2014	8,017	8,017	100	17.83

As shown in the Table 2, extreme wind speed values is about 18 m/s to 23 m/s. Highest wind speed value is seen in 2004 as 22.73 m/s. There is no linear trend of extreme wind speeds by the years.

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Test Statistic Analysis

Test statistics generally used for determine if two sets of data are significantly different from eachother. For our data set, following results were obtained.

Welch Two Sample t-test

```
data: BergamaT2$ws and BergamaT2$wd
t = -569.0597, df = 297952, p-value < 2.2e-16
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -112.8556 -112.0809
sample estimates:
mean of x mean of y
 8.36646 120.83472
```

Fig. 7 Student's t-test results

Student's t-test was applied for the data set between wind speed data and wind direction data. Firstly, we will look at H_0 hypothesis, H_0 hypothesis required to $\mu = \mu_0$. It means that there is a significant difference between the data sets. When we applied t test to the our data sets, our p-value is found $2.2e-16$, this value is smaller than accepted p value. So, we rejected the H_0 hypothesis and accepted to the H_1 hypothesis. It means that there is a significant difference between the data sets and their distribution is mostly different from eachother.

The other test is Kolmogorov-Smirnov test. For our data set, following results were obtained.

Two-sampleKolmogorov-Smirnov test

```
data: BergamaT2$ws and BergamaT2$wd
D = 0.9094, p-value< 2.2e-16
alternativehypothesis: two-sided
```

Fig. 8 Kolmogorov-Smirnov test results

In here, again our p value is smaller than 0.05. So we rejected H_0 hypothesis, and accepted H_1 hypothesis. This test also confirmed t-test that there is a significant difference between the data sets in terms of distribution functions.

Quantile-QuantilePlot

QQ-Plot is a graphicaltechniquethatusedfordeterminingifthe 2 datasetscomefromsamepopulationwithsamedistribution. Thefollowingresult is obtainedfromourdatasets.

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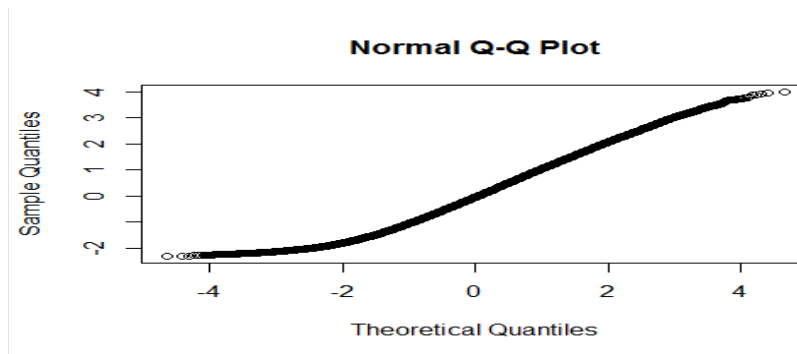


Fig. 9 QQ-Plot results

As shown in the Figure 9, there is no good relationship between the data sets. We can say that the data set has not come from same family, and they have a different distribution.

IV. CONCLUSION

When we look at the 34 years of wind data for selected area, there is a good average wind speeds observed for a long period. It is about 8.37 m/s and this value is highly good for wind energy sector. Also from the statistical results, there is not seen too much low level wind speeds values and extreme wind speed values. It is also good for wind farm. The selected coordinate in Bergama have a dominant wind direction that is North and Northeasterwinds. Looking at the extreme wind speed analysis, it is quite rare and wind speed ranges is about 18-23 m/s. It is important for wind turbines because of cut off situation. Generally, wind turbines cut off themselves at 25 m/s wind speeds and highest values of wind speeds. Lastly, two data sets distributions which are the distributions of wind speed and wind direction values, are not consistent and it confirmed by many tests.

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APPENDIX

Firstly data sets were imported to the R program, and opened many packages from Library.

```
library(xts)
library(zoo)
library(ggplot2)
library(seas)
library(Rcmdr)
library(lmtest)
library(oce)
library(maps)
library(mapproj)
library(evd)
```

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```
# The dates were arranged for the R Program.
tarih<-paste(BergamaT2_csv$Date,BergamaT2_csv$Hour)
strptime(tarih,"%d.%m.%Y %H")
tarih1<-strptime(tarih,"%d.%m.%Y %H")
BergamaT2_csv$Date<-tarih1
BergamaT2_csv$Hour<-NULL
# For wind speed and wind direction, xts format was applied.
wind=as.xts(BergamaT2_csv$windspeed_80m,order.by = tarih1,na.omit=T)
wind_dir=as.xts(BergamaT2_csv$winddirection_80m,order.by = tarih1,na.omit=T)
# ggplot
ggplot(wind,aes(tarih1,BergamaT2_csv$windspeed_80m))+geom_line(color="red")+labs(x="
Years",y="Wind Speed [m/s]")+geom_point(color="firebrick")+ggtitle('Hourly Wind
Speed')+theme(plot.title = element_text(size=14, face="bold", vjust=1))
# Hourly wind speed analysis for between the years 1981 and 1990
ruzgar_siddeti3=wind[(2):((8761*9)+40)]
tarih1981_1990=tarih1[(2):((8761*9)+40)]
ggplot(ruzgar_siddeti3,aes(tarih1981_1990,ruzgar_siddeti3))+geom_line(color="blue")+labs(x=
"Years",y="Wind Speed [m/s]")+geom_point(color="blue")+ggtitle('Hourly Wind Speed
Between 1981-1990 Years')+theme(plot.title = element_text(size=14, face="bold", vjust=1))
# Hourly wind speed analysis for between the years 1990 and 2000
ruzgar_siddeti2=wind[((8761*9)+40):((8761*19)+78)]
tarih1990_2000=tarih1[((8761*9)+40):((8761*19)+78)]
ggplot(ruzgar_siddeti2,aes(tarih1990_2000,ruzgar_siddeti2))+geom_line(color="blue")+labs(x=
"Years",y="Wind Speed [m/s]")+geom_point(color="blue")+ggtitle('Hourly Wind Speed
Between 1990-2000 Years')+theme(plot.title = element_text(size=14, face="bold", vjust=1))
# Hourly wind speed analysis for between the years 2000 and 2010
ruzgar_siddeti=wind[((8761*19)+78):((8761*29)+140)]
tarih2000_2010=tarih1[((8761*19)+78):((8761*29)+140)]
ggplot(ruzgar_siddeti,aes(tarih2000_2010,ruzgar_siddeti))+geom_line(color="blue")+labs(x="Y
ears",y="Wind Speed [m/s]")+geom_point(color="blue")+ggtitle('Hourly Wind Speed Between
2000-2010 Years')+theme(plot.title = element_text(size=14, face="bold", vjust=1))
# Hourly wind speed analysis for between the years 2010 and 2014
ruzgar_siddeti1=wind[((8761*29)+140):((8761*33)+8176)]
tarih2010_2014=tarih1[((8761*29)+140):((8761*33)+8176)]
ggplot(ruzgar_siddeti1,aes(tarih2010_2014,ruzgar_siddeti1))+geom_line(color="blue")+labs(x=
"Years",y="Wind Speed [m/s]")+geom_point(color="blue")+ggtitle('Hourly Wind Speed
Between 2010-2014 Years')+theme(plot.title = element_text(size=14, face="bold", vjust=1))

# Wind rose
vdata<-read.csv("BergamaT2.csv", sep=";", header=TRUE)
vdata$date<- as.POSIXct(strptime(vdata$date, format = "%d/%m/%Y %H:%M", tz = "GMT"))
windRose(vdata)
# Histogram of wind speed
hist(BergamaT2_csv$windspeed_80m, breaks=14, col="blue")
x <- BergamaT2_csv$windspeed_80m
h<-hist(x, breaks=25, col="red", xlab="Wind Speed [m/s]",main="Histogram of Wind Speed")
# Histogram of wind direction
hist(BergamaT2_csv$winddirection_80m, breaks=14, col="blue")
x <- BergamaT2_csv$winddirection_80m
h<-hist(x, breaks=25, col="red", xlab="Wind Direction",main="Histogram of Wind Direction")
# Student's t-test
t.test(BergamaT2$ws,BergamaT2$wd)
# Kolmogorov Smirnov test
ks.test(BergamaT2$ws, BergamaT2$wd)
```




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```
# QQ-Plot  
normalization = ((BergamaT2$ws)-mean(BergamaT2$ws))/sd(BergamaT2$ws)  
>qqnorm(normalization)  
ks.test(BergamaT2$ws,BergamaT2$wd)
```