

A new reference wind year approach to estimate long term wind characteristics

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Abstract

The typical meteorological year (TMY) method has common applications in building energy performance and solar energy studies. However, there is not any well accepted method for the wind energy applications such as the TMY. In the present study, a new reference year approach is proposed for wind energy applications. By using the proposed method, the reference wind year (RWY) datasets may be generated as in the TMY methodology for any measurement station which has the possibility to be used as a reference station in the measure-correlate-predict (MCP) analyses. The MCP calculations are so significant to estimate the long term wind conditions for a candidate wind farm site. In this study, a case study is performed for Turkey after giving the details of the proposed method. The results for the RWY approach has a good agreement with the long term data as in the TMY method. Therefore, the RWY concept has the possibility to make the MCP studies easier and faster.

Keywords

Reference wind year, typical meteorological year, Finkelstein–Schafer statistics, wind energy, measure correlate predict

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Introduction

Today, hourly or shorter-term data is used in any analysis and simulation, and the works are done for yearly basis. However, the climatic conditions change from year to year significantly. Therefore, it is easiness and necessity to create and utilize the typical meteorological year (TMY) datasets in most of the analyses.

The TMY approaches are widely used in building performance analysis studies. Using of the long term measured data instead of the TMY datasets takes more time, and it is unnecessary.¹ The TMY datasets are used in heating and cooling load calculations. Additionally, the typical solar radiation year (TSRY) datasets are used in assessment of solar energy applications. Performance of a solar system can be predicted easily by using the TSRY datasets.²

Today, there are lots of databases of the TMY and the TSRY for building energy performance and solar

energy analyses around the world. Using the yearly typical climatic data is a standard procedure anymore. Researchers do not spend time to obtain climatic data for any site to use in the analyses. However, the TMY approach has not been used much in wind energy studies.

A study was done by Kotroni et al.³ to determine the typical wind year (TWY). Their TWY approach is different from the TMY approach. They used

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measured wind speed and direction data at 10 m and 6 h intervals. They calculated the cumulative distribution functions (CDFs) based on 160 wind bins (20 bins for wind speed by 8 bins for wind direction) for each month of 20 years. Finally, they selected the best months for the TWY. Yang et al.⁴ stated that the TMY approaches are mostly used in estimation of building energy need and solar energy performance, and they indicated the necessity of such an approach for hybrid (wind-solar) systems. However, there aren't any attempt to use the TMY approach in wind energy studies, as far as the present author knows.

In wind energy applications, the long term measured data is used to estimate wind electricity production. Variability of wind resource is very significant and critical in planning and operating of wind power plants.⁵⁻⁷ Using of the measured data over a few years in the prediction of lifetime (20–25 years) electricity production of a possible wind farm isn't enough for such an investment. In the literature, the utilized measured data for a straight wind energy project changes such as 3 years,⁸ 10 years⁹ and 20 or more years.¹⁰ After all, in general, measurements are done over only 12 months in wind energy projects. It is impossible to estimate lifetime electricity production of a possible wind farm by using just 1 year measured data.¹¹ From an investor viewpoint, it seems impossible to measure wind conditions of a location for a long time.

The most known method to estimate the long term wind conditions for a candidate wind site is measure-correlate-predict (MCP).^{5,9,12-15} In this approach, the short term measured data is used with the long term measured data from a nearby weather station.^{5,9,16} The nearby weather station is used as a reference station⁵ in general, and it is tried to constitute a relationship between the dataset of the reference station and the station of the candidate wind site for the concurrent data period. Then, the long term wind conditions of the candidate wind site are estimated by using the specified relationship between the stations. By using the estimated long term wind data, long term energy output of a possible wind farm is estimated, and technical and economic feasibilities are done.

Sanz¹⁷ presented the results of a questionnaire about wind resource assessment. As an interesting output, only 70% of the respondents stated that they use the MCP methods. The fact remains that the MCP methods are necessary and standard for the development and planning of wind farms.^{6,18,19} There are lots of MCP methods in the literature.^{5,6,17,19}

There is a useful database of historical meteorological data that offers with a spatial resolution between 4 and 30 km.²⁰ The offered data is a result of simulation, not measured data. Another predicted weather dataset, ERA, is generated by European Centre for Medium-Range Weather Forecasts.²¹ The resolution of ERA

wind data is about 13 km. The Modern-Era Retrospective Analysis for Research and Applications, MERRA, was produced by NASA.²² The MERRA database offers a resolution of about 50 km. These kind of data cannot be used directly in wind energy analyses. However, they may be used to get general weather characteristics of any region.

In this study, a reference wind year (RWY) approach for wind energy applications is presented. The proposed method is similar to the TMY method and it uses the meteorological data (wind speed, wind direction, temperature and pressure) of the reference station. The RWY dataset can be used in the prediction of the candidate site long term wind resources effectively. The details of the RWY approach is presented in the following section, and the results of a case study are given for reference weather data in the section 3. The proposed RWY approach is original and important for the wind energy literature. Using of the RWY datasets in the MCP calculations makes it easier and faster. For every weather station having the long term measured data, the RWY datasets can be prepared as in the TMY approach. Therefore, the wind energy project developers can use the RWY datasets directly.

The RWY approach

In this section, the proposed RWY approach is presented. The proposed RWY approach uses same procedure with the TMY approach. Therefore, first of all, basics of the TMY approach should be given. The main aim of the TMY method is to select the most representative months from the long term measured data. There are lots of studies in the literature to generate the TMY datasets for different locations of the world.^{1,23-28}

In general, the Finkelstein and Schafer²⁹ (FS) statistic is used in the TMY generation. The FS statistic is calculated by the following equation:

$$FS = \frac{1}{n} \sum_{i=1}^n \delta_i \quad (1)$$

where the FS is the value of the FS statistic, δ_i is the absolute difference between the long term cumulative distribution function (CDF) and the yearly CDF for day i in the related month, and n is the number of the daily records for the same month. The CDF of a variable is given by a function as the following equation:

$$S_n(X) = \begin{cases} 0 & \text{for } X < X_1 \\ \frac{k-0.5}{n} & \text{for } X_k < X < X_{k+1} \\ 1 & \text{for } X > X_n \end{cases} \quad (2)$$

where X is the variable parameter, n is the number of observations of X . The FS values provide the necessary data to compare the individual months with the long

term averages. Therefore, the best months for any climatic parameter can be selected by using the FS values. However, there are lots of parameters on the building energy performance. In this case, the effects of the parameters gain importance. The weighing factors (WFs) are determined for every parameter that are effective on the building energy performance. The determined WFs are multiplied by the calculated FS values to compute the weighted sum (WS). Thus, effects of every parameter are considered. The WS is calculated by the following equation:

$$WS = \sum_{j=1}^m WF_j FS_j \quad (3)$$

where m is the number of the parameters.

The WS values are used to select the best months to produce the TMY dataset that will be used in the building energy performance studies.

In the present study, the same TMY procedure is applied to create the RWY data. In wind energy applications, the most important parameters are the wind speed, the wind direction, the temperature, the pressure, and the relative humidity.^{30–33}

The predicted power output of a wind turbine generator (P) is calculated by the following equation:³¹

$$P = 0.5 \rho A C_e V^3 \quad (4)$$

where ρ is the air density (kg/m^3), A is the wind turbine rotor swept area (m^2), C_e is the total efficiency of the wind turbine generator at the given wind speed (–) and V is the air velocity (m/s).

The air density is calculated by the following equation:³⁴

$$\rho = \left(\frac{P_a}{R_d T} \right) \left(1 - \frac{0.378 P_v}{P_a} \right) \quad (5)$$

where P_a is the moist air pressure (Pa), R_d is the gas constant for dry air (J/kg.K), T is the air temperature (K), P_v is the partial pressure of water vapor (Pa).

The partial pressure of water vapor is calculated by the following equation:³⁴

$$P_v = R H P_s \quad (6)$$

where RH is the air relative humidity (–) and P_s is the saturation vapor pressure (Pa).

Power of the wind is in proportion to the third power of the wind speed. Therefore, the wind speed is the most important parameter for the wind energy applications. The other parameters (the air pressure, temperature, and relative humidity) also have effect on wind power. The only parameter does not seem in the stated equations is the wind direction which affects the wind power significantly.³⁵ The proposed RWY approach takes in consideration these parameters (the wind speed, the

Table 1. The WFs for the RWY approach.

Parameters	Range of WFs investigated	
	Min	Max
Wind speed	50/100	75/100
Wind direction	5/100	20/100
Temperature	10/100	30/100
Pressure	10/100	15/100

wind direction, the temperature and the pressure). The relative humidity was not utilized in the proposed method due to not presented in the reference weather datasets. After preparation of the RWY datasets, one must calculate the wind speed at the hub height of the possible wind turbine. At this point, wind shear effect and surface roughness must be included to the calculations. Wind shear effect and surface roughness are the major parameters to be considered in the calculations.

To be able to evaluate the effects of different WFs and determine the RWY, a wide range of WFs were investigated (Table 1). As can be seen, the wind speed has the highest WF values. In the evaluation of the parameters about the wind (the wind speed and the wind direction) have a total impact between 60% and 80%, and the other weather parameters (the temperature and the pressure) have a total impact between 20% and 40%. In this study, the WFs were evaluated by investigating the different values, and the best months representing wind characteristics of the region. The optimum WFs should be determined by making analyses for different climates. As a further study, the optimum WFs may be determined with detailed analyses as in the study of Chan.³⁶ The resulting RWY was created by using the mostly selected months obtained for different WFs.

Similar to the procedure of the TMY generation, the RWY procedure is as follows:

- The necessary data (the wind speed, the wind direction, the temperature and the pressure) are collected
- The FS values are calculated for each month and parameter
- The WS values are calculated for each month by using FS values and WFs
- The months with the smallest WS values are selected as the best months
- The best months are combined to form the RWY dataset.

By using this procedure, the RWY dataset may be generated for any location.

The obtained RWY datasets for any location (reference station) may be used in the MCP analyses. Firstly,

Table 2. Weather data used in this study.

Database	Time step (min)	Start	End	Height (m)	Data
ERA	60	01.01.1979	01.12.2019	100	Wind speed, wind direction, temperature, and pressure
MERRA2	60	01.01.1980	01.01.2020	50	Wind speed, wind direction, temperature, and pressure
Wind Site	10	27.03.2014	27.03.2015	30, 45, 60 and 61	Wind speed, wind direction, temperature, and pressure

Table 3. Mean average statistics for datasets.

Parameter	Unit	ERA	MERRA2	Wind site
Wind speed	m/s	2.88 (100 m)	4.38 (50 m)	4.99 (30 m)
Wind speed (predicted)	m/s	3.12 (125 m)	5.59 (125 m)	7.42 (125 m)
Wind direction	Deg	139	155	136
Air temperature	°C	11.13	10.12	10.88
Air pressure	kPa	92.73	91.81	90.58

the relationship between the reference station and the candidate wind site is constituted. Then, by using the specified relationship between the stations and the RWY data, the long term characteristics of the wind site is obtained as a yearly format not as a long term data format as in the traditional MCP analyses. Therefore, at the end of the MCP work with the RWY data, the researcher obtains a yearly dataset for the candidate wind site, which shows the future typical wind characteristic (FTWC) of the site. Finally, the obtained FTWC data is used in the estimation of wind energy production of the candidate wind site for a possible wind farm. In the traditional application, the obtained long term data with the MCP work is used in the estimation of wind energy production. However, in the proposed approach, the future energy production potential of a candidate wind site is presented only for a year. Therefore, the proposed methodology makes the MCP analysis faster and easier. In the case of lack of reference weather data for a location or to make analyses more detailed, the historic data proposed by different simulation packages such as history⁺, ERA and MERRA may be used to get RWY datasets for any location.

A case study

The proposed RWY approach was applied for a Turkish city as a case study. The wind speed measurement station was located in Samsun for a possible wind farm site project. Samsun is located on the north coast of Turkey. As reference weather data, the MERRA2 and ERA datasets were utilized. All the RWY and MCP calculations were done for both of the reference datasets. Some features of the data used in the study are presented in the Table 2.

For this study, as a reference, a wind turbine with a hub height of 125 m was utilized. Wind speed at 125 m and power output were calculated for Gamesa G114 – 2.0 MW turbine. In the calculations, Windographer software were utilized. In the estimation of wind speed at 125 m, statistics of wind site at different heights were used. The wind data at different heights are necessary to predict wind data for hub height of a possible wind turbine.

Some average statistical data calculated for wind site and reference datasets are presented in the Table 3. The reference datasets have lower wind speed levels. The estimated average wind speed values at 125 m for wind site, ERA and MERRA2 datasets were 7.42, 3.12, and 5.59 m/s, respectively. The average temperature and pressure values seem similar for the datasets.

As mentioned in the introduction section, the wind speed fluctuates too much. In the Figure 1, the yearly changes of the average wind speed are shown. The highest wind speed value for ERA and MERRA2 is 3.10 m/s and 4.74 m/s at 1981, respectively. The lowest wind speed value for ERA and MERRA2 is 2.61 m/s at 1984 and 4.04 m/s at 1991, respectively. The high fluctuations of the wind speed show the importance of the RWY approach.

The WSs of the FS values for the reference datasets were calculated for different WFs and each month of each year. Then, the best years for each month with the lowest values of the WS were specified. The selected best months were combined to generate the RWY datasets. The best years for each month with the lowest WS values are shown in Table 4. Same years were selected as the best months for ERA and MERRA2 datasets.

After the selection of the best months for the generation of the RWY datasets, it would be very useful to compare the monthly averages of the RWY data with the long term (LT) means and averages of wind site.

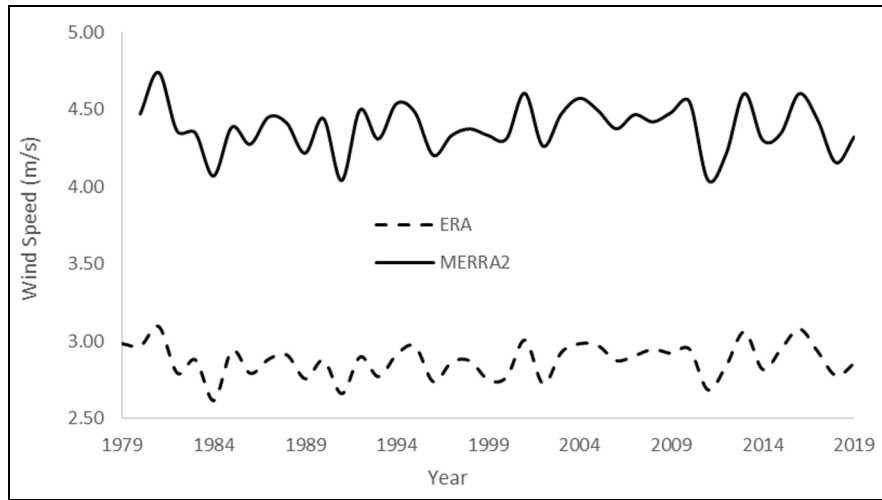


Figure 1. The yearly change of the mean wind speed.

Table 4. The results of the RWY selection for ERA and MERRA2.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ERA	2018	2007	2019	2006	1994	1980	1988	1988	2016	1990	2017	1997
MERRA2	2018	2007	2019	2006	1994	1980	1988	1988	2016	1990	2017	1997

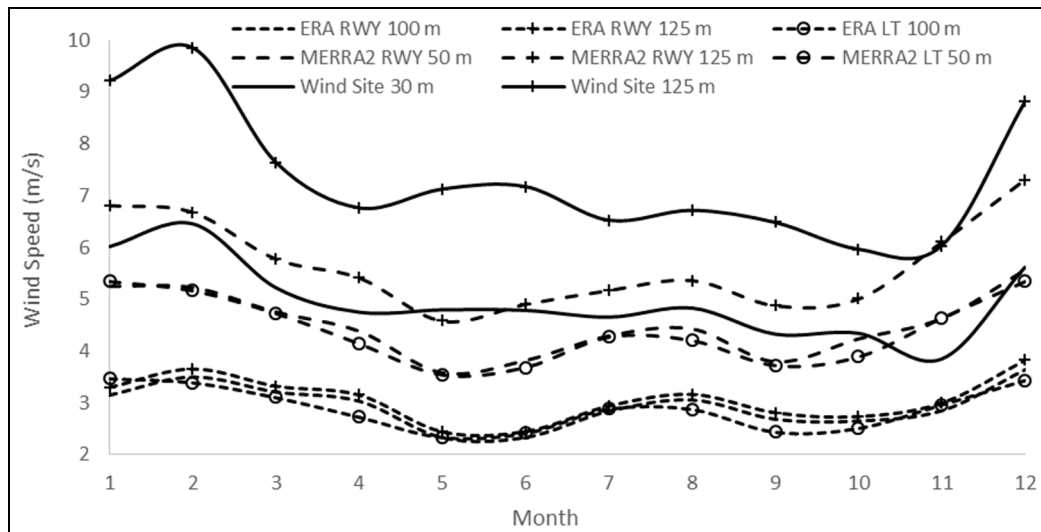


Figure 2. The monthly mean wind speed values for different data at different heights.

The estimated wind speed values at 125m seem different for each datasets. The RWY datasets are compatible with the LT averages.

The yearly mean wind speed of the ERA RWY (2.94 m/s at 100 m) is higher than the long term mean (2.88 m/s at 100 m). The yearly mean wind speed of the MERRA2 RWY (4.50 m/s at 50 m) is lower than the long term mean (4.38 m/s at 50 m). The estimated yearly mean wind speed at 125 m for ERA RWY, MERRA2

RWY and Wind Site are 3.11 m/s, 5.71 m/s and 7.42 m/s, respectively, see Figure 2.

After generating the RWY datasets for the reference datasets, the MCP studies were carried out. As in the classical MCP studies, the relationships between the wind site data and reference sites were determined. In the MCP analysis linear regression method was used for wind speed data in this study. For the wind site, wind speed at 30 m was utilized for regression analysis.

Table 5. The results of the MCP studies.

Parameter	Unit	Cases			
		ERA LT MCP	MERRA2 LT MCP	ERA RWY MCP	MERRA2 RWY MCP
Wind speed – 30 m	m/s	4.91	4.95	4.96	5.01
Wind speed – 125 m	m/s	7.25	7.31	7.32	7.39
Net power	kW	893.60	910.40	864.70	882.50
Wind direction – 30 m	Deg	134.90	134.14	135.84	135.84
Wind direction – 125 m	Deg	138.30	158.40	134.40	135.50
Temperature	°C	10.21	10.09	9.73	10.07
Pressure	kPa	90.59	90.59	90.61	90.58

The relationship between the wind site and reference datasets were utilized in two different methods. The first method is the classical MCP method: The relationship between the reference dataset and the wind site is used to predict the long term characteristics. The second method is the proposed method: The relationship between the reference dataset and the wind site is used to create predicted RWY data that represents the characteristics of the site by a yearly dataset. In the proposed method, the long term datasets were not necessary as in the classical MCP method. One need only the RWY data of the reference site. The researchers may prepare the RWY datasets for the reference stations from the long term data to be used in the analyses as proposed in the present study. Therefore, the RWY approach has the possibility to make the MCP studies easier and faster.

The results of the MCP studies are presented in Table 5. ERA LT MCP and MERRA2 LT MCP columns represent the results for the first method (the classical MCP method), and ERA RWY MCP and MERRA2 RWY MCP represent the results for the proposed method. As can be seen, the results for the proposed approach have a good agreement with the classical MCP method. The predicted annual mean wind speed values at 125 m are 7.25, 7.31, 7.32, and 7.39 m/s for ERA LT MCP, MERRA2 LT MCP, ERA RWY MCP, and MERRA2 RWY MCP, respectively. The difference between the ERA LT MCP and the ERA RWY MCP is about 1% for 30 and 125 m. The difference is similar for MERRA2 cases. The power outputs for the different cases are so close together. The difference of the classical and proposed methods for the power output is about 3%. As can be seen from the result, the proposed method gives similar results with the classical MCP method in the estimation of long term behavior of a possible wind site.

Conclusion

In the present study, the new RWY approach is proposed. The proposed approach is similar to the TMY method, and four different weather parameters (the

wind speed, the wind direction, the temperature, and the pressure) are used in the calculations. For the selected parameters, different WFs were utilized for the proposed method.

The proposed RWY method and the created RWY datasets may be used in the MCP calculations. For every weather station having the long term measured data, the RWY datasets may be prepared as in the TMY datasets. Therefore, the wind energy project developers can use the RWY datasets directly and easily.

A case study for Samsun is done by using the proposed method. As expectedly, the results for the proposed approach has a good agreement with the classical MCP method. Therefore, the proposed approach has the possibility to make the MCP studies easier and faster.

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