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Weather Data Based Analysis of Existing Solar and Wind potential of Karachi, Pakistan

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Abstract

The solar irradiation and wind speed show random as well as periodic variations as a function of variations in the weather. In this paper, an effort is made to detect, analyze, model and predict in order to be able to forecast the variations in solar irradiations and the wind parameters to be able to efficiently employ these renewable energy sources in meeting the current and future power needs of Karachi mega city.

Keywords: *Weather data; Analysis; Solar Irradiation; Wind Parameter.*

Important Solar and Wind Parameters

GHI (Global Horizontal Irradiation): is the sum of direct and diffuse components of solar radiation in kilo watt hour per meter square.

DNI (Direct Normal Irradiation): is the solar irradiation component that directly touches the surface in kilo watt hour per meter square.

DNIcs: Direct normal irradiance under clear sky

DNIcn: Maximum direct normal radiation under cloudy sky during the day (W/m^2)

DHI (Diffuse Horizontal Irradiation): is the solar irradiation component that is scattered by the atmosphere in kilo watt hour per meter square.

DHIcs: Diffuse horizontal irradiance under clear sky

GTI (Global Tilted Irradiation): Sum of direct and diffuse solar radiation falling on a tilted surface of fixed-mounted PV modules in kilo watt hour per meter square.

PVOUT (PV Electricity output): Amount of energy, converted by a PV system into electricity [kWh/kWp].

OPTA (Optimum angle): Optimum inclination of an inclined and fixed PV modules for a specific azimuth (orientation

TEMP (Air Temperature at 2 meters above ground): Air temperature [ºC or ºF] determines the temperature of PV cells and modules

ELE (Elevation): Represents terrain elevation (altitude) relative to the sea level [m or ft].

Location (site): Site of interest can be located by latitude and longitude values

System size: Total DC capacity (installed power) of a PV system is considered

Azimuth: Orientation of the PV modules.
Inclination: Tilt of PV modules measured from a horizontal surface as a reference.
A: Apparent extra-terrestrial irradiance (W/m^2)
B: Atmospheric attenuation coefficient (W/m^2)
C: A dimensionless constant
Cn: Cloud cover index DHI (Diffuse horizontal irradiance) (W/m^2)
-z: The zenith angle is similar to the elevation
T_I: Turbulence intensity
WS_{max}: wind speed max
WS_{min}: wind speed min
WS_{mean}: wind speed mean
WS_{sd}: wind speed stddev
WAsP: Software, as wind industry-standard
GWA: Global wind alliance

1. Introduction

Majority of Researchers have always tried to investigate various aspects of the energy in Pakistan. However, very few researchers have studied the energy profile of southern part of Pakistan, namely Karachi region. According to these researchers, the current state of energy in Pakistan shows a consistent dependence on the traditional fossil fuels. There is constant deficit in the traditional fossil fuel-based energy resources while the lack of progress persists in the exploration and consumption of wind and solar energy sectors [1-3].
Studies on southern regions of Pakistan indicate that there is a highly promising wind energy potential of over 50,000MW with a median wind speed of over 7m/s at 80m height in most of the coastal regions of Sindh and Baluchistan. This Coastal Belt of Pakistan is endued with a wind passageway that is 60km wide (Gharo Kati Bandar) and 180km long (up to Hyderabad). The wind potential recorded is in between 6.2 to 6.9m/s in the Pakistan coastal region Karachi.
The government has put in eight 300W turbines in Baluchistan and six 500W turbines in Sindh and it absolutely was all over that it's cost-effective and technically doable choice for electrification of remote villages [4-8].
The southern Pakistan has around 1100 kilometers of the coastal line with the ample amount of wind energy potential. However, the earlier researchers have focused on the specific wind corridors only. Through these earlier approaches by these researchers, the specific regions of interest or wind corridors have been proved to have theoretically optimum wind potential. Moreover, the future challenges in implementation of the wind energy have also remained the focus [5].
The researchers have also investigated the potential of reducing energy consumption by using daylight through domes in roofs. They have used the ***energy Plus*** software to analyze the energy capacity in buildings in Karachi city. The authors have found the ways to reduce the customer energy bills and by saving the bills they have claimed to avert the energy crisis. Some other researchers have suggested Automatic Metering Interface (AMI) for Karachi and Lahore. They have proposed the hybrid system model for Lahore and Karachi consists of smart meter, gateway (i.e., data concentrator (DC)) and meter data management system (MDMS) [9].
According to prior research on energy, Pakistan is facing a large gap between the demand and supply of energy. This gap exists due to large energy demand and no investment in energy resources since last several decades, so energy crises persist. These researchers have attempted to discuss the transition towards the green energy resources in order to fulfil this

gap. Moreover, they have attributed the energy gap to GDP and growing population as two drivers of energy demand which are pushing up the energy demand forever [10].
In Pakistan, the existing energy supply chain is predominantly based on oil and gas that offers 85% of the primary energy deliveries. Throughout years 2000-01, out of a complete 44 million tons of oil equivalent energy used, 43.5% was met from oil and 41.5% from gas.
Pakistan is in the list of developing countries with an associate annual GDP rate of 3.8% for the year 2011. Renewable energy resources are the key to success for Pakistan being a developing economy. The economic progress of Pakistan may be achieved by improving the renewable energy utilization which may shape the country economy as well. A wide variety of reviews are revealed stating the supply and usage of renewable energy in Pakistan, but no specific studies have been centered on the usage of renewable energy resources for an economic power generation generating [3, 11-19].
The World Bank group investigated the quantity of intermittent renewable energy usage in the Pakistan. The world solar Atlas has been ready by Solargis underneath a contract to the World Bank, supported solar resource information that they own and maintain [20].

2. Models

The photovoltaic model provides long-term averages of solar radiation such as global, diffuse and direct normal solar radiations based upon the data obtained from World Bank project for Pakistan [ ]. World Bank chooses GHI, DNI, DHI, GTI, ELE, and Temperature to calculate the solar energy available in Pakistan. To calculate the solar resource parameters, the Solargis model uses knowledge inputs from fixed satellites and meteorological models [20]. The strategies employed in the model calculation take into consideration the attenuation factors of radiation on the approach through the atmosphere until reaching the bottom surface.

The elevation measured relative to the sea level as the optimum choice of a site and performance for the solar energy system. Elevation Angle is measured as described in Eq.1.

$$Cos\,\theta = \sin\delta\sin\varphi + Cos\,\delta\,Cos\,\varphi\cos\omega \quad \text{Eq.1}$$

The zenith angle is the angle between the sun and it's vertical. The zenith angle is 90° - elevation as shown in Eq.2.

$$\zeta = 90 - \theta \quad \text{Eq.2}$$

The Direct Normal Irradiation is the solar irradiation component that directly drops the surface of the penal as shown in Eq.3.

$$\mathrm{DNI} = \mathrm{A}.\exp(-\mathrm{B}/\mathrm{Cos}\,\theta) \quad \text{Eq.3}$$

Diffuse Horizontal Irradiation is the solar irradiation that is scattered by the atmosphere as given below in Eq.4.

$$\mathrm{DHI} = \mathrm{C}.\,\mathrm{DNI} \quad \text{Eq.4}$$

The Global Horizontal Irradiation is the sum of direct and diffuse solar radiation. It is a climate reference as it enables the sites or regions selection as refer to Eq.5.

$$GHI = DHI + DNI \cdot \cos(\theta) \quad \text{Eq.5}$$

To calculate the solar resource parameters, the Solargis model uses knowledge inputs from fixed satellites and meteorological models. First, clear-sky irradiance (absence of clouds) is calculated. The clear-sky model, that considers the position of the sun at vapour content, the concentration of aerosols and ozone. Second, the fixed meteorological satellites are employed to quantify the attenuation impact of clouds by the cloud index calculation. The clear-sky irradiance calculated the cloud index to regain the all-sky irradiance values as [21]. The horizontal irradiance is additional post-processed by different models to urge direct and diffuse irradiance on leaning surfaces as shown in fig.1.

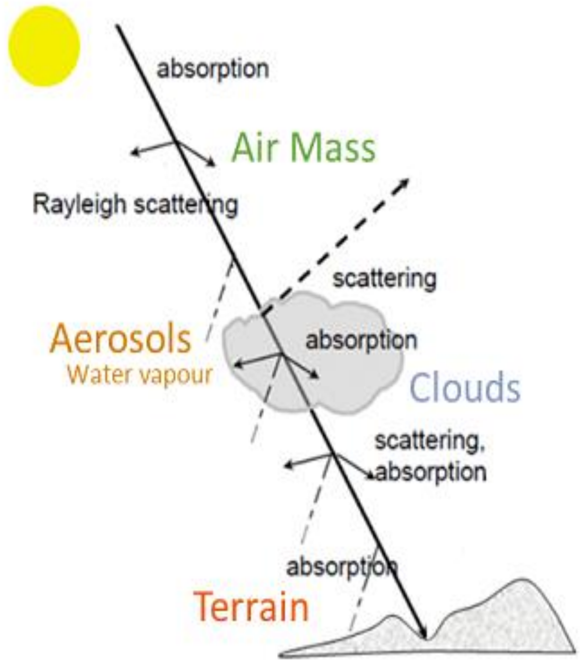

Fig.1. Solar irradiation. Source: [21]

Air temperature and meteorological parameters are very important for solar energy project. They used to determine the operating conditions and operational efficiency of the solar power plant as given in Eq.6.

$$\eta = \eta Tref[1 - \beta ref(Tc - Tref)] \quad \text{……………………..…………Eq.6}$$

The Atlas continually indicates the parameter that estimate the average values of power generation for PV modules. Meteorological parameters also are necessary, as they verify the in-operation conditions and performance potency of alternative energy plants as describe in Eq.7.

$$\eta_{pvg} = \eta_r \eta_{pc}[1 - \beta(T_c - T_{ref})] \quad \text{……………………..…………Eq.7}$$

The responsibility of meteorological information determines the accuracy of each solar power assessment. Besides radiation, air temperature and consequently the temperature of PV modules, have the foremost solar electricity simulation. The meteorological station with high-standard instruments so native values from the models might deviate from the native measurements and also the uncertainty of the meteorological is of identical importance as for solar resource.

$$T_c = T_a + \left(\frac{NOCT - 20}{800}\right) G_t \quad \text{…………...………..…………Eq.8}$$

$$P_{pv} = \eta_{pvg} A_{pvg} \quad \text{……..……..……….…………Eq.9}$$

$$P_M = I_S V_{oc} \quad \text{……………………..……..…………Eq.10}$$

$$P_{Array} = N_s N_s P_M \quad \text{…………………………..…………Eq.11}$$

Atmospheric temperature, known as air temperature, is another most important variable which determines the efficient performance of solar power system. Air temperature is taken at 2 meters above the ground. It is used to determine the temperature of PV modules and direct impact on PV conversion efficiency in energy losses.

The meteorological information for international models has lower special and temporal resolution compared to solar resource information. The World Bank parameter for installation of the solar power plant. The PV electricity simulation program, based on algorithm, is incorporated within the atlas which invariably provides secondary approximate estimation of the potential electrical phenomenon energy, which may be made at any location ruled by the interactive map as given below in Eq. 8 to Eq. 11.

The uncertainty of the long-term yearly solar resource estimates by satellite-based models can be characterized by calculating the systematic deviation at the validation sites, where high-quality solar measurements are available.

The ability of the model to characterize long-term annual GHI and DNI values should be evaluated at a sufficient number of validation sites.

Pakistan is the country in the world where there are great wind energy potentials. Electricity, in large quantities, can be produced by taking the advantage of the available renewable energies [2-3].
The wind energies of Pakistan especially Karachi have been investigated with the help of available World Bank data.

$$P_w = \frac{1}{2} C_p(\lambda, \beta)AV^3 \quad \text{Eq.12}$$

$$\lambda = R1\omega/v \quad \text{Eq.13}$$

$$Q_\omega = P \times \text{Time [KWh]} \quad \text{Eq.14}$$

The wind energies of the selected regions give the commendable measurement which can be exploited to generate the great amount of the wind energy.

$$P_w = \frac{1}{2} C_p(\lambda, \beta)A\left(\frac{R\omega}{\lambda}\right)^3 \quad \text{Eq.15}$$

$$T_t = \frac{1}{2} C_p(\lambda, \beta)A\left(\frac{R}{\lambda}\right) \quad \text{Eq.16}$$

The required parameters like turbulence intensity, min. wind speed, max, wind speed, mean wind speed & wind speed standard deviation have been studied to extract the wind energy. According to the analysis of the World Bank data, these parameters are based upon the World Bank wind calculations. The parameters are used to show the data of the provinces especially Karachi. The World Bank chooses these parameters to calculate the wind potential of the Pakistan as shown in Eq.12 to Eq.16.

3. Experimentation

The World Bank has installed the renewable energy project in order to assess the solar and wind energy potential in Pakistan. World Bank has installed … wind masts and …solar stations across world. Pakistan has got … number of these stations as a part of this global effort. The World Bank data site at Karachi is the experimentation set up behind the data reported in this paper.

The CSP Services (CSPS) ESMAP Project Tier2 meteorological station CSPS.MT.14.218 has been installed on the roof of the IM Department building of NED University of Engineering and Technology (NED-UET) in Karachi (24.9334°N, 67.1116°E) on April 22, 2015. The Tier2 station is equipped with a CSPS Twin-sensor Rotating Shadow band Irradi-ometer (RSI), a Kipp&Zonen CMP10 pyranometer for redundant GHI measurement, a Campbell Scientific CR1000 data logger, CS215 temperature and relative humidity probe, CS100 barometric pressure sensor, NRG #40C anemometer and NRG #200P wind direction sensor on a wind mast of 10 m height above the roof top. All sensors are integrated into the Tier2 meteorological data acquisition system. Power supply is provided by a solar panel and battery, designed for fully autonomous operation.

Figs. 1-8 have been shown to reveal the minute details of the equipment employed by the World Bank on the typical weather monitoring site.

Figure 2: The wind and solar Station [22]

 

Fig. 2: RSI (red: protection caps) Fig. 3: CMP10 w. sun shield [22]

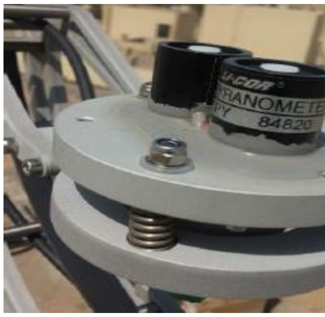

Fig. 4: Pyranometer Unit on RSI Fig. 5: Setra 278 pressure sensor [22]

Fig. 6: Control box with data logger, battery and electric equipment
Fig. 7. Solar panel [22]

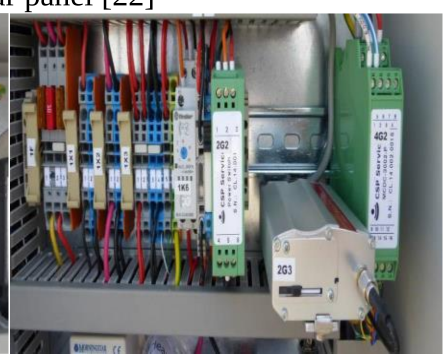

Fig. 8: Data logger. Figure 8: Connectors, GPRS modem, automatic switch [22]

Results

Pandas, a package called in Python Software is employed for handling large set of dates, times, and time-indexed weather data.

This data is obtained from an automated data logger, installed in 2015, which employs a variety of sensors. The minute by minute data can be downloaded from the internet. The Excel and CSV can also be downloaded from the web link of the World Bank group.
The Pandas within Python is employed to read the CSV file. The date has been set as an index and are automatically parsed. The raw data obtained from World Bank site is further processed using the code in order to gain some insight into the dataset by visualizing it.

Plotting the raw data about GHI,DNI, DHI, Air Temperature, Relative Humidity, Wind-speed, wind direction and Biometric pressure for Karachi region from 2016 till 2017, One may not get a clear idea about the complete set of weather data as the plot show a wide degree.

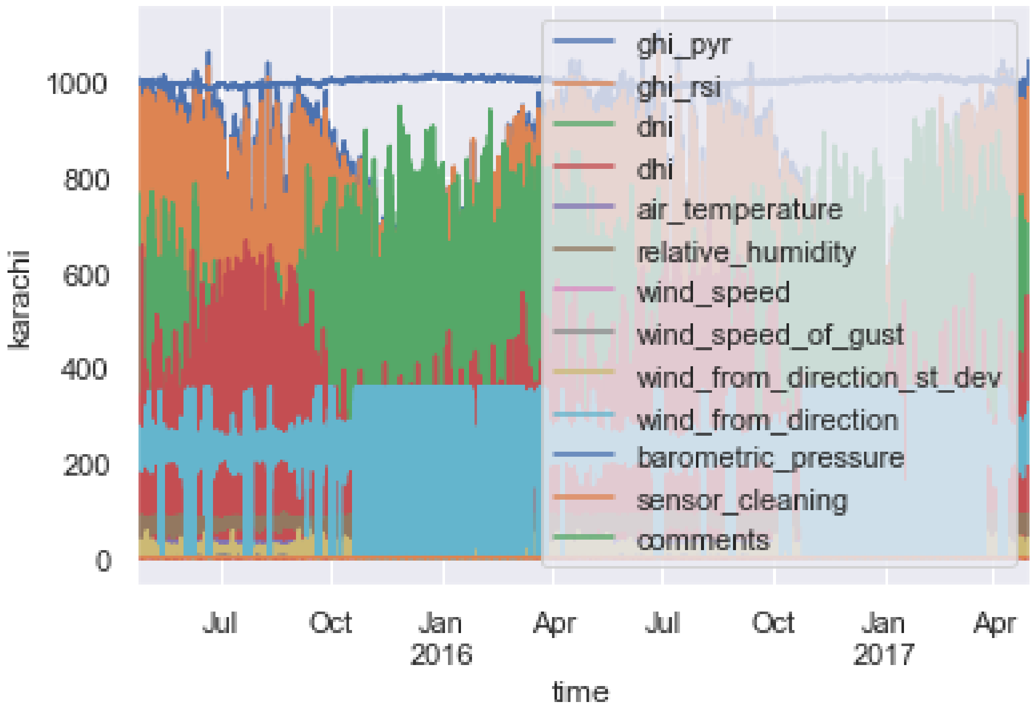

Fig.1. The raw weather data of variation in each category of the solar and wind data. All parameter of solar and wind for daily, weekly, monthly and yearly trendline are observed for the future trend.

The minute-wise data samples shown in Fig.1. Above show a widely varied, highly crowded to be analyzed. Resampling the data on a coarser grid further helps in gaining a better insight. Sampling the weather data on weekly basis is shown in Fig.1. Below.

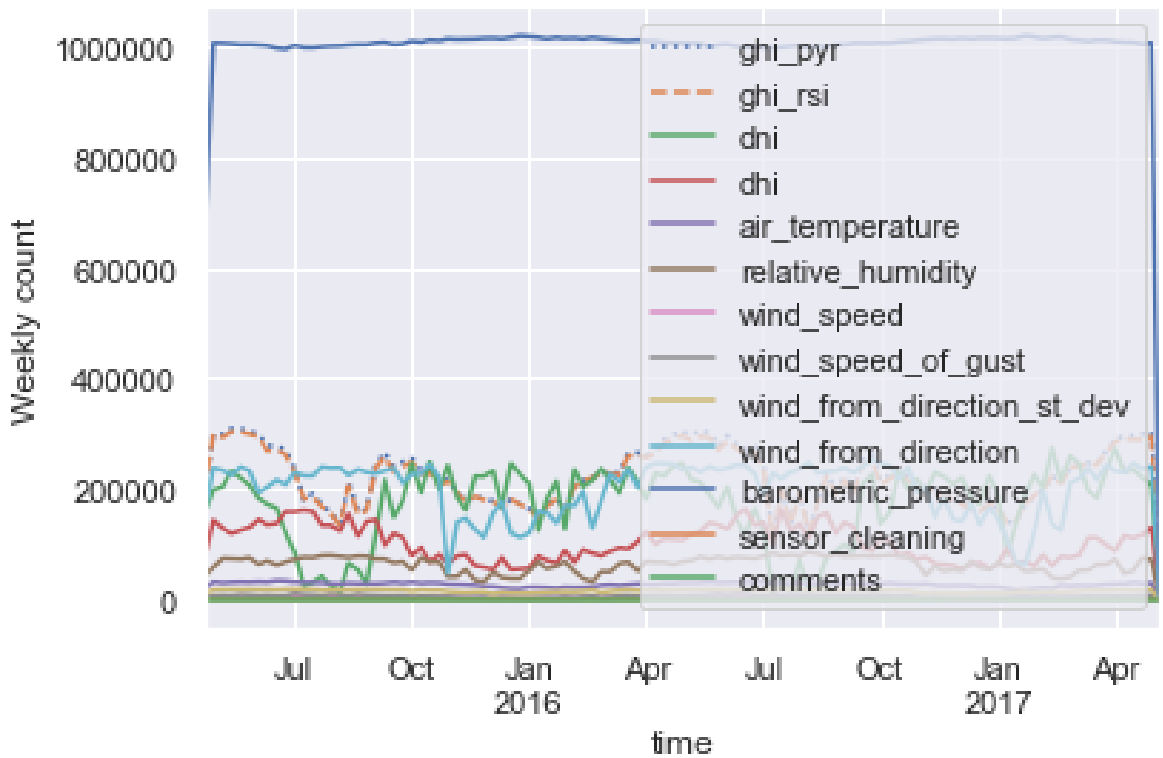

Fig.2. Solar and wind Parameter observation based on the weekly count. The weekly count are analyzed for the period of Jan 2015 to April 2017. The comparison show the weekly basis measurement on the ground observations for the uncertainty factor in Karachi.

This plot shows some seasonal trends as sunshine and wind varies as a function of the weather throughout the year. One may observe more GHI, DHI, DNI in the summer than in the winter, and even within a particular season, there are huge variations in some cases from week to week. However, there must be some coarser grid to provide better insight as refer fig.2.
A particular way which appears as smarter in the data analysis employs a **rolling mean**. In this technique, a 30-day rolling mean of the data is employed.

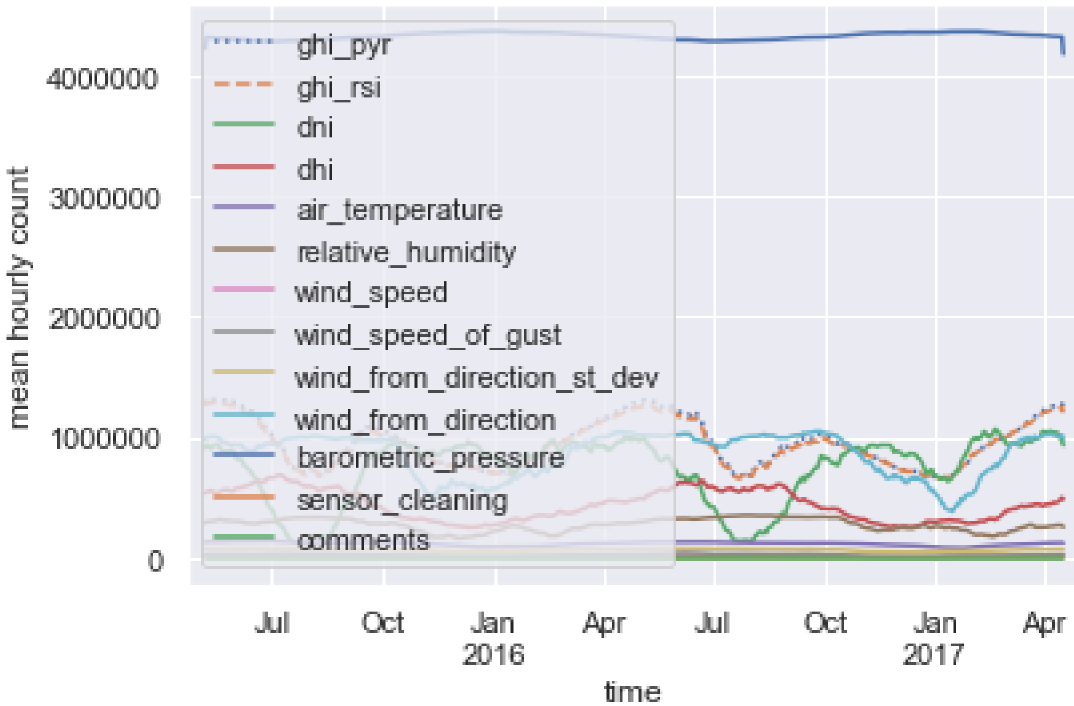

Fig.3. The periodic trend of solar and wind parameter version with the mean hourly count. The mean hourly count is analyzed for the period of Jan 2015 to April 2017. The comparison show the hourly basis measurement on the ground observations for the uncertainty factor in Karachi.

The periodic trend follows the season as it is visible in higher values of GHI, DHI, DNI in summer as compared with those in winter. The wind parameters show a seasonal trend as well but the values being very small on the scale are barely visible in the plot as shown fig.3. A smoother version of a rolling mean using a Gaussian window with the width of the window being 50 days, and the width of the Gaussian within the window being 10 days:

Looking at the data plot, it can be seen that these smoothed data views are useful to get an idea of the general trend in the data, however, the plot hide much of the interesting structures.
For example, if one wants to know the average irradiation and wind speed as a function of the time of day. This particular plot shows the time wise trend throughout the day as shown fig.3.

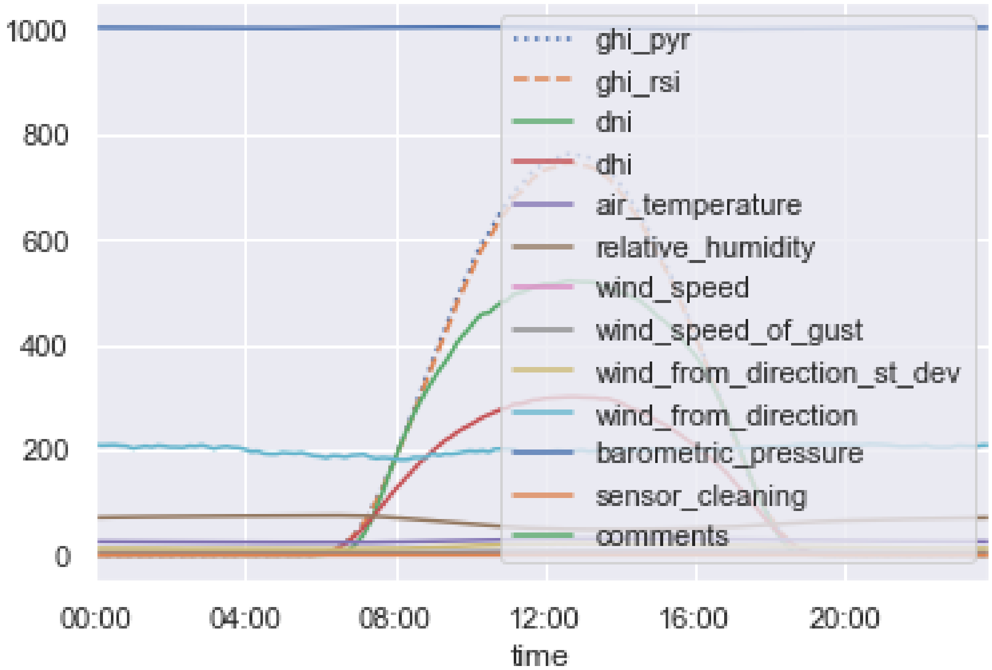

Fig.4. Hourly observation of the solar throughout the day. The different parameters are analyzed for the period of 23th April 2017.

The hourly solar irradiation is a strong bimodal distribution, with peaks around 12:00 in the noon and it goes to minimum at 8:00 AM in the morning as well as 5:00 PM in the evening as shown in Fig.4. The high irradiation is likely evidence of a strong dependence of sun movement. The lack of variation in wind parameters is further evidenced by the uniformity throughout the day, except for the consistent variations visible throughout the day. We may be curious about the trend of variations throughout the week as refer Fig.5.

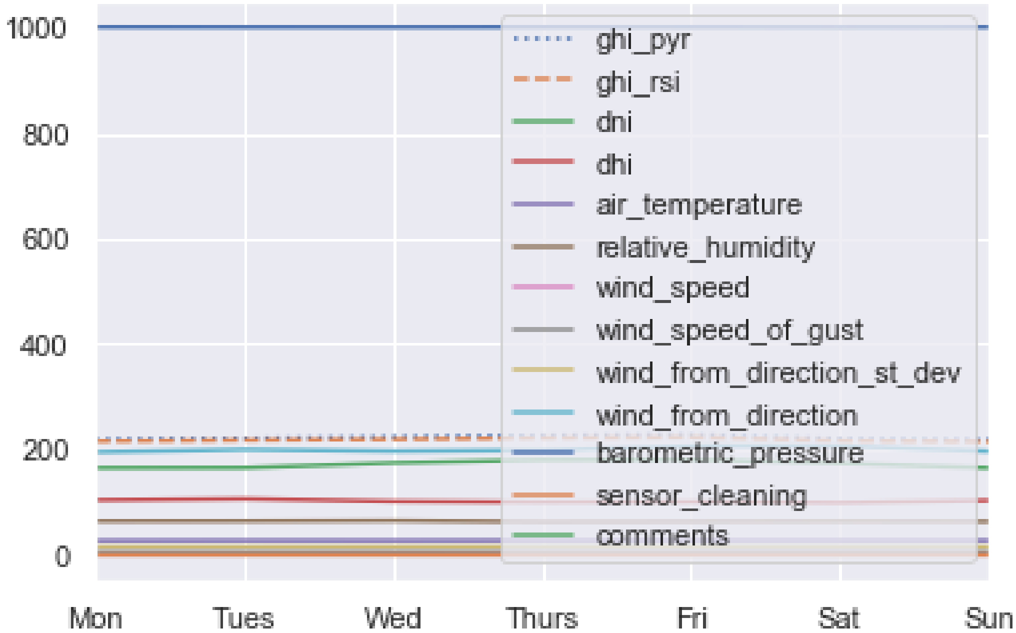

Fig.5. Consistent variations visible throughout the day.

This shows a weaker dependence between weekday and weekend totals, with same average irradiation and wind speed on Monday through Friday as well as Saturday and Sunday. With the weekly dependence in the mind, let's look at the hourly trend on weekdays versus weekends. The weekly count is analyzed as the regular weekdays and the weekend days for the period of Jan 2015 to April 2017 as study in Fig.6.

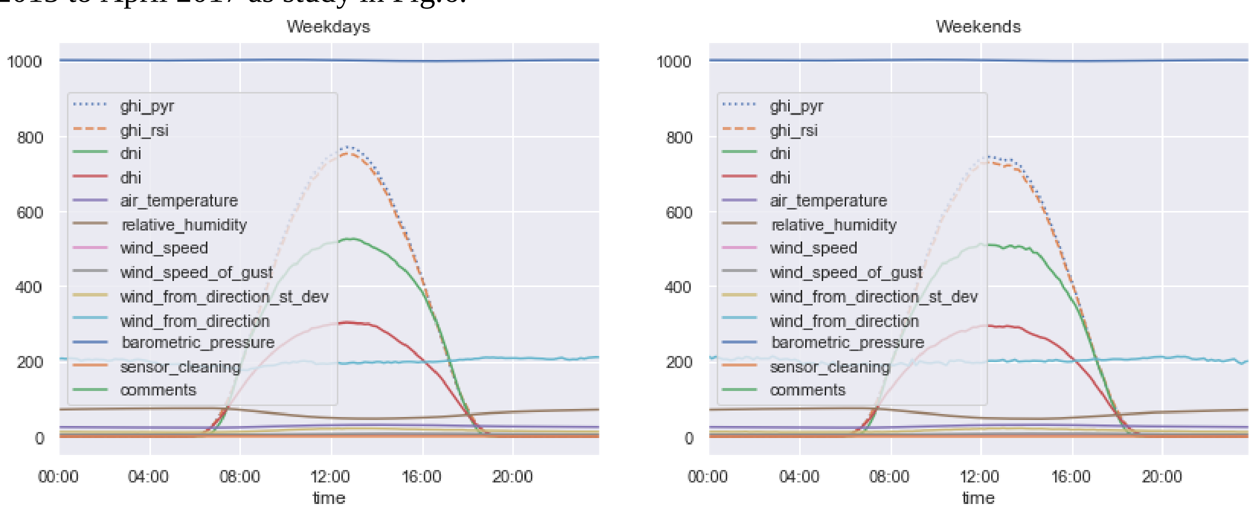

Fig.6. solar Parameter observation that shows a weaker dependence between weekday and weekend totals based on the weekly count. The comparison show the weekly basis Measurement on the ground observations for the uncertainty factor in Karachi.

The result is very interesting showing a bimodal pattern during the work weekdays as well as the weekends. It would be interesting to dig through this data in more detail, and examine the effect of weather, temperature, time of year, and other factors on solar irradiation and wind speed.

The results are based upon the data obtained from World Bank solar and wind station located at NED University, Karachi. The data were collected from the 2015 to 2017. The time duration between two consecutive readings is 10 minutes. The solar and wind data was studied for daily, weekly and yearly durations from 2015 till 2017. The hourly measurements were used as a time-based data; the collective data is being started from 00:00 to 24:00 as shown in fig.4.
The Figures shown below contain the data obtained from World Bank site located across Karachi.
The first section of figures shows the day-wise trend. It can be clearly seen that the trend has been uniform as for as the particular sunny and windy day as shown in fig.1.

The solar and wind data was studied for daily, weekly and yearly durations for the data sets in 2015-2017. In the second section, the data was studied on weekly basis and following trends were observed as shown in the fig.2. From the diagrams based upon the daily irradiation. It can be clearly seen that the trend has been uniform as for as the particular sunny and windy day is concerned. In the monthly and yearly trend the polynomial regression is concerned for the future prediction of the parameter trend.

This data obtained from World Bank sites located across Karachi. The solar and wind data was studied for yearly durations for the data sets in 2015-2017. The year wise trend is studied based on available data and following trends were observed. It can be clearly seen that the trend is fluctuated as for as the sunny and wind day is concerned. In the yearly data, the polynomial regression is concerned for the future prediction of the trend as shown in fig.5.

1. Analysis of Results

The weather data shown in Figs. Has wide variety of variations apart from its dependence on various parameters. Due to these variations, the solar irradiation and wind speed are also vary at large scales. With the increasing involvement of the solar and wind based power in the national grid, it is highly necessary that the varied nature of the solar irradiation and the wind speed must be analyzed. The analysis of these variations arms us with the tools to predict the variations if we can detect the periodicity of these variations depending upon the weather patterns.

With this aim in mind, the daily, monthly and yearly solar irradiation data obtained from World Bank sites was analyzed. The linear regression is a versatile tool to detect and model the trend within a varied data from a typical month, day, week and even hour of the year to find a trend that may be easily predicted or forecasted for the future trends.

The daily, monthly and yearly irradiation data points were mapped to find a trend in the data. On the basis of the data for the particular period, a consistent trend is observed in weekly, daily, monthly and yearly data.

The models as well as the data got for the daily irradiation from 22rd till 30th April show that the irradiation is the highest on the day of 23 April 2015, 23 April 2016 and 24 April of 2017 similarly the lowest irradiation obtained on a following particular days of 27 April 2015, 24 April 2016 and 23 April 2017. The data trend points at the fact that the irradiation is one of the highest during the April-May-June months throughout the period from 2015 till 2017. On the other end, the irradiation data is the lowest on December-January of the year.

The solar irradiation shows a consistent trend on any day showing a peak at noon and the minimum at 8 AM as well as 5 PM. This trend is consistent throughout the year. Then, the solar irradiation is shown to have consistent weekly trend being it weekday or weekend. The solar irradiation is also analyzed for a complete month throughout the year. Here, there are variations: the solar irradiations being highest on the months containing sunny days. Consistent with the summer, the solar irradiations are higher in summer than the winter, corresponding with the solar angle.

The wind speed varies through the year. The daily trend shows the maximum wind speed as refer Fig.3. The trend shows Fig.1 is a clear trend of wind speed showing its maximum in months of. June and average in months of April to September Through the year, there is a variation showing in Fig.5.

5. Conclusion

An effort is made in the paper to analyze the solar irradiation and wind parameters on the basis of the weather data available thanks to World Bank. The solar irradiation and wind parameters are analyzed on daily, weekly, monthly and yearly basis. The variation in the solar and wind parameters has been a challenge as both suffer from variations in the weather patterns through the year. It is observed that the GHI, DHI, DNI vary as a function of the position of the sun throughout the day. Moreover, these values vary through the year as a function of the weather changes. The solar irradiation is the highest for summer and lowest for winter sessions.

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