Comparing MERRA and MERRA-2 Reanalysis Datasets with Mast Measured Wind Data for Karachi, Pakistan

Zia ul Rehman Tahir[*1], Muhammad Asim[1], Amjad Hussain[2], Ghulam Moeen uddin[1], Nasir Hayat[1], Faisal Iqbal Qureshi[1]

1 *Mechanical Engineering Department, University of Engineering and Technology Lahore, Pakistan*

2 *Industrial and Manufacturing Engineering Department, University of Engineering and Technology Lahore, Pakistan*

* **Corresponding Author:** E-mail: ziartahir@uet.edu.pk

Abstract

The aim of the study is to evaluate reanalysis wind data with mast measured data at Hawks Bay, Karachi, in the coastal region of Pakistan. MERRA and MERRA-2 reanalysis datasets, assimilated by NASA global data assimilation system, are evaluated in this study. The comparison between wind data has been performed for 10 m, 50 m and 80 m heights using hourly and daily data. Statistical Analysis using correlation coefficient (R), mean bias error (MBE), standard deviation of errors (STDE) and root mean square error (RMSE) was used for comparison. MERRA-2 data shows better results for wind speed at 10 m and for wind direction at 80 m in terms of statistical parameters and correlation coefficient. R of wind speed for MERRA-2 at 10 m are 0.70 and 0.91 for hourly and daily data respectively whereas R of wind direction at 80 m are 0.66 and 0.76 for hourly and daily data respectively. The wind energy industry is in developing phases in Pakistan, the present work will contribute towards the exploration of wind energy potential of the southern region of the country.

Key Words: Wind Resource Assessment, Reanalysis dataset, MERRA, MERRA-2, Offshore Wind, Pakistan

1. Introduction

Pakistan is a developing country, has been facing extreme energy crisis due to the increase in energy consumption and lesser amount of energy supply than the demand in the country for the last 2 decades. Wind energy is an environment friendly and sustainable energy option for Pakistan, as optimistic analysis says that by 2030 one fifth of planet's demand of electricity would be satisfied by the renewable resources; solar and wind projects. The same scenario might be possible for Pakistan as it is enriched in the renewable resources like wind energy, especially during the moon soon season and the wind coming from the coast of the Arabian sea [1]. In the last ten years (2009-18), 18 wind power projects of 937.27 MW capacity started commercial operation which makes up less than 1.5 % of total power production. This proportion is way less compared to other energy generation methods as almost 68% of the total energy of Pakistan is currently dependent on the thermal power plants operated by fossil fuels [2; 3]. The high dependence on imported fossil fuels has a bad impact when there is a fluctuation of crude oil price in the international market [4-6]. The prohibitive cost of electricity increases the circular debt and subsidy [3]. Apart from the economy, studies have shown that the use of fossil fuels are causing environmental pollution and global warming [7].

Pakistan has about 1100 km long coastal line on the Arabian Sea, but wind resource assessment work or even feasibility of wind farm installation has not been carried out so far. The start of commercial wind project includes various considerations to estimate energy potential of the site. Mast measured wind data for at least three years is required for estimation of wind power potential. In-accurate data is main reason behind the error in estimations and prediction of energy production for wind projects due to which many projects may have the less estimated capacity by as much as 60 percent [8]. This problem increases the importance of reliable wind data which is only possible using wind masts. The installation of wind mast and data measurement is too much expensive and time taking process. In the presence of reliable mast measured wind data, the long-term time series from reanalysis data can be evaluated which can be used in the nearby location using bias correction methods.

The objective of this paper is to compare mast measured wind data with reanalysis wind data. The mast measured wind data at Hawksbay near Karachi is compared with MERRA and MERRA-2 reanalysis datasets. If the reanalysis wind data shows the comparable results as of mast measured data, then the reanalysis data can be used for preliminary resource assessment of possible offshore wind power projects.

2. Wind Data

Alternative Energy Development Board (AEDB) of Pakistan in collaboration with the United Nations Development Programme (UNDP) had installed wind masts in the southern areas of Pakistan for accurate measurement of wind data [9]. The wind mast was installed on the premises of Hawksbay coast in Karachi [9]. The location of the site is 24° 52′ 02.025″ N and 66° 51′ 41.983″ E, which is about 1.0 km from the coastal line. The mast has five anemometers for measurement of wind speed at heights of 10 m, 30 m, 60 m, and 80 m and two wind vanes for measurement of wind direction at 28.5 m and 78.5 m. The wind mast was installed in March 2009 and it started collecting data from 19th March 2009. The data for two years duration from 1st May 2009 to 30th April 2011 was used in the current work.

MERRA reanalysis dataset [10] was developed by NASA based on its global data assimilation system. MERRA dataset has a spatial resolution of about 70 km (0.50° latitude and 0.677° longitude) and a temporal resolution of one hour. MERRA wind data is available at 2 m, 10 m and 50 m height above the ground. MERRA-2 reanalysis dataset [11] is the advanced version of MERRA reanalysis by the NASA, which replaces the original MERRA reanalysis [12] using an upgraded version of the GEOS-5 data assimilation system [13]. The other improvement in MERRA-2 is it assimilates the observation types which were not available in its previous version and includes updates to the Goddard Earth Observing System (GEOS) model and the analysis scheme which can provide a worthwhile ongoing climate analysis beyond MERRA’s capabilities. MERRA-2 has a spatial resolution of about 70 km (0.50° latitude and 0.625° longitude) and a temporal resolution of one hour. MERRA-2 wind data is available at 50 m, 10 m and 2 m height above the ground. MERRA-2 products can be easily accessed online [14] through the “NASA Goddard Earth Sciences Data Information Services Center (GES DISC)” [15]. The temporal resolution of both MERRA and MERRA-2 are similar but the spatial resolution is slightly different, so the grid points of both datasets are different.

3. Methodology

The mast measured data has a temporal resolution of 10 minutes whereas the reanalysis data have a temporal resolution of one hour, so measured data was converted to an hourly duration for comparison. Bilinear interpolation has been used to compute wind data at the mast location using four nearby grid points, which is used in the previous literature [16-21]. The measured wind speed at 50 m height and reanalysis data at 80 m were computed from wind data at other heights using logarithmic law, which has been used for a range of wind speeds, altitudes and locations [22; 23]. The reanalysis data were compared with mast measured data at 80m, 50 m and 10 m height using statistical analysis. The parameters used for comparison of the data are; the standard deviation of the error (STDE), correlation coefficient (R), the root mean square error (RMSE) and mean bias error (MBE). The MBE, RMSE and STDE for wind speed are given by the equations (1) to (3), where S_i is the reanalysis wind speed and M_i is the measured wind speed, these expressions were reported by Carvalho et al. [24]. The negative value of bias represents an underestimation of wind speed by reanalysis dataset compared to measured data and vice versa.

$$\text{MBE} = \frac{1}{n} \sum_{i=1}^{n} (S_i - M_i) \tag{1}$$

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (S_i - M_i)^2} \tag{2}$$

$$\text{STDE} = \sqrt{\text{RMSE}^2 - \text{MBE}^2} \tag{3}$$

4. Results

4.1 Statistical Analysis

The MBE, RMSE, STDE and R of reanalysis data for wind direction and speed for the hourly and daily duration at 10 m, 50 m and 80 m is presented in Table 1. The wind speed and wind direction are represented as WS and WD respectively. Both datasets show a very good agreement with the measured data. MERRA has a lower MBE for wind speed at 50 m and wind directions at 80 m height for hourly data compared to MERRA-2. MERRA-2 has lower RMSE, lower STDE and higher R for wind speed at 10 m height and wind direction at 80 m for hourly data compared to MERRA. Both reanalysis data show almost the same results for the daily data as for hourly data with a slight difference; MERRA-2 has the lower errors at 80 m compared to MERRA data whereas MERRA data has lower errors at other heights. The correlation between measured and reanalysis wind speeds at 10 m, 50 m and 80 m height are shown in Fig. 1.

4.2 Time Series Analysis

The comparison of monthly mean wind speed for two years duration is presented in Fig. 2. The results show monthly mean wind speeds are closely related, both reanalysis data underestimate wind speed throughout the year at 10 m height. At 50 m height, MERRA data underestimates the wind speed throughout the year while MERRA-2 wind speed overestimates the measured wind speed from March to June and underestimates the wind speed for the rest of the year. At 80 m height, MERRA-2 underestimates the wind speed for the whole year whereas MERRA overestimates the wind speed for the duration of March to June and underestimates for rest of the year.

4.3 Weibull PDF

The Weibull probability distribution function (PDF) is widely used to represent wind speed distribution [25; 26]. The Weibull PDF is based on two modelling parameters; shape parameter *k* (also known as Weibull slope parameter which is the direct measure of the spread of the distribution curve) and the scale parameter *A* (the direct measure of the skewness of the distribution curve) [27; 28].

The Weibull PDF of mast measured data and reanalysis data is presented in Fig. 3. For low-speed wind, the reanalysis values are higher whereas for high wind speed the values are lower than the measured values. The overall results show that reanalysis data has lower values than the measured values.

The value of *k* and *A* for both measured and reanalysis data is presented in Table 2, percentage errors of the reanalysis are presented in parenthesis. At 50 m height, the mean wind speed for reanalysis data shows a similar pattern with measured data within 8 % error, the similar behaviour is for Weibull factors *A* while Weibull shape factor *k* shows higher error within 18%. The overall predictions are better at 50 m height, the results of MERRA in terms of mean wind speed, wind power density and Weibull factors are better compared to MERRA-2.

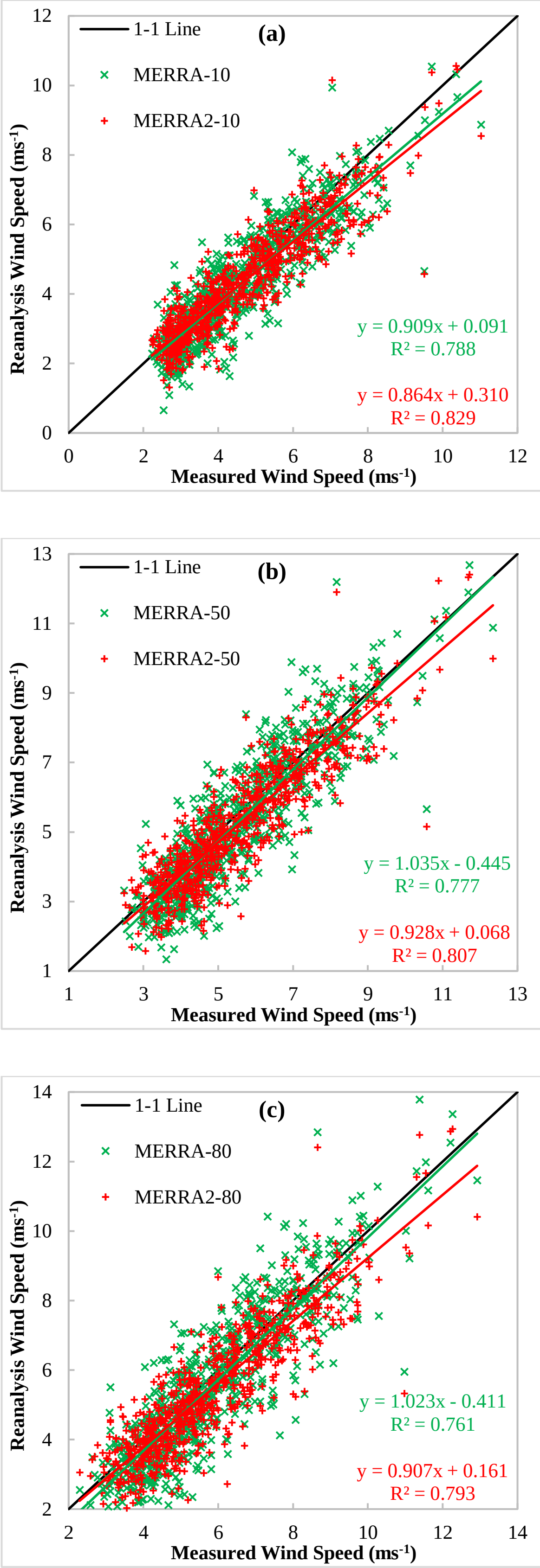

Fig.1: Correlation between measured and reanalysis wind speed at: (a) 10 m, (b) 50 m, (c) 80 m

5. Discussion

The mean wind speed, mean wind direction and wind power density at three heights are shown in Table 2, the percentage error of reanalysis is presented in parenthesis. The lowest difference for mean wind speed is 4.49 % for MERRA at 50 m and the maximum is 7.13 % at 10 m for MERRA. The percentage difference is around 6 % for all heights for MERRA-2. The percentage difference for mean wind direction for both datasets is less than 5%. The lowest difference in mean wind density is 10 % for MERRA at 50 m and 80 m.

MERRA wind data is underestimated at all three heights of 10 m, 50 m and 80 m. The hourly wind speed has Bias, RMSE, STDE and R values ranging from -0.25 to -0.33 ms^{-1}, 1.96 to 2.00 ms^{-1}, 1.94 to 1.97 ms^{-1} and 0.580 to 0.682 respectively. On the basis of statistical analysis, the best estimate of wind speed is for 50 m height (due to minimum bias, RMSE and STDE). The hourly wind direction has Bias, RMSE, STDE and R values ranging from -5.93º to -12.3º, 42.34º to 46.06º, 41.92º to 44.39º and 0.57 to 0.64 respectively, giving the best estimate of wind direction is for 80 m height (maximum correlation coefficient and minimum errors). The MBE, RMSE and STDE values for wind speed ranging from -0.98 to 0.52 ms^{-1}, 1.62 to 2.14 ms^{-1} and 1.55 to 2.14 ms^{-1} was reported in a similar study [24]. The MBE, RMSE, STDE and R for wind direction reported were ranging from -6.44º to 0.84º, 36.08º to 51.37º, 35.50º to 51.36º and 0.82 to 0.95 respectively in a similar study [24].

Table 1: Comparison between reanalysis with measured data

Duration	Data	Height	Bias		RMSE		STDE		R	
			WS	WD	WS	WD	WS	WD	WS	WD
Hourly	MERRA	10 m	-0.33	-12.3	2.00	46.06	1.97	44.39	0.58	0.574
		50 m	-0.25	-8.71	1.96	43.66	1.94	42.78	0.659	0.610
		80 m	-0.28	-5.93	1.98	42.34	1.96	41.92	0.682	0.639
	MERRA-2	10 m	-0.32	-13.52	1.75	42.74	1.72	40.55	0.700	0.600
		50 m	-0.33	-9.38	1.85	40.54	1.82	39.44	0.673	0.642
		80 m	-0.39	-6.62	1.91	39.50	1.87	38.94	0.686	0.664
Daily	MERRA	10 m	-0.33	-5.61	0.85	36.02	0.78	35.43	0.888	0.688
		50 m	-0.25	-5.47	1.00	32.61	0.97	32.15	0.881	0.699
		80 m	-0.64	-4.43	1.07	30.23	0.86	29.90	0.890	0.759
	MERRA-2	10 m	-0.32	-8.35	0.75	32.73	0.68	31.65	0.911	0.691
		50 m	-0.33	-6.31	0.87	29.95	0.80	29.28	0.899	0.757
		80 m	-0.39	-3.65	0.95	29.60	0.87	29.37	0.891	0.760

Table 2: Comparison reanalysis with measured data

Height	Data	Mean wind speed (ms^{-1})	Mean wind direction (º)	Wind power density (W/m^2)	Weibull scale factor *A* (ms^{-1})	Weibull shape factor *k*
10 m	Measured	4.658	268.2	111	5.271	2.145
	MERRA	4.326 (-7.13)	260.8 (-2.76)	80 (-27.93)	4.873 (-7.55)	2.398 (11.79)
	MERRA-2	4.336 (-6.91)	256.2 (-4.47)	77 (-30.63)	4.879 (-7.44)	2.537 (18.28)
50 m	Measured	5.543	267.8	163	6.249	2.538
	MERRA	5.294 (-4.49)	263.5 (-1.61)	146 (-10.43)	5.963 (-4.58)	2.386 (-5.99)
	MERRA-2	5.211 (-5.99)	259.6 (-3.06)	131 (-19.63)	5.854 (-6.32)	2.607 (2.72)
80 m	Measured	5.855	265.7	190	6.596	2.570
	MERRA	5.577 (-4.75)	264.3 (-0.53)	171 (-10.00)	6.282 (-4.76)	2.383 (-7.28)
	MERRA-2	5.470 (-6.58)	261.0 (-1.77)	151 (-20.53)	6.144 (-6.85)	2.612 (1.63)

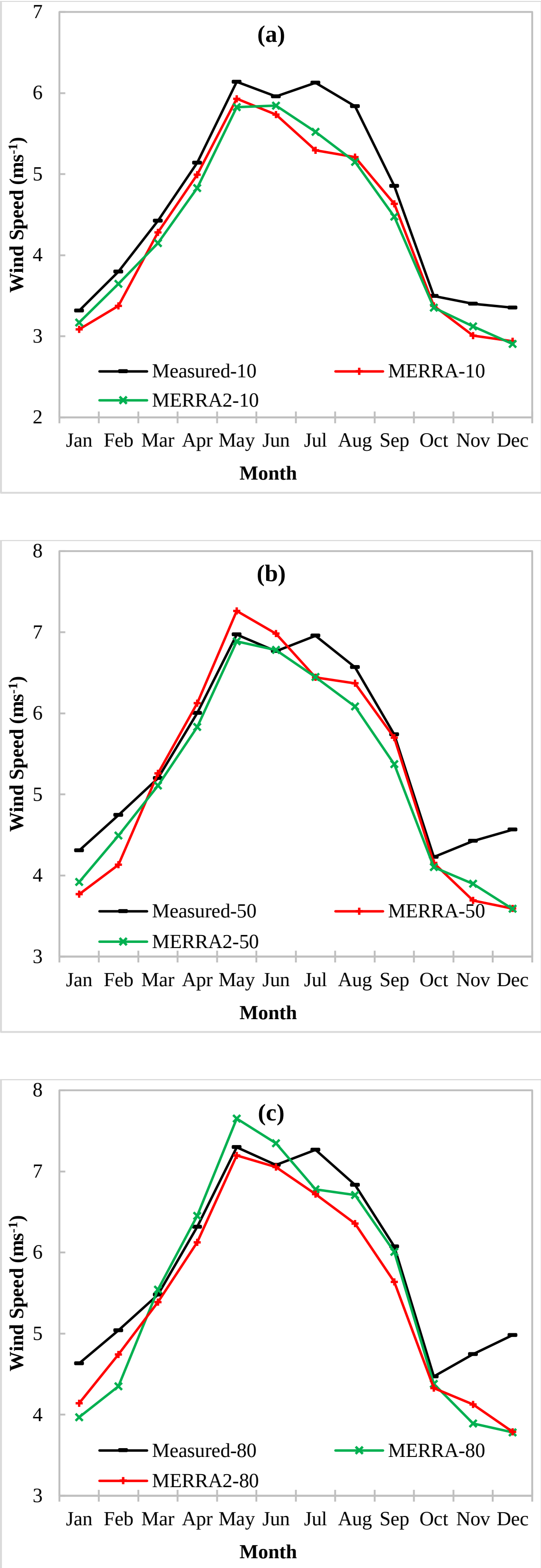

Fig. 2: Time Series of Measured, MERRA and MERRA-2 data at: (a) 10 m, (b) 50 m, (c) 80 m

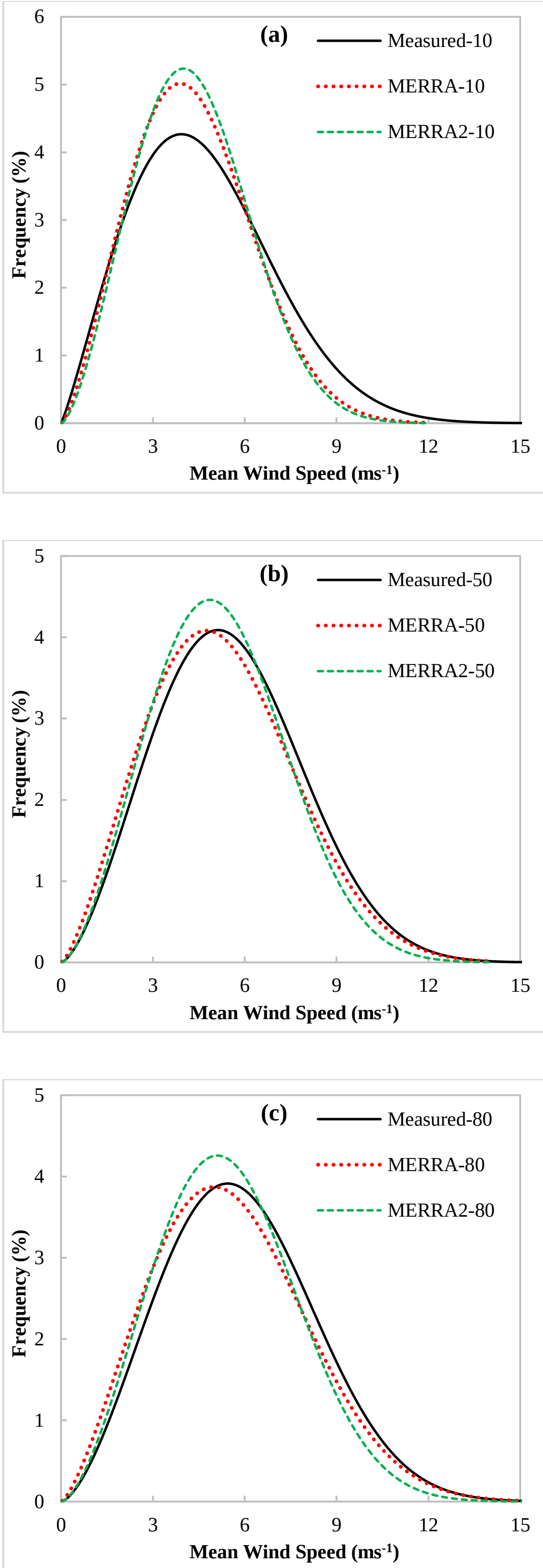

Fig. 3: Weibull probability distribution function of wind speed at: (a) 10 m, (b) 50 m, (c) 80 m

Carvalho et al. [29] in another study reported the values for MBE, RMSE, STDE and R of wind speed for five sites of compared with MERRA was range from 0.16 to 0.90 ms^{-1}, 1.76 to 2.39 ms^{-1}, 1.75 to 2.21 ms^{-1} and 0.81 to 0.89 whereas the values of wind direction range from -1.99º to 4.28º, 34.64º to 52.36º, 34.58º to 54.18º and 0.78 to 0.89 respectively. Stafell et al. [30] compared MERRA with 23 European countries gave a range of correlation coefficient range from 0.87 to 0.97. A comparison of current work with previous work [29-31] done by other researchers on wind speed and wind direction reveals that MERRA data has better Correlation (R) values in European region compared to the site in Pakistan. MERRA wind data is underestimated in Pakistan whereas it both overestimates and underestimates along the Iberian Peninsula coast and in Europe.

The hourly wind speed data from MERRA-2 at 10 m, 50 m and 80 m has the MBE, RMSE, STDE and R values for ranges from -0.32 to -0.39 ms^{-1}, 1.75 to 1.91 ms^{-1}, 1.72 to 1.87 ms^{-1} and 0.60 to 0.66 respectively while these values for wind direction ranges from -6.62° to -13.52°, 39.50° to 42.74°, 38.94° to 40.55° and 0.60 to 0.66 respectively.

The best estimates of MERRA-2 wind speed are at 10 m height whereas for wind direction best estimation is for 80 m height. Miinalainen [32] compared four sites on the coastline of Norway with MERRA-2 at 10 m, the statistical parameters for wind speed for those four sites were reported as MBE, RMSE, STDE and R ranging from 2.10 to 4.32 ms^{-1}, 2.59 to 5.10 ms^{-1}, and 2.0 to 2.68 ms^{-1}, 0.48 to 0.74 respectively. A comparison of the present study with of Miinalainen [32] reveals that MERRA-2 shows fewer bias values for Pakistan than Norway and almost better estimation for Pakistan as compared to Norway.

6. Conclusions

The evaluation of MERRA and MERRA-2 reanalysis datasets for the coastal region of Pakistan was performed. MERRA-2 data gave better results in terms of all the statistical parameters compared to MERRA data at 10 m height. Both MERRA and MERRA-2 data show similar results compared to mast measured data at 50 m height. The estimation from MERRA data is more accurate than MERRA-2 data in terms of wind power density, mean wind speed, and Weibull factors. MERRA-2 show better results in terms of RMSE, STDE and R as compared to MERRA data at 80 m. The percentage difference of wind speed from reanalysis data and surface data is about 5 % and for wind direction is about 3 %, which is very good for initial site assessment in the absence of surface measured data.

7. References

[1] Siddique, S., & Wazir, R. (2016). A review of the wind power developments in Pakistan. *Renewable and Sustainable Energy Reviews, 57*, 351-361.

[2] Kamran, M. (2018). Current status and future success of renewable energy in Pakistan. *Renewable and Sustainable Energy Reviews, 82*, 609-617. doi:https://doi.org/10.1016/j.rser.2017.09.049.

[3] Zameer, H., & Wang, Y. (2018). Energy production system optimization: Evidence from Pakistan. *Renewable and Sustainable Energy Reviews, 82*, 886-893. doi:https://doi.org/10.1016/j.rser.2017.09.089.

[4] Mahmood, A., Javaid, N., Zafar, A., Ali Riaz, R., Ahmed, S., & Razzaq, S. (2014). Pakistan's overall energy potential assessment, comparison of LNG, TAPI and IPI gas projects. *Renewable and Sustainable Energy Reviews, 31*, 182-193. doi:https://doi.org/10.1016/j.rser.2013.11.047.

[5] Hong, S.-Y., & Pan, H.-L. (1996). Nonlocal boundary layer vertical diffusion in a medium-range forecast model. *Monthly Weather Review, 124*(10), 2322-2339.

[6] Sher, H. A., Murtaza, A. F., Addoweesh, K. E., & Chiaberge, M. (2015). Pakistan's progress in solar PV based energy generation. *Renewable and Sustainable Energy Reviews, 47*, 213-217.

[7] Zecca, A., & Chiari, L. (2010). Fossil-fuel constraints on global warming. *Energy Policy, 38*(1), 1-3. doi:https://doi.org/10.1016/j.enpol.2009.06.068.

[8] Khan, K. S., & Tariq, M. (2018). Wind resource assessment using SODAR and meteorological mast – A case study of Pakistan. *Renewable and Sustainable Energy Reviews, 81*, 2443-2449. doi:https://doi.org/10.1016/j.rser.2017.06.050.

[9] Memon, N., Jafari, A. H., Yousuf, I., & Khan, S. A. (2010). *Analysis of data of AEDB-UNDP (WEP) wind masts installed*

in Gharo-Keti Bandar wind corridor: AEDB, Islamabad, Pakistan.

[10] Rienecker, M. M., Suarez, M. J., Gelaro, R., Todling, R., Julio Bacmeister, Liu, E., Woollen, J. (2011). MERRA: NASA's Modern-Era Retrospective Analysis for Research and Applications. *Journal of Climate, 24*(14), 3624-3648. doi:10.1175/jcli-d-11-00015.1.

[11] Gelaro, R., McCarty, W., Suárez, M. J., Todling, R., Molod, A., Takacs, L., Zhao, B. (2017). The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2). *Journal of Climate, 30*(14), 5419-5454. doi:10.1175/jcli-d-16-0758.1.

[12] Rienecker, M. M., Suarez, M. J., Gelaro, R., Todling, R., Bacmeister, J., Liu, E., Kim, G.-K. (2011). MERRA: NASA's modern-era retrospective analysis for research and applications. *Journal of Climate, 24*(14), 3624-3648.

[13] Bosilovich, M., Lucchesi, R., & Suarez, M. (2015). MERRA-2: file specification.

[14] Janjai, S., Laksanaboonsong, J., Nunez, M., & Thongsathitya, A. (2005). Development of a method for generating operational solar radiation maps from satellite data for a tropical environment. *Solar energy, 78*(6), 739-751. doi:http://dx.doi.org/10.1016/j.solener.2004.09.009.

[15] Gelaro, R., McCarty, W., Suárez, M. J., Todling, R., Molod, A., Takacs, L., Reichle, R. (2017). The modern-era retrospective analysis for research and applications, version 2 (MERRA-2). *Journal of Climate, 30*(14), 5419-5454.

[16] Staffell, I., & Green, R. (2014). How does wind farm performance decline with age? *Renewable Energy, 66*, 775-786. doi:http://dx.doi.org/10.1016/j.renene.2013.10.041.

[17] Carvalho, D., Rocha, A., Gómez-Gesteira, M., & Silva Santos, C. (2014). Comparison of reanalyzed, analyzed, satellite-retrieved and NWP modelled winds with buoy data along the Iberian Peninsula coast. *Remote Sensing of Environment, 152*, 480-492. doi:http://dx.doi.org/10.1016/j.rse.2014.07.017.

[18] Hawkins, S., Eager, D., & Harrison, G. P. (2011, 6-8 Sept. 2011). *Characterising the reliability of production from future British offshore wind fleets.* Paper presented at the IET Conference on Renewable Power Generation (RPG 2011).

[19] Ruti, P. M., Marullo, S., D'Ortenzio, F., & Tremant, M. (2008). Comparison of analyzed and measured wind speeds in the perspective of oceanic simulations over the Mediterranean basin: Analyses, QuikSCAT and buoy data. *Journal of Marine Systems, 70*(1–2), 33-48. doi:http://dx.doi.org/10.1016/j.jmarsys.2007.02.026.

[20] Dhanju, A., Whitaker, P., & Kempton, W. (2008). Assessing offshore wind resources: An accessible methodology. *Renewable Energy, 33*(1), 55-64. doi:http://dx.doi.org/10.1016/j.renene.2007.03.006.

[21] Petersen, E. L., Mortensen, N. G., Landberg, L., Højstrup, J., & Frank, H. P. (1998). Wind power meteorology. Part I: climate and turbulence. *Wind Energy, 1*(1), 2-22. doi:10.1002/(SICI)1099-1824(199809)1:1<2::AID-WE15>3.0.CO;2-Y.

[22] Schallenberg-Rodriguez, J. (2013). A methodological review to estimate techno-economical wind energy production. *Renewable and Sustainable Energy Reviews, 21*, 272-287. doi:http://dx.doi.org/10.1016/j.rser.2012.12.032.

[23] Fox, N. I. (2011). A tall tower study of Missouri winds. *Renewable Energy, 36*(1), 330-337. doi:http://dx.doi.org/10.1016/j.renene.2010.06.047.

[24] Carvalho, D., Rocha, A., & Gómez-Gesteira, M. (2012). *Ocean surface wind simulation forced by different reanalyses: Comparison with observed data along the Iberian Peninsula coast* (Vol. 56).

[25] Tahir, Z. R., Asim, M., Jamil, S., Shad, R., Hayat, N., Moaz, A., Safyan, M. (2018). Comparison of Reanalysis, Analysis and Forecast datasets with measured wind data for a Wind Power Project in Jhimpir, Pakistan. *Journal of Physics: Conference Series, 1102*, 012004. doi:10.1088/1742-6596/1102/1/012004.

[26] Tahir, Z. R., Sarfraz, M. S., Asim, M., Kamran, M. S., Imran, S., & Hayat, N.

(2018). Evaluation of ERA-Interim and NCEP-CFSR Reanalysis Datasets against in-situ Measured Wind Speed Data for Keti Bandar Port, Pakistan. *Journal of Physics: Conference Series, 1102*, 012001. doi:10.1088/1742-6596/1102/1/012001.

[27] Lun, I. Y., & Lam, J. C. (2000). A study of Weibull parameters using long-term wind observations. *Renewable Energy, 20*(2), 145-153.

[28] Carvalho, D., Rocha, A., Gómez-Gesteira, M., & Silva Santos, C. (2014). WRF wind simulation and wind energy production estimates forced by different reanalyses: Comparison with observed data for Portugal. *Applied Energy, 117*, 116-126. doi:http://dx.doi.org/10.1016/j.apenergy.2013.12.001.

[29] Carvalho, D., Rocha, A., Gómez-Gesteira, M., & Silva Santos, C. (2014). *Offshore wind energy resource simulation forced by different reanalyses: Comparison with observed data in the Iberian Peninsula* (Vol. 134).

[30] Staffell, I., & Pfenninger, S. (2016). Using bias-corrected reanalysis to simulate current and future wind power output. *Energy, 114,* 1224-1239.

[31] Carvalho, D., Rocha, A., Gómez-Gesteira, M., & Santos, C. S. (2014). Comparison of reanalyzed, analyzed, satellite-retrieved and NWP modelled winds with buoy data along the Iberian Peninsula coast. *Remote sensing of environment, 152*, 480-492.

[32] Miinalainen, T. (2017). An evaluation of wind indices for KVT Meso, MERRA and MERRA2: Comparison for 4 met stations in Norway.