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لشراء الطاقة والمياه
POWER & WATER PROCUREMENT

PWP's Wind Resource Assessment

Wind Resource Data Collection and Analyses

Contents

1. Glossary

Agl	Above ground level
IPP	Independent Power Plant
kPa	Kilopascal
KPIs	Key Performance Indicators
m/s	Meters per second
mbar	Millibar
MET Mast	Tower carrying meteorological instruments
MW	Megawatt
O&M	Operations and Maintenance
NWS	Nama Water Services
PWP	Nama Power and Water Procurement Company SAOC
PAW	Public Authority for Water
Project Area(s)	Locations shortlisted and included as part of the WRA campaign
RE	Renewable Energy
SEZAD	Special Economic Zone Authority at Duqm
TBD	To be defined
The Study	Refers to the Wind Atlas Report as prepared by the PAW in 2015
V	Volt
W/m^2	Watt per square meter
WRA	Wind Resource Assessment

2. Introduction & Background

The Government of Oman adopted a fuel diversification policy in 2017 aimed at enhancing national energy security and promoting economic growth. As of 2024, majority of the power plants contracted by Nama Power and Water Procurement Company SAOC (PWP) use natural gas as their primary fuel, however, the fuel diversification policy requires that by 2030, at least 30% of demand is met through renewable energy sources. A key objective of this policy is to release domestic gas committed to the power sector, to be available to stimulate industrial and economic development. PWP has embraced this policy and has prepared a development plan to achieve the target, which is then updated annually and reflected in PWP's 7 Year Statement publications.

In-line with this policy decision, PWP commenced a detailed Wind Resource Assessment (WRA) in the Sultanate of Oman; which includes the installation of wind masts across a number of pre-defined sites. PWP recognizes that a robust and detailed WRA aims to quantify wind resource potential which is not only determine the financial viability of a specific wind project, but to also assist in mapping wind resources for the country. Through the WRA, PWP intends to collect and make available a bankable set of wind data to support the future development of wind power. This data will be published on PWP's website, in addition to being shared directly with interested developers during the procurement activities for a utility-scale wind power project. By undertaking this activity on behalf of project companies/developers and well in advance of the initiation of the procurement activities for wind IPPs, PWP aims to provide a clear and accurate representation of wind resources at key wind-sites in Oman.

The scope of the WRA is to cover six different locations (Project Areas) over three phases up to date, with two Project Areas per phase. The data to be collected is expected to provide a representation of the wind resource characteristics at each Project Area. The WRA is expected to be carried out over a period of 4 years, such that at least 12 consecutive months of wind resource data is collected from each Project Area. As per industrial best practices, this is the minimum amount of data to be collected prior to moving to the next step of the development phase for a wind power project. That said, PWP reserves the right to extend the data collection period if anomalies, inconsistencies, or inaccuracies are discovered in the collected dataset.

The measurement of required data-points is expected to be carried out through a number of sensory equipment that measure various ambient and meteorological conditions, installed at various heights on the stations. Several supporting systems are also installed to provide, at a minimum, data storage/archiving, remote communication for data transmission, on-site electrical generation, and on-site security.

A total of four monitoring stations were procured and installed at Area 1 and 2 during the first phase of the WRA. The same monitoring stations have been installed at Area 3 and 4 for the second phase. In the end of 2023, the monitoring stations were moved at Area 5 and 6. With that being said, PWP may procure additional stations if needed for future phases to ensure that data collected is representative of the entire Project Area.

Along with this publication, PWP published the validated data that has been obtained from the wind monitoring stations of phase I and phase II as well as all the details regarding the equipment used to obtain the data shown and PWP intends to continue publishing the validated data from the wind monitoring stations of phase III. The objective of this publication is to offer the opportunity for all parties that are interested in future wind power projects in the Sultanate of Oman, whether for development, investment, or other purposes to receive an update of data collection progress and to allow for further analysis and interpretation of the data.

3. Site Study Selection and Results

The pre-feasibility study, known as the Wind Atlas Study (The Study), was led by the former Public Authority for Water (PAW) currently known as Nama Water Services (NWS) and was finalized in 2015. One of the objectives of the Study was to identify and rank a number of potential Project Areas based on a weighted selection criteria. This selection criteria consisted of a number of parameters to determine the preferential ranking of each Project Area, and included topographical, social, environmental, and proximity of the Project Area to the national electricity grid. From a wind-resource perspective, the following key factors/parameters were key in determining the overall potential for wind power production: wind speed, wind direction, temperature, humidity, air pressure, potential annual energy production, and the cost of energy for wind power generation.

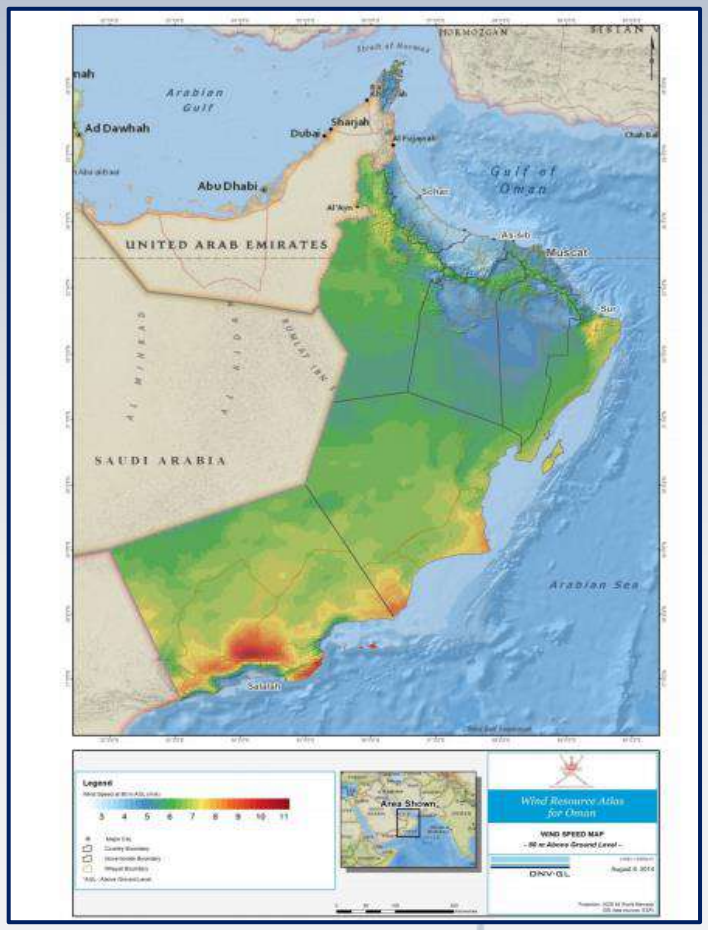

Figure 1: Estimated wind speeds for Oman at (80m agl)

The outcome of the Wind Atlas Report recommended at least seven (7) Project Areas to be investigated further for the future development of wind power projects in Oman. This WRA is currently focused on the following six Project Areas, but may be extended in the future to include more potential area, subject to approvals and permits:

- Project Area 1: Jaalan Bani Bu Ali
- Project Area 2: Duqm 1 (SEZAD)
- Project Area 3: Ras Madrakah
- Project Area 4: Sadah
- Project Area 5: Ras Madrakah (new)
- Project Area 6: Mahoot

4. Wind Stations & Monitoring Equipment

4.1 Locations

A total of four monitoring stations were procured for Phase I, with two monitoring stations installed per Project Area and similar case were applied for the second phase. At the time of writing this report the four monitoring stations have been relocated from Area 3 and 4 into Area 5 and 6 for the third phase of WRA.

Table 1: Different potential locations for the WRA

Phase	Project Areas Studied	Proposed Sites	Min. Potential Wind Capacity	Indicative Data Collection Period (12 Consecutive Months)
Phase I	Project Area 1	Jalan Bani Bu Ali	100 MW	Feb 2020 – Feb 2021
	Project Area 2	Duqm 1 (SEZAD)	200 MW	Feb 2020 – Feb 2021
Phase II	Project Area 3	Ras Madrakah	200 MW	Nov 2021 – Nov 2022
	Project Area 4	Sadah	100 MW	Nov 2021 – Nov 2022
Phase III	Project Area 5	Ras Madrakah	200 MW	Nov 2023 – Nov 2024 (expected)
	Project Area 6	Mahoot	350 MW	Dec 2023 – Dec 2024 (expected)

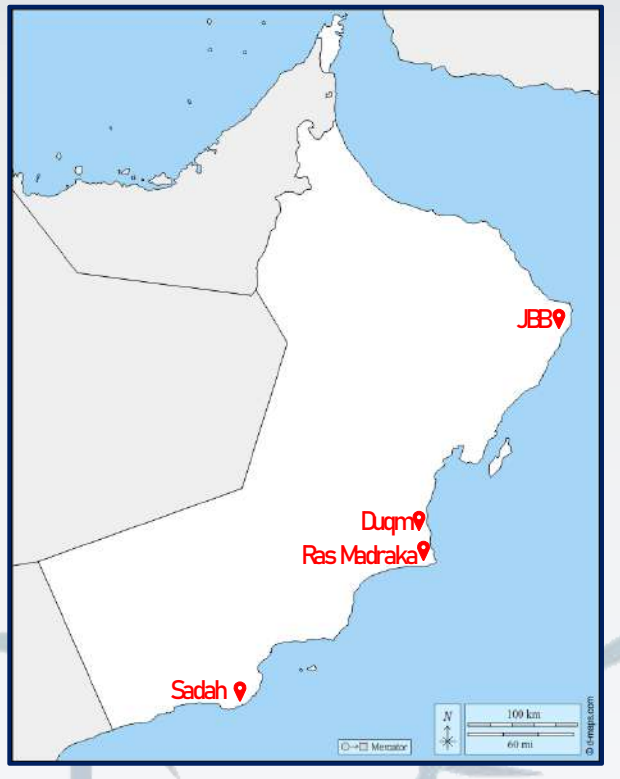

Figure 2: Geographical map for the inductive project areas in Table 1

[1] The final capacity for each project will be determined based on the wind resource assessment

4.2 MET Mast Stations

The MET masts are based on lattice towers and constructed to a height of 100 meters. These guyed structures are designed to be highly resilient, optimized for meteorological applications, and easy to assemble, and do not require significant excavation or civil works. Each tower has been secured using 9 anchor points per tower, at 120° angles, and is sufficiently rugged to ensure the safety of operators and maintenance personnel tasked with climbing the structure. Mast coordinates details for phase I (Duqm & Jalan Bani Bu Ali), phase II (Ras Madraka & Sadah), and phase III (Ras Madraka New & Mahoot) are shown below.

Table 2: Mast Co-ordinates Details for Phase I , Phase II, and Phase III

Mast Name	Tower Type & Height (m)	Zone	X coordinate (m)	Y coordinate (m)	Latitude (WGS 84)	Longitude (WGS 84)	Elevation(m)
Phase 1							
Duqm-1	Lattice – 100 m	40 Q	538966	2154144	19.481465°	57.371303°	179
Duqm-2	Lattice - 100m	UTM zones go from 1-60	546138	2153174	19.472546°	57.439619°	178
Jalan-1	Lattice - 100m	UTM zones go from 1-60	753980	2445518	22.096108°	59.461665°	78
Jalan-2	Lattice - 100m	UTM zones go from 1-60	755669	2443192	22.074866°	59.477657°	48
Phase 2							
Ras Madraka-1	Lattice - 100m	40 Q	572085	2104017	19.027556°	57.684994°	65
Ras Madraka-2	Lattice - 100m	40 Q	576627	2106878	19.053246°	57.728265°	103
Sadah-1	Lattice - 100m	40 Q	297397	1892223	17.105558°	55.095832°	61
Sadah-2	Lattice - 100m	40 Q	572085	2104017	19.027556°	57.684994°	56
Phase 3							
Ras Madraka-New 1	Lattice - 100m	40Q	581759	2103952	19.026605°	57.776913°	116
Ras Madraka-2	Lattice - 100m	40Q	575617	2106883	19.053329°	57.718666°	83
Mahoot-North	Lattice - 100m	40Q	579600	2222272	20.095869°	57.761401°	108
Mahoot-South	Lattice - 100m	40Q	574951	2217576	20.053623°	57.716742°	112

Figure 3: Installation of Anchors

4.3 Instruments

Several sensors were installed in each tower, each one has a specific purpose and function. A brief description of each of these can be found as per the following:

1. **Datalogger:** Each station contains a single datalogger installed at a height of 15m. Dataloggers are electronic devices that are connected to all other instruments and consolidate measurements. This allows the stations to monitor and record environmental parameters over time, ensuring conditions are measured, documented, analysed and validated. The datalogger is also connected to a modem that allows for remote access to the site and the data.

2. **Anemometer:** There are a total of four anemometers installed in each tower, such that two are located at 100m height, and the other two are placed at heights of 80m & 60m respectively. Anemometers are instruments that measure the speed of the wind using a relatively simplistic approach of measuring/counting number of revolutions the reference cup makes around the axis.

3. **Wind vane:** A total of 2 wind vanes, measuring wind direction, are installed in each tower at heights of 97m and 80m respectively.

4. **Pyranometer**: One pyranometer is installed at each of the MET masts at a height of 15m. These sensors measure solar irradiance from a hemispherical field of view incident on a flat surface.

Table 3 List of instruments installed in the stations

Instrument	Manufacturer	Model	Qty per Monitoring Station
Data Logger	Kintech	EOL Zenith	1
Anemometer	Thies	FCAd	4
Wind Vane	Thies	Compact TMR	3
Temperature and Humidity	Galltec	KPC	2
Pressure Sensor	Kintech	K611p-B	1
Pyranometer	Hukseflux	SR11	1

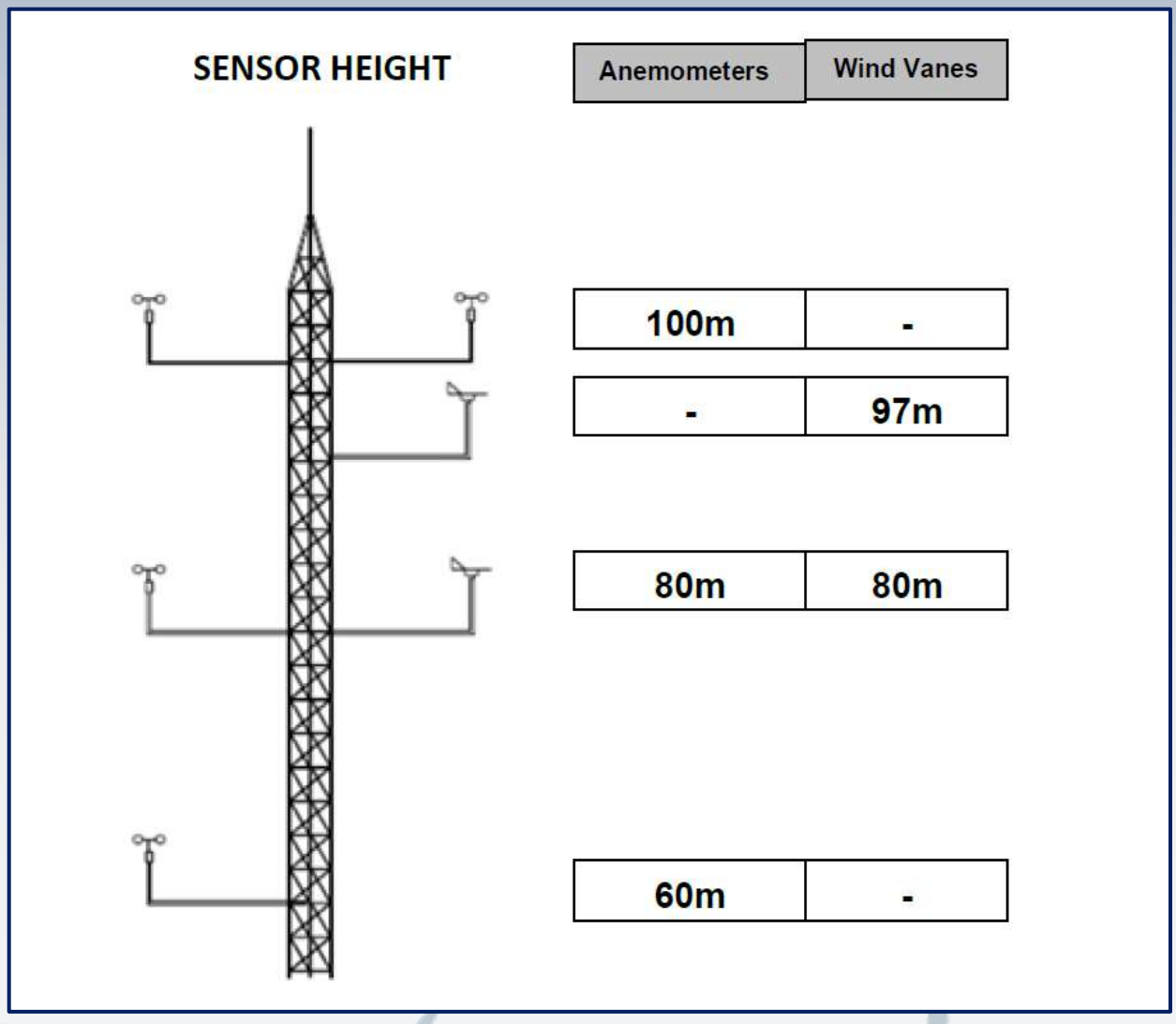

Figure 4: Sensor's heights

5. Data Validation Methodology

The data validation methodology which has been used to validate the data collected during the wind resource measurement campaign is "Measent evaluation of site- specific wind conditions" version 2, April 2016. With the data validation methodology, PWP ensures that data published and is used for further analytics are free from errors and is deemed reliable. This also enables PWP to detect any failure with the sensors installed in the stations. The validation methodology adopts a two-step approach, where:

- First, a series of validation routines and algorithms are used to automatically screen all measured data for questionable and erroneous values. The result of these automated checks is a list of measurement values, where some have been flagged for further screening and assessment.
- Second, a qualified wind engineer will conduct a visual inspection of measurement data and review the flagged values raised via the automated routines/algorithms.

A one-year of data collection is planned in the base contract with the option of extending this period for an additional year if required.

5.1 Automated data validation

This section of the report will describe the different checks and tests carried out on the collected wind measurement data. These include:

1. Data completeness
2. Range tests
3. Relational tests
4. Trend tests
5. Constant value tests
6. Tower shadowing
7. Related parameter tests.

Data that breach the above tests are assigned a specific code and are flagged during this process; where it will also show if the data is completed and reasonable to be used.

5.1.1 Check for data completeness

Two tests are used to evaluate the completeness of the collected data as outlined in Table 4.

Table 4: Check for data completeness

Type of check	Description
Number of data records	The number of data fields must equal the expected number of measured parameters for each record
Time sequence	The time and date stamp of each data record is examined to see if there are any missing or out-of-sequence data.

5.1.2 Range tests

This test is carried out by comparing the measured data to allowable upper and lower limiting values. The range test criteria are provided in Table 5.

Table 5: Range tests criteria

Parameter	Interval	Range validation criteria
Wind Speed*	10-min-average	The feasible range for 10-minute average wind speeds is from zero (or the anemometer offset) to 50 m/s. Any values that fall below the anemometer offset is flagged; speeds above 50 m/s are possible, but it will be pointed for manual review.
	10-min-standard deviation**	0 < Std.Dev. < 5 m/s
Wind Direction	10-min-average	0° < Avg. < 360°
	10-min-standard deviation**	0° < Std.Dev. < 75°. Any values that fall outside the given value and the average windspeed value above 4m/s is flagged. Since direction is unstable in calm windspeeds.
Temperature range*	10-min-average	0° C< Avg. < 50° C
Barometric Pressure*	10-min-average	85 kPa < Avg. < 120 kPa 850 mbar < Avg < 1200 mbar
Humidity	10-min-average	0 to 100%
Pyranometer	10-min-average	Global Horizontal irradiation -15 < Avg. < 1400 W/m²
Pyrheliometer	10-min-average	Direct normal irradiation ranges 0 < Avg. < 1400 W/m²
	10-min-average	Diffuse horizontal irradiation 0 < Avg. < 800 W/m²
Battery	10 -min-average	>= 11.7 volt

Beacon battery	10 -min-average	>=22.5 volt (If Beacon battery falls below this range, the power supply for obstructions lights will be stopped.
Obstruct light (32cndl)	10-min-average	>0 Volt (If obstruction light voltage equal to or below 0, it point to malfunction in the obstruction light).
Note: If any of the parameters fall outside the given ranges, the data point will be flagged for manual review process . *These ranges are based on the long term reference data (ERA[1]). ** Since the raw data contains only 3 decimal point we also round of the standard deviation value to three decimal points and will follow the both the conditions Condition 1 :if standard deviation is 0 Consition 2: we will check and minimum and maximum of those samples(Average signal), if it is equal then we will flag it.		

The limits of each range test have been set so they span nearly the full range of plausible values for the site. In addition, the limits may be adjusted seasonally, where applicable.

5.1.3 Relational tests

This comparison is based on relationships between selected measured parameters. Relational check is done to ensure that sensors that measure similar parameters, though at different heights, follow a reasonable relationship.

Table 6: Relational tests criteria

Parameters	Interval	Relation validation criteria
Wind Speed – Same height	10-min-average	The average difference in wind speed between two anemometers at the same level in the same met mast should not exceed 0.5 m/s, unless already flagged for tower shadow. Please refer for more information about tower shadow flagging in section 5.1.6).
Wind Speed difference with respect to different measurement heights.	10-min-average	Average difference between anemometers located at 20 meters vertical distance should be below 3 m/s.
Wind Direction difference with respect to different measurement heights.	10-min-average	The difference between the wind vane at 97m and 80m should be below 20^{o} except during periods with wind Speed ≤ 3 m/s)

5.1.4 Trend tests

Trend checks are based on the rate of change in value over time. Table 7 lists the trend test criteria.

Table 7: Trend tests criteria

Parameters	Trend validation criteria
Average Wind Speed changes in 1 hour	<5 m/s
Average Temperature changes in 1 hour	≤ 5°C
Average Barometric Pressure change in 3 hours	≤1kPa

5.1.5 Constant value test

Repetitions of consecutive wind data with the same values (actual values from the data logger is considered without rounding) will be flagged for potential sensor failure. The 10-minute average values of wind speed and direction should not show more than three consecutive constant repetitions. For pyranometer, consecutive irradiation should not occur more than three hours in the daytime (6.00 am to 6.00 pm).

5.1.6 Tower Shadow flagging

Tower shadows is flagged when an anemometer is located downwind of the tower. For example, with the boom direction Northwest (300^{o}), the wind from 105^{o} to 135^{o} would be flagged. Before applying this condition, the direction of peak shadow and the width of the shaded zone by plotting the ratio of speeds between two redundant anemometers would be verified.

5.1.7 Related parameter test

Comparison based on the expected values for the physical relationships between the different parameters (e.g. V min ≤ V mean ≤ V max). If one data value is assessed as erroneous all related quantities will be rejected. For example, if the mean wind speed value is deemed invalid, the wind speed standard deviation, as well as maximum and minimum, are also to be considered as invalid.

5.2 Manual review of data

A visual inspection for the data and reports will be applied using the time series graph after the automated validation process is being completed. This process will be done by a qualified wind engineer/ analyst to investigate the flagged set of values. The flagged data may be allowed to be passed through to the final published dataset as the suspected values might reflect real weather conditions and not necessarily sensor or logger issues which should be excluded. This process will be initialized by a number of steps which are as follows:

1) Comparing the data sets with available closest stations,
2) the study of the meteorological condition of mast location occurring around the time of suspected observations.

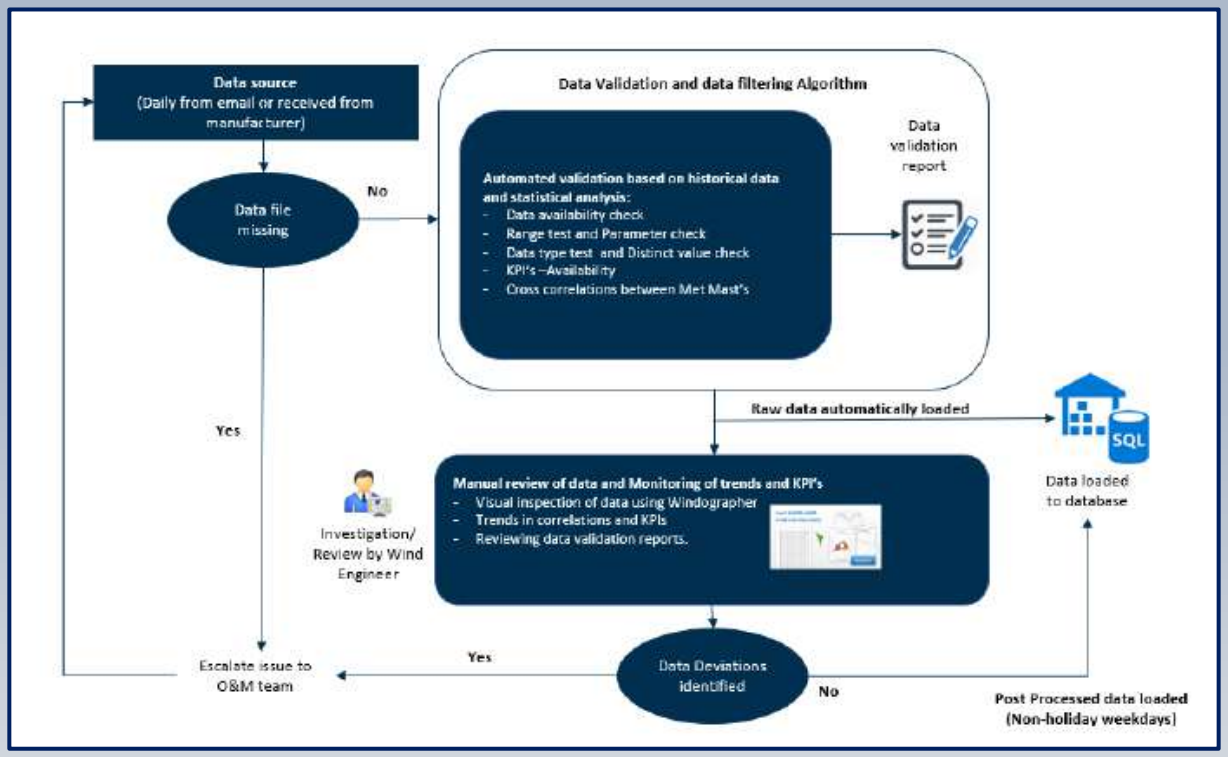

Figure 5: ***Overall work-flow model***

6. What's Next

- Potential Phase IV of the Wind Resource Assessment: PWP wishes to explore the opportunity to further sites which are subject to the site availability and the need of wind IPP projects.
- PWP use of the data to run a feasibility study to advise on and guide the future development of wind power projects in Sultanate of Oman.

7. References

- Data Logger User Manual EOL Zenith: https://www.kintech-engineering.com/pdf_docs/EN_EOL_Zenith_Brochure.pdf
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