Republic of the Marshall Islands Energy Future

Electricity Roadmap

Technical Note 01:
Wind Energy in RMI

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Elemental
Power & Renewables

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Summary

This technical note has been undertaken to investigate the viability of utilising wind power in the RMI.

A windspeed dataset was developed at ten-minute and hourly average resolution, for one full year, for use in techno-economic HOMER modelling for Ebeye and Majuro. The dataset was developed from measured windspeeds on Jaluit (mean wind speed of 6.8 m/s), considered likely to be lower than Majuro and very likely lower than Ebeye. Using this dataset, assumed to be conservative, it was found wind energy in RMI is potentially the least cost form of generation and could provide a significant portion of the energy generation in Majuro and Ebeye. NREL separately reports that there is a mean wind speed of 7.8 m/s at 50 m near Ebeye, confirming that there is a good wind resource for Ebeye.

Majuro and Ebeye are not considered to be particularly prone to experiencing damaging extreme winds such as are experienced during the most powerful Tropical Cyclones. Therefore, it may be practical and cost-effective to specify larger, more productive turbines. Smaller wind turbines from manufacturers such as Vergnet, Xant, Windflow and Enercon have been considered in this note.

Suitable sites for sufficient wind power capacity may need to be located on reef flats as securing land-based sites is expected to be challenging on both islands.

The findings of our initial modelling show that, from an economic perspective, the use of wind should be maximised. The modelling shows wind energy to be the least cost form of generation and effectively delays the need for load-shifting storage. It should be noted that further wind generation capacity is expected to be practical in both locations.

It is recommended in particular that wind resource monitoring be implemented in Majuro, close to a proposed wind energy project site. LiDAR monitoring may be easier to implement than installing a tall wind monitoring mast. This would reduce the uncertainties in the wind resource in Majuro that currently exist.

Key issues also include social acceptance (and therefore access to potential sites) and the availability and cost of equipment for installation (e.g. cranes).

1 Background / Introduction

The *Majuro Power Network Strengthening* report [1], funded by the ADB, presented energy modelling for Majuro using HOMER software. The report presents a case for addition of 2.2 MW of wind turbines in the Majuro power system in order to achieve 40% renewable energy contribution at the lowest level of capital investment. The report however did not recommend that wind should be part of the generation mix to achieve 20% renewable energy contribution.

Wind energy was therefore considered in this Technical Note for Majuro and Ebeye where larger, typically more cost-effective turbines could potentially be used. In the smaller islands, with a seasonal wind resource and where RE penetration is proposed to be 90% or more, wind turbines are unlikely to be cost-effective compared to solar PV.

2 Turbine Siting

Wind turbines have a small footprint. However, in order to preserve amenity values with regard to noise levels, it is suggested that turbines should be located at least 300 m away from any inhabited dwellings. The noise level depends strongly on the type of turbine considered, however a noise level in the range of 40 to 45 dB might be anticipated at that distance (Figure 1).

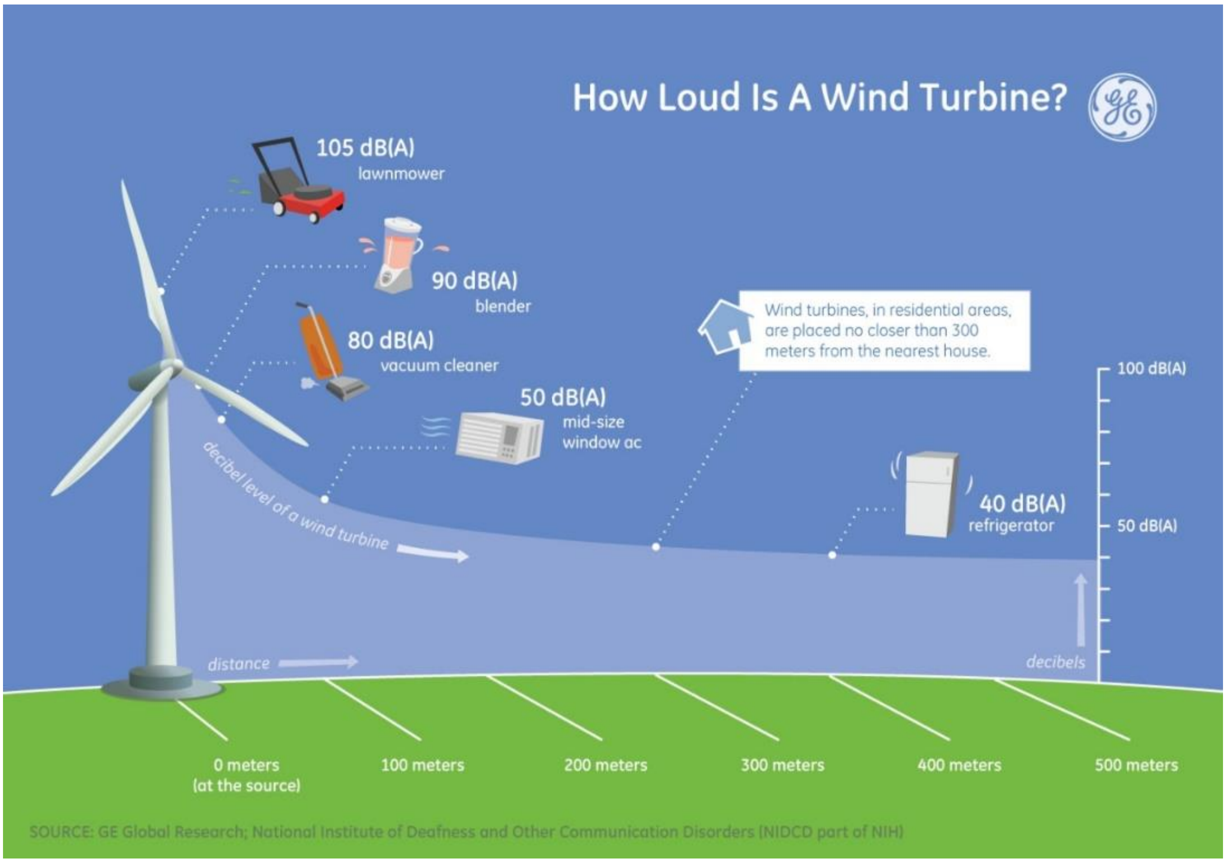

Figure 1 Wind turbine noise levels (source: GE)

The noise level at a receptor is strongly affected by the wind direction. With the strong predominance of winds from the east-northeast in RMI, particular care should be taken in the planning process to site turbines where there are no nearby inhabited dwellings to the west-southwest. Background noise, due to surf, wind in trees, traffic on roads, etc., has a mitigation effect on a wind energy project as it acts to mask noise generated by turbines.

The impact on visual amenity due to wind turbines has not been assessed however this should be considered in the planning process. Visual influence can be in the form of a direct view of turbines, but also in the form of shadow flicker in which the moving blades of the wind turbine pass between the sun and a receptor. At the low latitudes of RMI the shadow flicker is expected to be relatively minor, however it should be assessed.

Another siting issue is the potential for interference with radar. Any potential for impact on radar should be investigated, particularly for a development in Ebeye as the US Army has radar facilities at the base which is 6 km to the south.

Micro-siting of turbines to ensure adequate wind resource is considered to be less of an issue in the Marshall Islands than in many other places, as the islands experience oceanic weather and there are no hills to cause wind shadows. Possible effects from tall vegetation should be considered.

Spacing requirements between wind turbines are typically in the order of 7 rotor diameters in the predominant wind direction and 3 rotor diameters perpendicular to the predominant wind direction. These requirements are to mitigate energy production losses due to inter-turbine wakes and to mitigate wake-induced wind loads. Rotor diameters of turbines considered range between 32 m and 53 m.

Wind energy project design and planning software (for example: EMD windPRO) should be used to analyse these planning issues and predict the project's energy production.

2.1 Majuro Sites

There is no consideration of suitable locations for installing wind turbines in the ADB report. As Majuro has complex land issues, innovative solutions for wind turbine installation locations are required. Two options that have been proposed are:

a. On other islands of the atoll (which are accessible by reef flat at low tide); and
b. On the reef flats.

Several small islands extend from Rita in the north of Majuro towards the west (Figure 2). These include Ejit which is relatively densely populated and four others that are sparsely populated. Due to the noise and spacing requirements described, there may be sufficient sites for four or five 500 kW turbines with a 45 m rotor diameter, however this may require special consideration of the impact on a few isolated dwellings. Wind speed and direction-based curtailment may be possible to mitigate noise impact in infrequent wind directions.

Figure 2 Northern Majuro and islands including Ejit

The reef flats on the ocean side exceed 200 m in width in places on the east-facing side of Majuro atoll between Uliga in the south and Rita in the north, a distance of approximately 4 km. However, this is also a densely populated area meaning that siting would need to be careful to keep sufficient distance away from noise sensitive locations and to preserve amenity values.

Turbine foundations could be installed on platforms constructed on the reef flat (which is currently exposed to shallow sea water and light surf at high tide). Additional costs should therefore be anticipated. Accessibility for installation and maintenance will also be reduced compared to an onshore location. Corrosion conditions will be extremely demanding due to the tropical temperature, humidity and windward surf spray zone location.

Figure 3 Reef flats on the ocean side adjacent to the College of the Marshall Islands (CMI)

The reef flats on the lagoon side exceed 400 m in width in places. Candidate sites include the area shown in Figure 4 below, which shows approximate spacing requirements for turbine capacity totalling in excess of 3 MW, located approximately 7 km west of the airport. Lagoon side siting would be slightly less challenging than ocean side in terms of proximity to noise sensitive locations, the generally calmer water state, and the somewhat less extreme sea-spray corrosion conditions.

Figure 4 Reef flats within Majuro lagoon showing indicative turbine spacing requirements

Environmental impact on the reef would need to be considered. PII (a local construction contractor) has indicated that installation on the reef flats would be relatively straightforward. However a detailed structural assessment of the reef would be required to withstand the dynamic loads that wind turbines deliver. It is anticipated that platforms would be built for the foundations to be installed with the tower base above high tide level.

A potential issue with this site is the proximity of dwellings downwind of turbine sites that might be affected by noise levels in excess of common recommendations, however noise levels may be mitigated by the presence of background noise. Studies would be required.

PII has indicated that it has a 250T crane and a 100T crane on Majuro. The 100T crane has a 150-foot boom but would need to be rigged for height. PII also has a 1,000T jack-up barge which could be useful for reef flat installations.

2.2 Ebeye Sites

The World Bank RMI Renewable Energy Project Options Report [2] proposed the use of the reef flats on the lagoon side of the existing causeway north of Ebeye for a solar PV installation. This location, pictured in Figure 5 and located as shown in Figure 6 would also be well suited for wind turbines as it is well-oriented to receive unobstructed wind from the predominant east-northeast direction. This site would also mitigate the risk around land acquisition. Required distances from dwellings (to limit noise at receptors) should be achievable for in excess of 2.5 MW of wind turbine capacity.

Further up the chain of small islands north of Ebeye there are other onshore and reef flat locations for more wind capacity than could be utilised in Ebeye. Onshore sites are expected to be cheaper however they may be subject to risks around land acquisition. It should be noted that the footprint of a wind turbine is very small.

The largest crane available on Ebeye is thought to be a 40T crane. Therefore for larger turbines it is likely that a larger crane would need to be shipped in from Majuro or elsewhere. An arrangement may be possible to barge a suitable size crane to Ebeye from USAKA, although it is not known what capacity crane may be available.

(Source: IT Power) [2]

Figure 5 Potential site for wind turbines in Ebeye

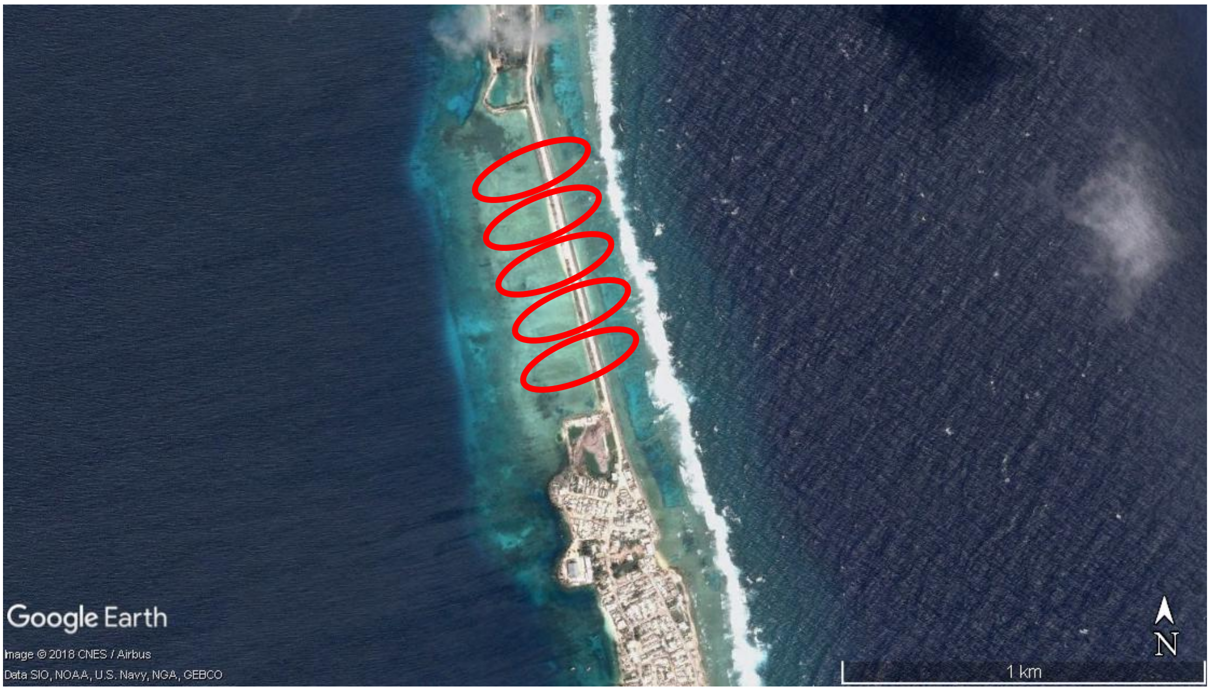

Figure 6 Potential location for wind turbines in Ebeye showing turbine spacing requirements

3 Wind Resource

The World Bank Global Wind Atlas [3] indicates mean wind speeds at 50m height (estimated from Figure 7) that are somewhat lower than were monitored in Jaluit and Wotje during 2012 and 2013. However the relationship between the Global Atlas wind speeds and the monitored wind speeds presented in Table 1 adds confidence in the assessment that use of the wind data monitored on Jaluit would be a suitable (but conservative) approach to estimating wind resource in both Majuro and Ebeye in the absence of having monitored data in those locations. It is considered likely that the wind resource in Majuro and in Ebeye is higher than in Jaluit, particularly in Ebeye which is significantly further north. It is also clear that the predominant wind direction is from the east-northeast.

It is recommended in particular that wind resource monitoring be implemented in Majuro, close to a proposed wind energy project site. LiDAR monitoring may be easier to implement than installing a tall wind monitoring mast. This would reduce the uncertainties in the wind resource in Majuro that currently exist.

Table 1 Predicted annual mean wind speeds at locations in RMI

Location	Coordinates	Global Atlas wind speed prediction @ 50m (m/s)	Monitored wind speed prediction @ 34m (m/s)[1]
Jaluit wind monitoring mast (34m)	5.92°N, 169.64°E	5.25	6.8[2]
Wotje wind monitoring mast (34m)	9.465°N, 170.238°E	6.75	8.4[3]
Majuro site	7.067°N, 171.201°E	6.00	-
Ebeye site	8.793°N, 167.735°E	6.25	-

[1] Central estimate based on one year of processed data. Note that annual variability of mean wind speed is in the order of 6% and that additional uncertainties are introduced through data processing and monitoring.
[2] Calculated based on a combination of data monitored at Jaluit and synthesised through correlation with data monitored at Wotje.
[3] Prediction using "mean of monthly means" method, assuming that valid data during September 2012 and August 2013 are representative of the missing data during those months.

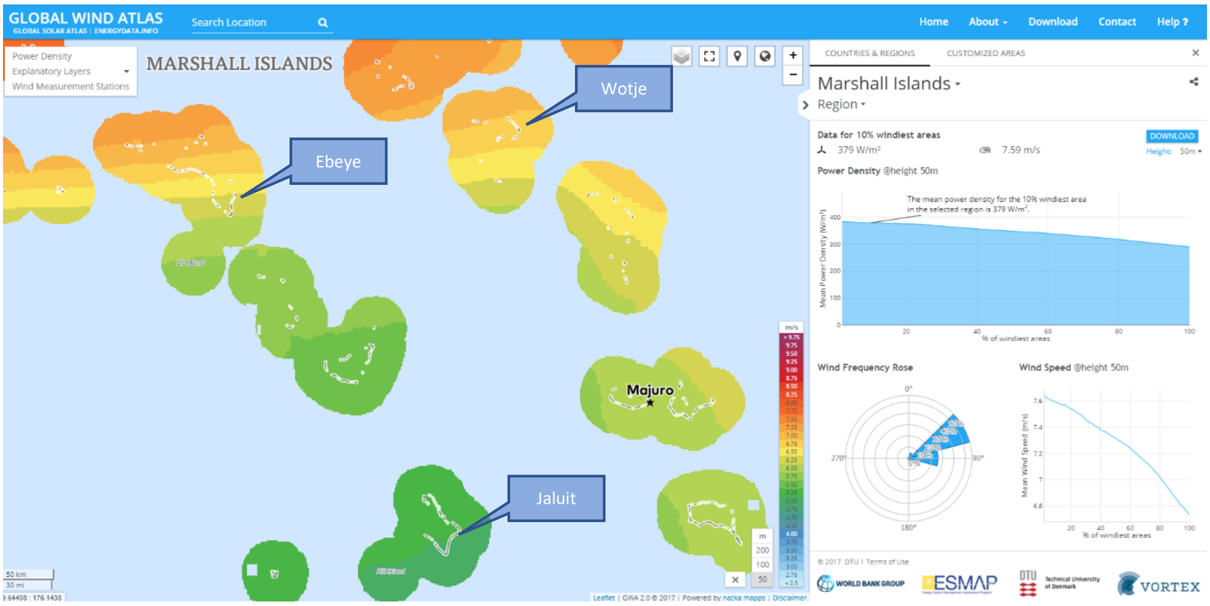

Figure 7 World Bank Global Wind Atlas

Less than 82% of a year of monitored data is available at Jaluit. Since at least one complete year is desirable to remove any seasonal effect from the characterisation of the wind resource a correlation-synthesis approach was used with data monitored at Wotje to fill the missing period. Hourly and daily correlations were investigated but only the monthly correlation was found to be sufficiently well-correlated to infer a relationship with some confidence (see Figure 8).

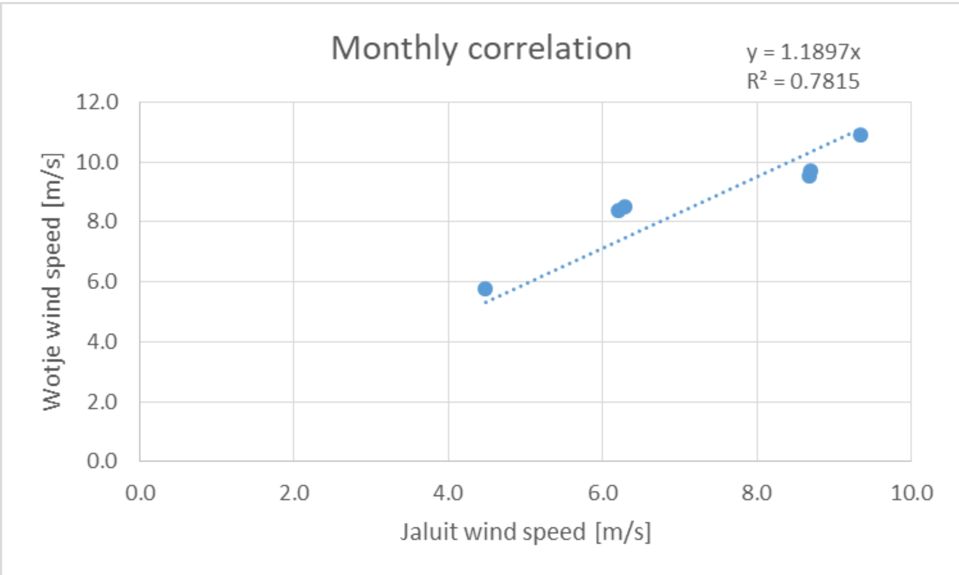

Figure 8 Monthly correlation of wind speed between monitored data at Jaluit and Wotje

The resulting combined monitored and synthesised dataset at Jaluit shows a marked seasonal variation as shown in Figure 9. However, the wind resource is considered to be poor for only three to four months out of the year.

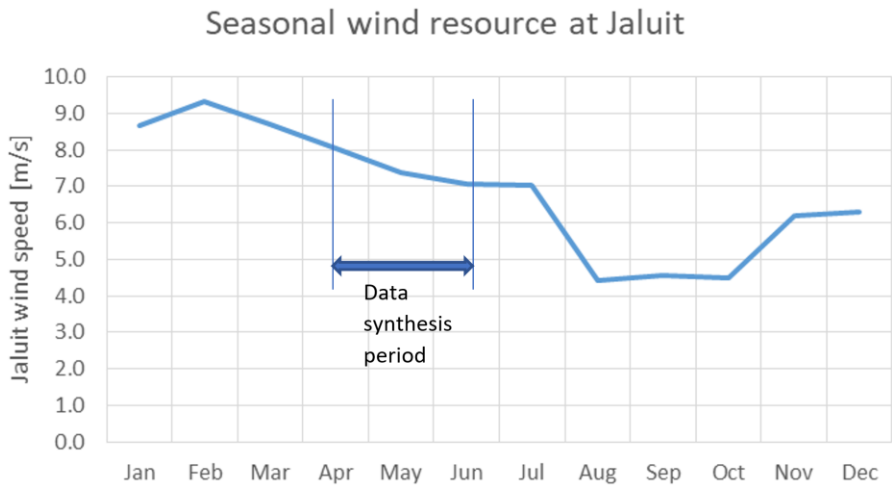

Figure 9 Seasonal variation of monthly average wind resource in RMI

Applying the monitored wind shear exponent of 0.085 to the predicted mean wind speed of 6.8 m/s at 34 m height results in an estimate of 7.0 m/s at a typical 50 m hub height. It is recommended that measurements on Majuro and Ebeye are obtained and correlated with long term reference data in order to improve confidence in this rough estimate. For the purposes of this brief study, a hub height mean wind speed of 7.0 m/s is considered. The frequency distribution and diurnal variation of the resulting dataset are shown below in Figure 10 and Figure 11 below. Note the lack of diurnal variation of the wind resource in comparison with the solar resource in Figure 11.

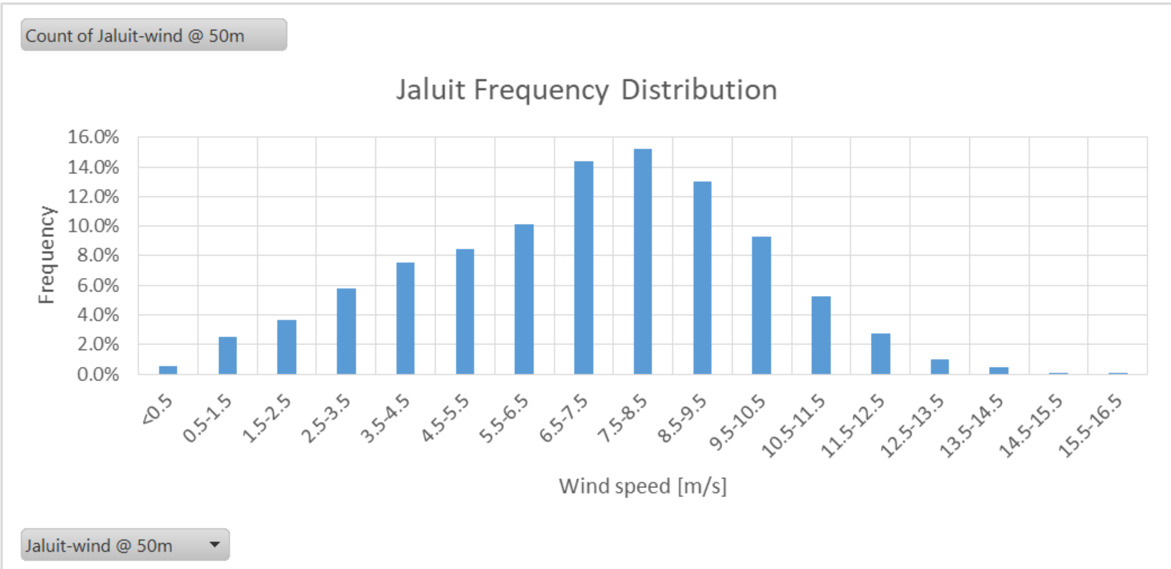

Figure 10 Predicted frequency distribution of wind resource at Jaluit at 50m

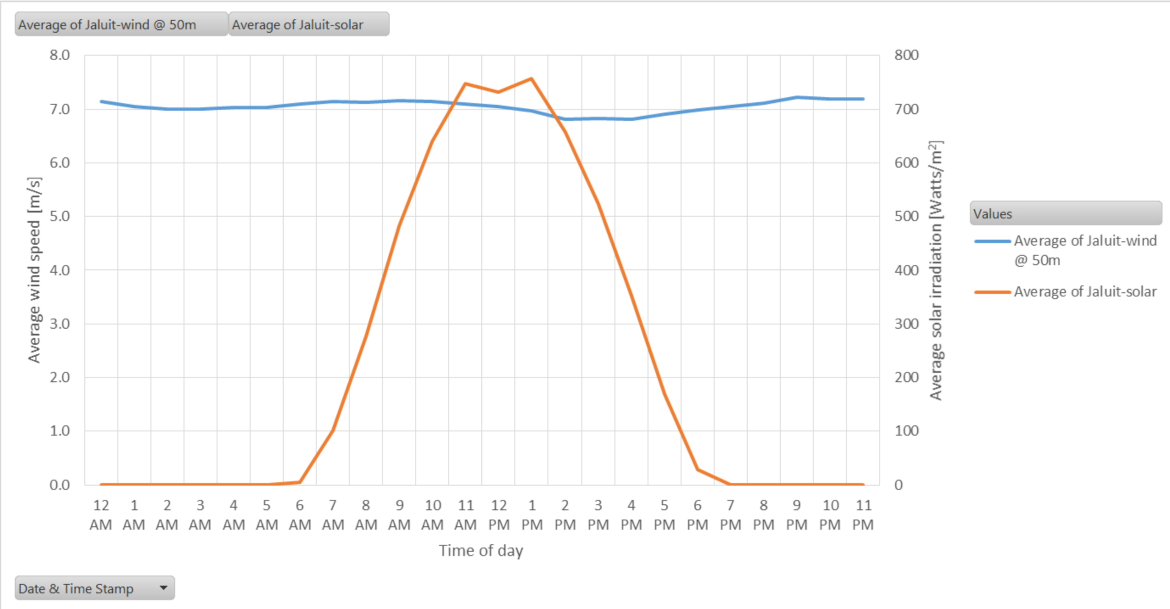

Figure 11 Diurnal variation of coincident wind and solar resource at Jaluit

The long-term NOAA dataset from Kwajalein station begins in May 2013. Unfortunately, it is not useful to adjust monitored data to the long-term as there is too little overlap with data recorded at Wotje and there is no overlap with data recorded at Jaluit. It is recommended that long-term wind resource predictions are undertaken using long-term reference data such as MERRA-2 data.

The expectation that Ebeye has a higher wind resource than Jaluit can now be supported by reference to a wind resource assessment [4] performed using a 60 m mast on Ennylabegan (Carlos) Island which is located approximately 13 km to the west of Ebeye, and which is expected to experience a practically identical wind climate. The wind speed presented by the report is 7.8 m/s at 50m above ground level. This wind resource is considered excellent, and therefore very suitable for a wind energy project for Ebeye.

4 Risk Assessment of Extreme Wind Speeds Predictions

In the approximately 10-month period of data monitored at Jaluit, the maximum recorded 3-second gust wind speed (at 34m) was 23.8 m/s. At this wind speed, most wind turbines will continue to operate and produce power.

The ADB report considered only the Vergnet GEV MP 275 kW. This turbine has been the turbine most commonly used in the Pacific Islands, primarily because it is a tilt-down “cyclone-proof” design. Majuro is not considered to be a particularly high-risk location for the most powerful categories of typhoon, however the 50-year return period cyclonic 3-second gust wind speed has been determined by Geoscience Australia’s PACCSAP program simulations to be 68.1 m/s [5]. It should be noted that this estimate is for wind speed over open, flat terrain at 10 m height and does not account for local factors such as terrain roughness, wind shielding effects and topographic acceleration. If a typical tropical cyclone wind shear exponent of 0.11 is used and a hub height of 50 m is assumed, a hub height, 3-second gust wind speed of 81.3 m/s can be calculated.

The World Bank funded Pacific Catastrophe Risk Assessment and Financing Initiative [6] suggests a maximum "sustained" (1-minute average) 100-year return period wind speed (at 10m height) of about 90 miles per hour (40 m/s). This can be converted to a 3-second gust using a factor of 1.11 [7] and adjusted to a 50m hub height to give a 100-year return period of approximately 53 m/s, considerably lower than that asserted by Geoscience Australia's PACCSAP program and within the survival limits of all turbines considered in this analysis (assuming the Vergnet turbine can be tilted down).

It may be considered whether designing to survive major tropical cyclone wind speeds is appropriate, or whether the risk should be mitigated via some form of insurance. Turbines can be designed to higher survival strengths but there is likely to be an energy penalty due to the use of shorter blades, or extra costs associated with tilt-down capability or special strengthening.

5 Turbine Selection

Turbine size is limited by what can be supplied by manufacturers and installed at reasonable cost. Larger, "utility-scale" turbines tend to have a higher energy production per kW capacity (Capacity Factor) and are typically more cost-effective on a $/MWh basis for equipment supply. However, in remote island countries such as the Marshall Islands this must be balanced against increased logistics, installation and balance of plant parts of the project that can dominate costs. Turbines from manufacturers that have expressed an interest in supplying to the Pacific Islands are summarised below in

Table 2.

Table 2 Selected wind turbine data

Turbine	Hub height(s) (m)	Heaviest lift (kg) / recommended crane	Estimated costs (US$/W) Supplied only / installed	Gross AEP (MWh) (7m/s @ hub height)	IEC Class / Survival wind speed (m/s)[4]
Vergnet GEV 275 kW	55, 60	9,000 / 25T and tilt-up	2.50 / 3.77	780	Class 2 to Class 4 / 36.9 to 52.3 m/s [7] (operating), 85 m/s (tilted-down)
Xant L 330 kW	38, 44, 50, 55	- / 25T and tilt-up	2.3 / 3.6	1,000	Class 1A / 70 m/s (can potentially tilt-down)
Komai Haltec KWT300 300 kW	41.5	18,000 / 160T (possible to reduce requirement to 60T)	- / -	740	Class 1A / 70 m/s
Windflow 45-500	31.5, 37, 48	20,400 / 160T (can also be lifted in 2 lifts with a lower capacity crane)	2.1 / 3.2	1,450	Class 2A / 60 m/s
Windflow 33-500	29, 39, 49	12,700 / 80T	- / -	940	Class 1A / 70 m/s
Enercon E53, 800 kW	50 to 73	- / 500T	- / -	2,594	Class 2A / 59.5 m/s (for 50m hub ht)
Enercon E48, 800 kW	50 to 75.6	- / 500T	- / -	2,300	Class 2A / 59.5 m/s
Enercon E44, 900 kW	45, 55	- / 500T	- / -	-	Class 1A / 70 m/s

[4] 3-second gust wind speed

In the ADB report Entura undertook HOMER modelling, considering only the Vergnet GEV ("cyclone-proof" wind turbine) with installed capacity of 275 kW. Equipment cost for the Vergnet GEV is estimated to be US$ 2.50 per Watt, and US$ 3.77 per Watt including installation for a project of a similar scale and in a similarly remote environment (based on a quantity of 8 wind turbines, or 2.2MW of installed capacity). Operational cost is assumed to be around $ 18,000 per turbine per annum. Turbine replacement is considered to be after 20 years.

The material cost of a Xant L 330 kW turbine is expected to be approximately US$ 750,000 or US$ 2.3 per Watt. A concrete-less foundation is being developed for the 330 kW turbine, however it is not thought to be available at this stage.

Equipment costs for the Windflow 45-500 wind turbine (based on 5 turbines delivered to site and including installation but excluding some balance of plant items) is expected to be approximately US$ 2.1 per Watt. The remainder of the works has been estimated to bring the cost to US$ 3.2 per Watt due to the more challenging logistics associated with the larger turbine. Maintenance costs are estimated to be approximately US$ 28,000 per turbine per year, typically for a term less than five years, during which time Windflow could train local staff to take over most maintenance work.

Equipment supply and installation costs for the Enercon turbines would require further project definition work to obtain. The requirement for a 500 tonne crane for turbine installation is likely to increase costs considerably.

Costs per kW of all these turbines and their installation are likely to be able to be reduced with a multiple turbine order. This can be investigated further as a project becomes more defined.

6 Conclusions and Recommendations

Analysis of available data has found that it is very likely that a sufficient wind resource exists (roughly 7.0 m/s average) for wind energy to be used cost-effectively in the two more populated islands, Ebeye and Majuro. It is strongly recommended that high-quality wind resource monitoring and analysis is undertaken for locations close to proposed wind turbine sites. Practically this would be easiest to achieve using LiDAR monitoring rather than a tall monitoring tower.

Wind energy in RMI is potentially the least cost form of generation and could provide a significant portion of the energy generation in Majuro and Ebeye.

Key steps to undertake to develop wind generation in RMI include:

- High quality wind resource and extreme wind analyses;
- Turbine siting studies;
- Grid integration and grid stability assessment;
- Social acceptance work and environmental impact studies;
- Assessment of availability and cost of equipment for installation; and
- Turbine manufacturers, balance of plant contractor and power utility coordination.

7 References

[1] David Procter, Dusan Nikolic, Geoff McDougal, Horst Kruse, Jayath Atukorala, Janybek Omorov, Tim O'Meara; TA-9225 RMI: Majuro Power Network Strengthening; Entura / Asian Development Bank (ADB), 1 March 2018.

[2] J McDonald; World Bank RMI Renewable Energy Project Options Report; IT Power; September 2016.

[3] Global Wind Atlas 2.0, a free, web-based application developed, owned and operated by the Technical University of Denmark (DTU) in partnership with the World Bank Group, utilizing data provided by Vortex, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalwindatlas.info

[4] Kwajalein Wind Resource Assessment, May 2015 - December 2017; Robi Robichaud, Dan Olis; NREL

[5] Siqueira,A.A.,Arthur, C.,& Woolf,M.2014. Evaluation of severe wind hazard from tropical cyclones - current and future climate simulations. Pacific-Australia Climate Change Science and Adaptation Planning Program. Record 2014/47. Geoscience Australia, Canberra.http://dx.doi.org/10.11636/Record.2014.047

[6] Pacific Catastrophe Risk Assessment And Financing Initiative; siteresources.worldbank.org/EXTDISASTER/Resources/MarshallIslands.pdf; September 2011.

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