Wind resource assessment and energy potential of selected locations in Fiji

Kunal K. Dayal^{1*}, John E. Cater², Michael J. Kingan¹, Gilles D. Bellon³, and Rajnish N. Sharma¹

¹ Department of Mechanical Engineering, University of Auckland, Auckland 1023, New Zealand. Email: kday202@aucklanduni.ac.nz

² Department of Engineering Science, University of Auckland, Auckland 1010, New Zealand.

³ Department of Physics, University of Auckland, Auckland 1010, New Zealand.

Abstract

This study summarizes an assessment of the wind resource at selected locations in Fiji for the potential of future utility-scale wind-power development. We use 2 - 8 years of near surface wind observations (2011 – 2018) from thirty automatic weather stations. The standard wind-industry software, WAsP is used to simulate the wind resource in terms of mean wind speed, dominant wind direction, power density and annual energy production (AEP) using a Vergnet 275-kW wind turbine. Our analysis identifies three sites: Rakiraki, Nabouwalu and Udu, which should be considered for a future comprehensive resource assessment for utility-scale wind-power development once further wind resource data is available. High-resolution resource maps for each wind resource parameter at a horizontal resolution of 50 m are produced for 6 km × 6 km domains around these sites. Rakiraki, Nabouwalu and Udu have average wind speeds of 7.6 m/s, 7.1 m/s and 7.0 m/s, with an average power density of 401 W/m², 512 W/m² and 294 W/m², and a potential average AEP of 0.91 GWh, 0.80 GWh and 0.72 GWh at 55 m AGL, respectively. The dominant wind direction is southeasterly. Modelling a 10 MW wind farm at each site yields a net AEP of 43 GWh, 42 GWh and 37 GWh for Rakiraki, Nabouwalu and Udu, respectively with capacity factors of 0.42 – 0.48 and wind farm efficiencies of 97 – 98 %.

Key words: Fiji; wind resource assessment; power density; energy potential; WAsP.

1. Introduction

Wind energy plays an integral role in providing environmentally friendly, renewable electrical energy in many developed and developing countries around the globe. In the year 2018, the worldwide installed capacity of wind energy grew to 591 GW from 59 GW in 2005 [1, 2]. This growth is by an order of magnitude, which highlights the global move towards clean energy from traditional fossil fuel-based power generation. It is likely that wind energy will continue

with this steady growth in the near future [1, 2]. Consequently, new resource assessments, construction permits, and developments are currently underway in many countries [1, 2].

Wind resource assessment is fundamental to determine whether a particular site or region has potential for installing an economically viable wind farm [3, 4]. An assessment of the wind characteristics is vital in terms of the average wind speed, dominant wind direction, wind distribution, diurnal and annual wind speed patterns, wind shear coefficient, turbulence intensity, wind power density, potential annual energy production from a turbine and appropriate wind availability in terms of usable wind for generating electricity using wind turbines, amongst other factors [3, 4].

A number of methods can be employed for wind resource assessment, from the traditional method of setting up a mast with anemometers and wind vanes at different heights, to the use of reanalysis datasets and satellite estimates, as well as the latest technology of using SODAR and LIDAR [3, 4]. For a preliminary understanding of the wind characteristics and the energy potential for a site, at least one full year of ground-based measured wind data is necessary [3, 4].

Small developing countries with limited financial resources face numerous challenges in setting up masts specifically for wind-resource monitoring, thus the long time series of ground-based wind measurements from existing meteorological stations provide an opportunity to estimate the wind-resource parameters.

Fiji is a small island developing state (SIDS) located in the South-West Pacific Ocean between the latitudes of 12 °S - 22 °S and longitudes of 177 °E – 178 °W. There are more than 332 islands with a total land area of 18,333-km² spread out over a sea surface area of 1.3 million km². One-third (110) of these islands are inhabited. Around 87 % of the total land area is taken-up by the two largest islands of Viti Levu (10,400 km²) and Vanua Levu (5,540 km²). The islands are of volcanic origin, mountainous and with maximum peaks of around 1300 m.

Fiji is located on the margin of the South Pacific Convergence Zone (SPCZ), a rainy region that extends southeastward from the equatorial west Pacific [5]. As a result, Fiji has a tropical marine climate with a dry, cool season in austral winter when the SPCZ is small and weak, and a warm, wet season in austral summer when the SPCZ expands and intensifies. In terms of wind, Fiji is in the region of southeasterly trade winds. The stable, regular breeze power the existing wind turbines. Additionally, Fijian coasts experience a strong diurnal cycle of land-sea breeze circulation.

The Fiji Department of Energy manages the off-grid electrification on the islands. Fiji targets to produce 100 % electricity from renewable energy resources by 2030 [6, 7]. Energy Fiji Limited (EFL) is a corporate statutory body responsible for electricity generation, transmission and distribution to the majority of the population in Fiji [6]. Currently, EFL has about 90 % of the total population of 884,887 connected to its electricity grid network with a target of connecting 100 % population by 2030 [6]. The EFL grid network supplies electricity to Viti Levu, Vanua Levu, Ovalau and Taveuni only, whereby the overall peak load fluctuates from 80 – 180 MW [6]. Hydropower and the conventional power plants support the base load while other sources provide support on an intermittent basis. Other islands are dependent on diesel generators, solar home systems, micro-hydro systems and biofuel-based power generation.

Electricity generation in Fiji is from numerous sources including hydro, industrial diesel, heavy fuel oil, biomass and wind [6]. From the most recent statistics in 2018, these sources generated 1032.94 GWh of electricity in total with 59 % (609 GWh) from renewable and 41 % (423.7 GWh) from conventional power plants. The hydropower plants contributed 54.9 % (566.7 GWh); independent power producers contributed 3.9 % (39.94 GWh) and 0.25 % (2.6 GWh) was contributed from wind [6]. Six hydropower stations are connected to the electricity grid network with a total installed capacity of 131 MW, several industrial diesel and heavy fuel oil power plants with a total installed capacity of 147 MW, a 10 MW wind farm and around 40 MW of biomass fired co-generation power plants operated by Independent Power Producers (IPPs) [6].

Fiji has a 10 MW onshore wind farm located on the Butoni hills in Sigatoka on Viti Levu. It consists of 37×275 -kW Vergnet wind turbines, which operate at an annual average wind speed of 5.47 m/s at a hub height of 55 m [6].

The Fiji Department of Energy has carried out a number of wind measurements over time with the aim to assist in electrification of rural inland regions and the outer islands where there is no grid access [8]. Some researchers have used these measurements to assess the potential of wind energy in a few locations [9 – 12], but the data has not gone through a proper quality-control process and some of it lacks consistency. It was reported via the analysis done using the Wind Atlas Analysis and Application Program (WAsP) that average yearly wind speeds for Fiji is between 5 to 6 m/s with an average power density of 160 W/m^2 [13]. Others have measured the wind parameters by setting up masts funded via international donor agencies such as KOICA [14 – 16]. Similar studies have been performed in other regions such as Mexico [17], Kiribati [18] and Brazil [19], using WAsP. WAsP is a common tool for wind resource

assessment and estimation of energy production from selected wind turbines for microsite locations in the range of 5 – 15 km. New wind resource knowledge has been created even though it has not yet led to any new wind farm installations in the areas studied [13 - 16, 17 - 19]. This can be useful for future wind energy planning and development.

In the Fiji Group, the wind resources for the remote island of Kadavu and the urban Suva Peninsula have been previously analysed using WAsP [15]. A wind resource map developed at a height of 34 m for both sites, earmarked locations for future wind-farm development. It was reported that the overall wind speed in these regions is 3.5 - 6.4 m/s at heights of 20 – 34 m above ground level (AGL), predominantly south-easterly. The wind speed was categorised as being in the low-medium wind speed regime, which is suitable for small-medium scale wind turbines like the Vestas V27 225-kW. The analysis indicated promising wind-power development potential for the windward side of the Kadavu ridge in the eastern region with an average net AEP of around 650 MWh and for Laucala Bay (Suva Peninsula) with an average net AEP around 400 - 500 MWh [15]. Onsite measurement analysis of Laucala Bay showed a prevailing south-easterly wind direction with a mean wind speed of 5.03 m/s and a power density of 131 W/m² at 55 m AGL, corresponding to an average energy output of 344 MWh for a 275-kW Vergnet wind turbine [13].

In addition, the wind quality and power availability for the two major islands in Fiji were examined using NASA's MERRA reanalysis at a height of 50 m [13]. A comparison of modelled wind speed with ground-based measurement for Laucala Bay showed that the MERRA dataset overestimated wind speeds by more than 25 %. This shows that reanalysis may be unsuitable for assessment in the vicinity of an island because it is produced by a general circulation model, and the spatial resolution was too coarse to properly represent the details of the island's geography.

Satellite estimates from WindPRO database were also utilized for offshore wind resource assessment of Bligh Waters, north of Viti Levu [21]. The mean wind speeds and the power density for these studies [9 – 16, 21] were found to range from 4.6 m/s and 160 W/m² respectively, at 10 m of altitude to 10.8 m/s and 1128 W/m² at 55 m. These correspond to a low-to-medium wind speed regime that is suitable for small to medium-scale wind turbines.

In summary, only a few studies and only a few locations have been considered to date in Fiji. Consequently, the wind resource potential across the Fiji Group is mostly unknown, thus this study aims to carry out a wind-resource assessment of selected locations, across the Fiji Group,

where automatic weather stations (AWSs) provide long-term measurements of near surface wind. The analysis evaluates the wind characteristics in terms of mean wind speed, dominant wind direction, mean power density, diurnal and annual wind speed patterns, average wind shear coefficient and the energy potential via resource mapping of a 275-kW Vergnet wind turbine using WAsP analysis. In addition, the potential for future utility-scale wind power development is assessed. Section 2 of this work provides background material, section 3 describes the methodology, and the results are presented in section 4 then discussed in section 5. The conclusions are presented in section 6.

2. Background

This section contains all the mathematical definitions of the wind parameters computed by WAsP together with the wind shear coefficient and the capacity factor computation [20].

2.1 Weibull Distribution

In most places, surface wind speed distribution is well approximated by a Weibull distribution [3, 4, 20]. The Weibull distribution fitting is therefore the method most commonly used in wind energy studies to obtain a smooth distribution despite under-sampling of wind speed due to limited observation periods. The Weibull distribution is a two-parameter function, mathematically represented by $f(u)$ while the cumulative distribution function is represented by $F(u)$:

$$f(u) = \frac{k}{A} \left(\frac{u}{A}\right)^{k-1} e^{-\left(\frac{u}{A}\right)^k} \quad (1)$$

$$F(u) = 1 - e^{-\left(\frac{u}{A}\right)^k}, \quad (2)$$

where u is the reference wind speed at the height of measurement, k the non-dimensional shape parameter, and A the scale parameter whose dimensions coincides with that of u (m/s). $k, A, u > 0$. In the observed wind climate analysis of WAsP, the Weibull distribution function of wind speed is represented with an estimated Weibull A parameter which indicates on average how windy the site is, the Weibull shape parameter k which indicates how peaked the distribution is, Weibull mean U which indicates the long-term mean wind speed and P which indicates the available power density at the sites.

2.2 Power and Energy Production from a Wind Turbine

The power production P (in units of W) from a wind turbine is estimated using the wind turbine power curve $p(u)$ and the probability density function of the wind speed at the hub height of the wind turbine as follows:

$$P = \int_0^{\infty} f(u) p(u) du. \quad (3)$$

The annual energy output from a wind turbine E (in units of Wh) is estimated using the product of the wind power production with the time and the efficiency as follows:

$$E = \eta T \int_0^{\infty} f(u) p(u) du, \quad (4)$$

where u is the wind speed at the hub height in m s^{-1} , T is the number of hours in one year and η is the efficiency of the wind turbine.

2.3 Wind Speed calculation using WAsP

WAsP is a linear wind simulation model and takes into account the following factors when calculating wind speed:

1. The geostrophic balance, where the geostrophic drag law gives the geostrophic wind ‘G’:

$$G = \frac{U^*}{K} \sqrt{\left[\ln \frac{U^*}{F z_0} - \mathcal{A}(\mu) \right]^2 + B^2(\mu)}, \quad (5)$$

where $\mathcal{A}$, B are dimensionless functions of stability, U^* is the friction velocity, K is the von Karman’s constant ($= 0.4$), z_0 is the surface roughness length and F is the Coriolis parameter.

2. The modified logarithmic wind profile.

$$u(z) = \frac{U^*}{k} \left(\ln \frac{z}{z_0} - \psi \left(\frac{z}{L} \right) \right) \quad (6)$$

where $u(z)$ is the wind speed at height z , ψ is the stability dependent function which is positive for unstable and negative for stable conditions and L is the Monin-Obukhov Length [20].

3. A specific (but uniform) stability, roughness variations and height variations.

2.4 Vertical Profile of Wind Speed and Wind Shear

A power law or a log law are often used to describe the wind profile near the surface and are commonly used to model the vertical profile of wind speed over regions of homogeneous, flat terrain and prairies. The two laws are:

$$u(z) = \frac{U^*}{k} \ln \left(\frac{z}{z_0} \right) \quad (7)$$

$$\frac{u(z)}{u(z_r)} = \left(\frac{z}{z_r} \right)^\alpha, \quad (8)$$

where $u(z_r)$ is the reference wind speed at height z_r and α is the power law exponent or the wind shear coefficient.

The wind shear is the vertical variation of wind speed with height. It results from the surface drag which slows down the wind at the surface. It depends on how the effect of this drag is transported upwards by turbulence, and in particular on the surface roughness, which modulates turbulence. It is an important parameter not only for power production from wind turbines, but also for aerodynamic loadings on the wind turbine blades. The wind shear coefficient can be computed using known wind speeds at two heights, as in equation (9):

$$\alpha = \frac{\ln\left(\frac{u(z)}{u(z_r)}\right)}{\ln\left(\frac{z}{z_r}\right)} \quad (9)$$

2.5 Capacity Factor

The capacity factor (CF) is the ratio of the actual energy output (E_T) produced by a wind power system to the output that would have been generated if the system operated full-time at its full rated power (P_R) over a given time period (T). The dimensionless CF is given by:

$$CF = \frac{E_T}{P_R T} \quad (10)$$

3. Methodology

Fiji Meteorological Services (FMS) provided wind data for all Automatic Weather Stations (AWSs) in Fiji, since their installation. This wind data is for periods of between 2 and 8 years from 2011 to 2018 for this study. Thirty AWSs average wind speed and wind direction datasets were recorded using mechanical anemometers and wind vanes. The anemometer used to measure wind speed at the 30 AWSs is Vector A100M, which has a range of 0 to 75 m/s, resolution of 0.1 m, accuracy of 1 % of readings between 10 and 55 m/s, 2 % above 55 m/s, 0.1 m/s for 0.1 to 10 m/s and threshold of 0.15 m/s. The wind vane used to measure wind direction at the 30 AWSs is Vector W200P, which has a range of 0 to 360° degrees, distance constant of 2.3 m, accuracy of $\pm 3^\circ$ and threshold of 0.6 m/s. Twenty-nine AWSs record wind measurements at a height of 10 m above ground while one station records at 5 m. The altitudes of the AWSs range from 2 m to 791 m above sea level. The temporal resolution of the wind data ranges from 10 minutes to 3 hours.

Figure 1 shows a map of Fiji with the locations of the thirty stations, and Table 1 shows station details in terms of their latitude, longitude, altitude, observation periods and the total number of observations and data availability of these locations. Fourteen stations are located around Viti Levu (Keiyasi, Korolevu, Lomaivuna, Momi, Nadarivatu, Nadi, Nausori, Rakiraki, Rarawai, RKS Lovoni, Sigatoka, Suva, Tokotoko and Yaqara), six located around Vanua Levu

(Labasa, Nabouwalu, Saqani, Seaqaqa, Wainikoro and Udu) and the remaining ten are located on outer islands (Koro, Lakeba, Levuka, Matuku, Ono-I-Lau, Rotuma, Vanuabalavu, Viwa, Vunisea and Yasawa-I-Rara). Almost all the sites have a data availability of more than 75 % over the study period except Nabouwalu that has 27 % data availability. All the sites have data records at 10-minutes intervals except Nabouwalu that records the data at 3-hour intervals.

Figure 1. Map of Fiji showing the locations of the 30 AWSs (Original Map Source: Google Earth).

Our study utilizes WASP Climate Analyst 3.1 with observed wind climatology as input, WASP Map Editor 12.1 for topography and land roughness maps and WASP 12.1 for mean wind speed, power density, and annual energy production analysis. WASP is a PC-based wind simulation software, developed and distributed by researchers within the Department of Wind Energy of the Denmark Technical University (formerly known as the Risø Laboratory) [20]. It is a standard wind resource assessment, siting, and energy-yield calculation tool used in the wind-power industry and in scientific research. It produces spatial patterns of wind and mapping of wind resources by extrapolation of wind data. The accuracy of the predictions are subject to the assumption that there is the same overall weather regime for the reference and predicted sites, the weather conditions are close to neutrally stable, the reference wind data is

reliable, the surrounding terrain is sufficiently gentle and smooth, and the topographical inputs are adequate and reliable [20].

WAsP Climate Analyst 3.1 generated an estimate of the wind climatology for all 30 locations using the raw data provided by FMS. It uses average hourly data for the analysis, and since Nabouwalu has records every 3 hours, WAsP regarded the hourly data as missing. This is one of the reasons for the lower percentage availability in comparison to the other locations. The data at Nabouwalu are also 10-minute averages of wind measurements but they are recorded as an average every 3 hours.

Table 1. Location and Data Records for the 30 AWSs

Station	Latitude (degrees)	Longitude (degrees)	Height (m)	Elevation (m)	Data Period	# of Records	Availability
Keiyasi	-17.879	177.755	10	89.8	2015 - 2018	206458	97.11%
Koro Is	-17.345	179.418	10	108.8	2014 - 2018	276573	99.75%
Korolevu	-18.212	177.730	10	25.7	2015 - 2018	184615	77.45%
Labasa	-16.433	179.400	10	8.5	2016 - 2018	154081	94.02%
Lakeba	-18.236	-178.804	10	8.9	2012 - 2018	347776	90.55%
Levuka	-17.640	178.818	10	41.5	2015-2018	209922	99.77%
Lomaivuna	-17.871	178.360	10	122.1	2014 - 2018	262525	92.76%
Matuku	-19.126	179.738	10	15.1	2012 - 2018	349434	91.12%
Momi	-17.895	177.266	10	43.8	2015 - 2018	225886	97.24%
Nabouwalu	-16.993	178.689	5	25.3	2013 - 2017	13684	27.27%
Nadarivatu	-17.567	177.963	10	824.1	2014 - 2018	276248	97.25%
Nadi	-17.759	177.444	10	20.7	2013 - 2018	278708	98.86%
Nausori	-18.046	178.559	10	5.7	2013 - 2017	43815	98.20%
Ono-I-Lau	-20.655	-178.720	10	18.2	2012 - 2018	383119	99.83%
Rakiraki	-17.340	178.221	10	8.1	2013 - 2018	320194	97.30%
Rarawai	-17.556	177.681	10	9.3	2011 - 2018	397017	92.10%
RKS Lovoni	-17.726	178.555	10	17.1	2014 - 2018	275930	97.60%
Rotuma	-12.499	177.046	10	22.1	2014 - 2018	204793	89.33%
Saqani	-16.474	179.708	10	30	2016 - 2018	158452	97.60%
Seaqaqa	-16.475	179.157	10	101.8	2016 - 2018	155983	90.67%
Sigatoka	-18.142	177.503	10	6.7	2013 - 2018	286189	89.39%
Suva	-18.147	178.453	10	6.6	2015 - 2017	1048575	95.58%
Tokotoko	-18.218	178.170	10	4.9	2013 - 2018	426425	98.99%
Udu	-16.141	-179.994	10	43.7	2013 - 2018	325924	98.95%
Vanuabalavu	-17.241	-178.952	10	66.1	2012 - 2018	297033	76.81%
Viwa	-17.149	176.911	10	2	2013 - 2018	294573	88.38%
Vunisea	-19.046	178.165	10	31.9	2014 - 2018	257896	96.79%
Wainikoro	-16.304	179.558	10	15.1	2016 - 2018	152692	88.96%
Yaqara	-17.433	177.977	10	20	2014 - 2018	284646	99.92%
Yasawa	-16.698	177.574	10	40	2013 - 2018	295182	89.30%

The estimated wind climatology is presented sector wise in the form of a wind rose and a Weibull distribution function. The wind rose indicates the relative frequency of occurrence of wind direction grouped in 12 sectors. The annual value of the Weibull parameters from the real data for the available years was calculated using the WAsP Weibull method [20]. Equation (9), which comes from the power law, computes the wind shear coefficient α using the average wind speeds at 10 m and 55 m above ground level (AGL) as the reference and calculation height for wind shear coefficient respectively. These elevations have been used because WAsP processed the 10 m wind speed from AWSs and WAsP modelled the wind speed at 55 m AGL, and measurements are not available at any other heights.

The topography and land roughness maps for the 30 locations were generated on the WAsP Map Editor 12.1. The topography maps were imported from the SRTM ver.2 Database (http://dds.cr.usgs.gov/srtm/version2_1/SRTM3) at a horizontal resolution of 3 arc seconds (about 90 m). A land roughness of 0.03 at a height of 10 m was used in the topography map aided with additional 4 to 5 roughness line changes from 0.03 – 1.5 via digitizing by closely studying the land roughness of the sites using Google Earth. This completed the land roughness maps in the WAsP Map Editor for a 6 km $\times$ 6 km grid, for each location.

WAsP 12.1 was then used to analyse all sites for their wind energy resource in terms of mean wind speed, power density, orography, and the AEP using a Vergnet 275-kW wind turbine on a resource grid of 6 km $\times$ 6 km at a height of 55 m AGL. The obstacles and sheltering effects from nearby vegetation and buildings were taken into account in the WAsP analysis. To consider the impact of air density in the wind energy calculation, the WAsP model uses the WAsP Air Density Calculator to calculate the air density (kg/m^3) as a function of altitude (elevation in meters above sea level) and mean air temperature at the same altitude. A lapse rate of 6.5 K/km and a sea level pressure of 1013.25 hPa are assumed and the estimate is based on a standard atmosphere. High-resolution micro-scale resource maps for the resource grid of 6 km $\times$ 6 km at 50 m horizontal resolution was developed for each resource parameter. Finally, locations with the potential for supporting future utility-scale wind power development were identified and an evaluation of the minimum installed capacity and the corresponding energy production using Vergnet 275-kW wind turbines were computed using WAsP 12.1.

The Vergnet 275-kW wind turbine has been selected for this study as these turbines can be lowered to the ground and secured in place during extreme wind conditions, such as tropical cyclones, which are not uncommon in Fiji. Vergnet wind turbines are in use at an existing wind farm in Fiji and in other Southwest Pacific island countries prone to tropical cyclones such as

Samoa, Vanuatu and New Caledonia. Table 2 presents the specifications of the Vergnet 275-kW wind turbine.

Table 2. Vergnet 275-kW turbine specifications

Rotor Diameter	Hub Height	Cut-in speed	Cut-out speed	Rotation rate	Rated Power	Rated wind speed
32 m	55 m	3.5 m/s	25 m/s	31 rpm	275-kW	12 m/s

Figures 2 – 4 present the elevation maps with respective roughness changes incorporated for the three potential sites of Rakiraki, Nabouwalu and Udu respectively with a contour interval of 10 m. The elevation for the three sites varies from sea level to 250 m, 530 m and 160 m with an average of 23.6 m, 163.8 and 15.7 m respectively.

Figure 2. Topography and elevation map of Rakiraki (x denotes the location of the AWS).

Figure 3. Topography and elevation map of Nabouwalu (x denotes the location of the AWS).

Figure 4. Topography and elevation map of Udu (x denotes the location of the AWS).

3.2 Resource Maps

Resource maps are generated using WAsP on a $6\text{ km} \times 6\text{ km}$ domain each, for the surroundings of Rakiraki, Nabouwalu and Udu AWSs, which have been identified as suitable for potential wind power sites. The mean wind speed is the first important parameter in determining whether a particular site has potential wind speed resource to rotate a site-specific wind turbine to generate electricity to feed into an electrical grid network. The wind power density is the second most important parameter in determining whether a particular site has potential wind power resource in terms of the available power in the wind. The annual energy production is another important parameter in determining whether a particular site has potential wind energy resource for a specific wind turbine placed at any location within the resource grid. Wind speed and wind power density in the range of Class 3 or higher and AEP of 0.5 GWh/year or higher are considered feasible for utility-scale wind power development [4, 22 and 23].

4. Results

This section presents the results as follows: wind speed frequency, wind direction and wind speed patterns. In addition, there is a more detailed analysis of the three sites with the potential for future utility-scale wind power development.

4.1 Wind Speed Frequency and Wind Direction

The wind speed frequency and direction distributions provide site-specific information on wind resources, in particular the average power density available at the height of measurement. Figures 5 (a) – (c) show the wind speed frequency distribution and the wind direction analysis of the 3 suitable AWS sites. As for the other AWS sites, it is provided in the form of supplementary data.

The mean wind speed is 5.01 m/s at Nabouwalu at a height of 5 m, 6.31 m/s and 5.45 m/s at Rakiraki and Udu respectively, at a height of 10 m. Wind direction is dominated by the southeasterly trade winds. In addition, the wind rose also shows wind direction in other sectors caused by island-scale circulation as well as local sheltering effects from nearby buildings and vegetation.

Figure 5 (a). Wind rose and wind speed frequency distribution at Nabouwalu at 5 m AGL.

Figure 5 (b). Wind rose and wind speed frequency distribution at Rakiraki at 10 m AGL.

Figure 5 (c). Wind rose and wind speed frequency distribution at Udu at 10 m AGL.

The Weibull A parameter is 5.6 m/s at Nabouwalu at a height of 5 m, and 7.1 m/s and 6.1 m/s at Rakiraki and Udu respectively, at a height of 10 m. A lower Weibull A parameter means lower mean wind speed at a site, while a higher Weibull A parameter means higher mean wind speed at a site. A higher Weibull A parameter also indicates an increase in the dispersion of wind around the mean wind speed [3, 4]. The Weibull A parameter observed at all 3 sites are considered higher. The Weibull shape parameter k is 1.91 at Nabouwalu at a height of 5 m, and 2.53 and 2.49 at Rakiraki and Udu respectively, at a height of 10 m. A lower Weibull shape parameter k (of 1.5 or 2) indicates a greater deviation away from the mean wind speed, while a higher Weibull shape parameter k (> 2.5) indicates that the variation of mean wind speed is small [3, 4]. The Weibull shape parameter k observed at sites of Rakiraki and Udu are considered on the higher side, according to this measure. The percentage of the time when the wind speeds is greater than 3.5 m/s (cut-in wind speed of the Vergnet 275-kW wind turbine) is approximately 73 %, 58.5 % and 71.4 % for Rakiraki, Nabouwalu and Udu, respectively.

The wind power class is a function of wind speed, and the corresponding wind power densities at heights of 10 m and 50 m, are as presented in Table 3 [22].

Table 3. Wind Power Class [22]

Wind Power Class	10 m Wind Power Density (W/m ²)	10 m Wind Speed (m/s)	50 m Wind Power Density (W/m ²)	50 m Wind Speed (m/s)
1	0 - 100	0 - 4.4	0 - 200	0 - 5.6
2	100 - 150	4.4 - 5.1	200 - 300	5.6 - 6.4
3	150 - 200	5.1 - 5.6	300 - 400	6.4 - 7.0
4	200 - 250	5.6 - 6.0	400 - 500	7.0 - 7.5
5	250 - 300	6.0 - 6.4	500 - 600	7.5 - 8.0
6	300 - 400	6.4 - 7.0	600 - 800	8.0 - 8.8
7	400 -1000	7.0 - 9.4	800 -2000	8.8 - 11.9

A Wind Power Class of 3 or above is considered suitable for most utility scale wind power developments [4, 22 and 23]. The sites of Rakiraki and Udu have mean wind speeds of 6.31 m/s and 5.45 m/s and power densities of 241 W/m² and 157 W/m² respectively, at a height of 10 m. Nabouwalu has a mean wind speed of 5.01 m/s and a power density of 154 W/m² at the height of 5 m. In terms of wind power class at a height of 10 m for utility-scale wind power development, Rakiraki is categorised as Class 5 where as Udu and Nabouwalu are categorised as Class 3. Yasawa-I-Rara is Class 5, while Ono-I-Lau and Vanuabalavu are Class 3, but these are outer islands that are located away from the central grid network, so are not suitable for

utility-scale wind power development. Nevertheless, these results suggest that wind power could be a reliable renewable power source for these islands.

The sites of Rakiraki, Nabouwalu and Udu meet the criteria of having sufficient mean wind speed and power density for future utility-scale wind power developments at a height of 10 m. The three sites have higher wind speeds and greater power density at lower heights compared to studies done at higher elevations [15, 13, and 18]. According to the present results, other mainland sites tested cannot be utilized for future utility-scale wind power development as the wind speed and wind power density fall below Class 3. Note that on small outer islands, wind power can be utilized for rural electrification purposes in stand-alone hybrid power systems despite having lower wind speeds.

4.2 Wind Speed Patterns

The diurnal wind speed pattern is the average diurnal cycle of the wind composed of the long-term averages of the wind at each hour of the day. Figures 6 (a) – (d) show the diurnal wind speed patterns for the 30 different AWS sites located around Fiji. The four figures show the diurnal cycle of wind speed for the AWSs on the leeward side of Viti Levu, the windward side of Viti Levu, Vanua Levu and the outer islands. Higher wind speeds in the order of 5 m/s or more are observed on AWSs that are located on either side of the channel between the two larger islands and on the north eastern tip of Vanua Levu. The sites of Rakiraki and Udu have a diurnal wind speed variation of 5.0 – 7.3 m/s and 5.2 – 5.9 m/s, respectively; at a height of 10 m. Nabouwalu has a diurnal wind speed variation of 4.1 – 5.9 m/s at a height of 5 m.

Figure 6 (a). Diurnal wind speed patterns for the 8 AWS sites on the leeward side of Viti Levu at 10 m.

Figure 6 (b). Diurnal wind speed patterns for the 6 AWS sites on the windward side of Viti Levu at 10 m.

Figure 6 (c). Diurnal wind speed patterns for the 6 AWS sites in Vanua Levu at 10 m.

Figure 6 (d). Diurnal wind speed patterns for the 10 AWS sites in outer islands at 10 m.

The annual wind speed pattern is the average, climatological seasonal cycle as represented by monthly means. Figures 7 (a) – (d) show the annual wind speed patterns for the 30 different AWS sites around Fiji. The four figures show the annual patterns of wind speed for AWSs on the leeward side of Viti Levu, the windward side of Viti Levu, Vanua Levu and the outer islands. Wind speeds vary seasonally, with weaker winds during the austral summer (November to April). The sites of Rakiraki and Udu have an annual wind speed of 3.8 – 7.0 m/s and 4.2 – 6.4 m/s respectively at a height of 10 m. Nabouwalu has an annual wind speed of 3.3 – 6.6 m/s at a height of 5 m.

Figure 7 (a). Annual wind speed patterns for the 8 AWS sites on the leeward side of Viti Levu at 10 m.

Figure 7 (b). Annual wind speed patterns for the 6 AWS sites on the leeward side of Viti Levu at 10 m.

Figure 7 (c). Annual wind speed patterns for the 6 AWS sites in Vanua Levu at 10 m.

Figure 7 (d). Annual wind speed patterns for the 10 AWS sites in Outer Islands at 10 m.

Figure 8 presents the monthly average wind speed for the three potential sites of Rakiraki, Nabouwalu and Udu with the corresponding 95 % confidence intervals. At 95 % confidence interval, the wind speed varies from 2.8 m/s to 8 m/s, 1.8 m/s to 7.8 m/s, 3.2 m/s to 7.4 m/s for Rakiraki, Nabouwalu and Udu, respectively. Looking at the 95 % confidence interval plots for the three sites, Nabouwalu is significantly different in comparison with Rakiraki and Udu.

404

405

406

Figure 8. Monthly average wind speed for the three potential sites. Error bars represent plus and minus two standard deviation.

407

408 **4.3 Wind Shear**

409

410

411

412

413

414

415

416

417

Table 4 shows the average wind shear coefficients for the 30 AWS locations. They vary from a minimum of 0.11 to a maximum of 0.35. We can compare these with published wind-shear coefficients [24]: the terrain type in Keiyasi, Korolevu, Nausori, Rotuma, Tokotoko and Yaqara is tall crops, hedges, and shrubs while in Momi, Nabouwalu, Saqani, Udu and Viwa, it is foot-high grass at ground level. In Lomaivuna, Nadarivatu, Rarawai, Sigatoka and Wainikoro, it is wooded country with many trees; Koro Island, Labasa, Nadi, RKS Lovoni, Seaqaqa, Suva, Vanuabalavu and Vunisea has a small town with few trees and shrubs; Lakeba, Levuka, Matuku, Ono-I-Lau, Rakiraki, and Yasawa-I-Rara has smooth-hard ground as terrain types.

Table 4. Mean Wind Shear Coefficient at 30 Locations in Fiji

Location	Wind speed @ 10 m [m/s]	Wind speed @ 55 m [m/s]	Mean wind shear coefficient [α]
Matuku	2.45	2.92	0.10
Ono-I-Lau	5.24	6.33	0.11
Rakiraki	6.31	7.57	0.11
Yasawa	6.56	7.87	0.11
Levuka	2.83	3.48	0.12
Lakeba	2.69	3.4	0.14
Nabouwalu	5.01	7.14	0.15
Udu	5.45	7.01	0.15
Momi	4.19	5.5	0.16
Saqani	2.58	3.45	0.17
Viwa	3.76	5.11	0.18

Nausori	2.46	3.47	0.20
Rotuma	2.51	3.58	0.21
Keiyasi	1.21	1.75	0.22
Korolevu	3.29	4.83	0.23
Yaqara	3.94	5.81	0.23
Tokotoko	2.4	3.64	0.24
Lomaivuna	1.95	3.05	0.26
Rarawai	1.73	2.7	0.26
Sigatoka	1.96	3.05	0.26
Wainikoro	1.75	2.81	0.28
Nadarivatu	2.76	4.5	0.29
Labasa	1.6	2.66	0.30
RKS Lovoni	2.04	3.46	0.31
Vanuabalavu	5.43	9.38	0.32
Vunisea	4.12	7.16	0.32
Koro Island	3.79	6.6	0.33
Suva	2.81	4.9	0.33
Seaqaqa	1.43	2.57	0.34
Nadi	2.57	4.66	0.35

The wind shear depends on the terrain type for each location that determines its roughness. A wind shear coefficient of $\alpha \leq 0.2$ is sufficient for normal wind turbine operation for all wind speed classes [25]. The locations of Lakeba, Levuka, Matuku, Momi, Nabouwalu, Nausori, Ono-I-Lau, Rakiraki, Saqani, Udu, Viwa, and Yasawa meet this requirement, while other sites are outside the range of normal working conditions of wind turbines.

4.4 Resource Maps of Potential Sites

Sections 4.4.1 – 4.4.3 present the resource maps of the three identified potential sites of Rakiraki, Nabouwalu and Udu that meet the criteria for having sufficient wind resources for future utility-scale wind power applications.

4.4.1 Rakiraki

Figures 9 (a) - (c) present high-resolution maps of mean wind speed, wind power density and the AEP using the Vergnet 275-kW wind turbine for the site of Rakiraki at 55 m AGL.

Figure 9 (a). Mean wind speed map of Rakiraki at 55 m AGL.

Figure 9 (b). Wind-power density map of Rakiraki at 55 m AGL.

Figure 9 (c). Annual Energy Production map of Rakiraki at 55 m AGL.

4.4.2 Nabouwalu

Figures 10 (a) - (c) present the high-resolution maps of mean wind speed, wind power density and the AEP using the Vergnet 275-kW wind turbine for the site of Nabouwalu at 55 m AGL.

Figure 10 (a). Mean wind speed map of Nabouwalu at 55 m AGL.

Figure 10 (b). Wind-power density map of Nabouwalu at 55 m AGL.

Figure 10 (c). Annual Energy Production map of Nabouwalu at 55 m AGL

4.4.3 Udu

Figures 11 (a) - (c) present the high-resolution mean wind speed, wind power density and the AEP maps using the Vergnet 275-kW wind turbine for the site of Udu at 55 m AGL.

Figure 11 (a). Mean wind speed map of Udu at 55 m AGL.

Figure 11 (b). Wind-power density map of Udu at 55 m AGL.

Figure 11 (c). Annual Energy Production map of Udu at 55 m AGL.

The mean wind speed in Rakiraki, Nabouwalu and Udu vary from 5.14 m/s to 10.26 m/s, 4.86 m/s to 11.60 m/s and 6.15 m/s to 9.29 m/s with an average of 7.57 m/s, 7.14 m/s and 7.01 m/s respectively, at a height of 55 m AGL. In comparison with classes for wind speed at a height of 50 m from [22], average mean wind speed in Rakiraki is Class 5 whereas Nabouwalu and Udu fall within Class 4. Similarly, the wind power density in Rakiraki, Nabouwalu, and Udu varies from 121 to 971 W/m², 148 to 2252 W/m² and 192 to 695 W/m² with an average of 401 W/m², 512 W/m² and 294 W/m² respectively, at a height of 55 m AGL. In comparison with classes for wind power density at a height of 50 m from [22], average wind power densities in Rakiraki and Udu fall within Class 3, where as in Nabouwalu it is Class 5. The AEP using the Vergnet 275-kW wind turbine for Rakiraki, Nabouwalu, and Udu varies from 0.285 to 1.476 GWh, 0.327 to 1.274 GWh and 0.480 to 1.268 GWh with an average of 0.907 GWh, 0.804 GWh and 0.716 GWh respectively.

In the present study, the wind resources are simulated at 55 m AGL with 5 - 6 years of wind data, while for other studies it was simulated at 34 m altitude with 12 – 18 months wind data and using a smaller wind turbine.

All three sites identified in the present study meet the criteria of having sufficient mean wind speed, power density and energy in the wind, using a Vergnet 275-kW wind turbine at the hub-

height of 55 m. These sites have the potential for future utility-scale wind power developments and this potential could be further explored using a comprehensive resource assessment once wind resource data is available for at least 10 years [4, 26].

Table 5 presents a summary of the minimum installed capacity and the wind energy resources for each modelled wind farm in the three sites of Rakiraki, Nabouwalu and Udu. Each of these sites can accommodate a minimum of 10 MW of wind turbine installations with each turbine occupying an area of approximately 804 m². A typical 10 MW wind farm using 37 × 275-kW wind turbines with 5-rotor diameter spacing modelled in Rakiraki, Nabouwalu and Udu would yield a net AEP of 42.869 GWh, 42.116 GWh and 37.005 GWh respectively. The 5-rotor diameter spacing is used to minimize the effects of one turbine working in the wake or disrupted flow of another turbine.

Table 5. Modelled Wind Farm Analysis

Location	Rakiraki	Nabouwalu	Udu
Installed Capacity [MW]	10	10	10
Wind Turbine	37 x 275-kW	37 x 275-kW	37 x 275-kW
Total gross AEP [GWh]	43.602	42.832	38.048
Mean gross AEP [GWh]	1.178	1.158	1.028
Min gross AEP [GWh]	0.854	0.994	0.801
Max gross AEP [GWh]	1.480	1.262	1.259
Total net AEP [GWh]	42.869	42.116	37.005
Mean net AEP [GWh]	1.159	1.138	1.000
Min net AEP [GWh]	0.851	0.966	0.749
Max net AEP [GWh]	1.477	1.257	1.215
Total proportional wake losses [%]	1.68	1.67	2.74
Mean speed [m/s]	8.71	9.75	8.21
Mean power density [W/m ²]	608	1300	485
Wind farm capacity factor	0.48	0.48	0.42
Wind farm efficiency (%)	98.32	98.33	97.26

5. Discussion

The three sites, Rakiraki, Nabouwalu and Udu, have higher wind speeds, power densities and AEP in comparison with the findings from previous studies done in Fiji and Kiribati [15, 13 and 18]. The differences between the present study and other studies [15, 18] is the height at which the wind resource is analysed, its geographical location and the duration of the data used.

The wind turbines in the wind farms modelled have a minimum-maximum energy production range of 0.851 to 1.477 GWh, 0.966 to 1.257 GWh and 0.749 to 1.215 GWh with an average of 1.159 GWh, 1.138 GWh and 1.000 GWh estimated per wind turbine for Rakiraki,

Nabouwalu and Udu respectively. The mean wind speed and the mean power density at the hub height of the wind turbines modelled at Rakiraki, Nabouwalu and Udu is 8.71 m/s, 9.75 m/s and 8.21 m/s with an average wind power density of 608 W/m², 1300 W/m² and 485 W/m² respectively. The proportional wake losses for the three sites is less than 2.74 % for all the three sets of 37 wind turbines. The capacity factor of the wind farms modelled ranges from 0.42 – 0.48 while the wind farm efficiency ranges from 97.26 - 98.33 %. Current operational onshore wind farms around the world have a capacity factor of 0.20 – 0.54 whereas in the Oceania region the capacity factors are in the range of 0.31 – 0.48 [1]. The capacity factor for the modelled wind farms falls within the range of operational wind farms in this region.

A total AEP of 121.99 GWh is possible from the 3 × 10 MW wind farms modelled. A minimum of 30 MW of wind energy in terms of installed capacity, could be added to the existing grid network at an estimated cost of approximately \$102 million FJD (using 3.4 million FJD/MW based on data from existing wind farm installation [27]). This estimated cost of installation is less than the fuel bill for the local utility providers to run diesel generators for 2017 and 2018, which was reported to be 252.2 million FJD [6]. The cost comparison does not compare the amount of energy produced by fossil fuel-based power plants.

Comparing the AEP of each of the 10 MW wind farms modelled with the existing wind farm in Butoni, which had an AEP of 2.56 GWh in 2018, indicates that these three sites have good wind energy potential. The analysis presented in this paper suggests that these sites provide a better wind energy utilization than the existing wind farm site. Another possibility is the transfer of under-performing wind turbines from the existing wind farm to the sites identified in the present study, for better utilization of the wind turbines in terms of energy production. Furthermore, the AEP of 121.99 GWh from the 30 MW modelled wind farms at these sites is larger than the 108.739 GWh of production from the new 40 MW Nadarivatu Hydropower plant in 2018. The new hydropower plant cost approximately \$300 million FJD to build and commission [6]. Appropriate decision-making on investment by EFL, government, private sector and international investors can turn out to be profitable while contributing significantly to reducing the carbon footprints for Fiji.

6. Conclusions

This study summarizes an assessment of the wind resource at selected locations in Fiji for the potential of future utility-scale wind-power development. We use 2 - 8 years of near surface wind observations (2011 – 2018) from thirty automatic weather stations. The standard wind-industry software, WAsP is used to simulate the wind resource in terms of mean wind speed,

dominant wind direction, power density and annual energy production (AEP) using a Vergnet 275-kW wind turbine.

The results of the WAsP analysis reveal three potential sites for future utility-scale wind power development: Rakiraki, Nabouwalu and Udu. High-resolution 6 km × 6 km resource maps were produced for these wind resource parameters at a horizontal resolution of 50 m at these sites. Rakiraki, Nabouwalu and Udu have an average wind speed of 7.6 m/s, 7.1 m/s and 7.0 m/s with an average power density of 401 W/m², 512 W/m² and 294 W/m², and an average annual production of 0.907 GWh, 0.804 GWh and 0.716 GWh using a 275-kW wind turbine, respectively, at a height of 55 m. The dominant wind direction is southeasterly. The wind shear coefficient computed for the potential sites are suitable and within the normal working conditions stipulated for standard wind turbines.

Each site can accommodate a minimum installed capacity of 10 MW to support the electricity grid network with clean and environmentally friendly renewable electrical energy. Modelling a 10 MW wind farm at each site yields a net annual energy production of 43 GWh, 42 GWh and 37 GWh for Rakiraki, Nabouwalu and Udu respectively, with capacity factors of 0.42 – 0.48 and wind farm efficiencies of 97 – 98 %. This research promotes the idea that the SIDS in the Pacific can utilize the wind resource to ease its dependence on diesel-based power generation using small-medium sized wind turbines and provides an initial pathway to future wind energy investment opportunities for government, private sector and international investors.

Acknowledgments

This study was conducted as part of a PhD scholarship project funded by the NZ Ministry of Foreign Affairs and Trade (NZMFAT). The authors would like to acknowledge the Fiji Meteorological Services for providing the ground-based wind data measurements and the Department of Wind Energy of the Denmark Technical University for providing a student license for the wind simulation software package WAsP.

References

- [1] REN21. Renewables 2019 Global Status Report (Paris: REN21 Secretariat); 2019.
- [2] GWEC, Global Wind Energy Council. Global Wind Statistics, 2018. Available at: www.gwec.net. Accessed on January 31, 2020.

- [3] Mathew Sathyajith. *Wind Energy: Fundamentals, Resource Analysis and Economics*. Berlin: Springer-Verlag; 2006.
- [4] Manwell, J.F., McGowan J.G., and Rogers, A.L. *Wind Energy Explained: Theory, Design and Application*. John Wiley & Sons, Chichester, 2009.
- [5] Rapaport, M. (2013). *The Pacific Islands: Environment and Society, Revised Edition*. University of Hawai'i Press. Retrieved from <http://www.jstor.org/stable/j.ctt6wqh08>
- [6] EFL, Energy Fiji Limited. Annual Report, 2018. Available at: www.efl.com.fj. Accessed on January 31, 2019.
- [7] Government of Fiji, 2015. Fiji's Intended Nationally Determined Contribution. Available at: <http://www4.unfccc.int>. Accessed on October 25, 2019.
- [8] Fiji Department of Energy. Renewable Energy - Wind, 2018. Available at: www.fdoe.gov.fj. Accessed on October 25, 2019.
- [9] Singh, R.A. (2015). A Pre-feasibility Study of Wind Resources in Vadravadra, Gau Island, Fiji. *Energy and Environmental Engineering*, 3(1), 5-14.
- [10] Kumar, A. and Nair, K. (2014). Wind energy potential, resource assessment and economics of wind power around Qamu, Navua, Fiji. *International Journal of Wind and Renewable Energy*, 3(1), 1-6.
- [11] Kumar, A. and Nair, A. (2013). Wind power potential at Benau, Savusavu, Vanua Levu, Fiji. *International Journal of Energy, Information and Communications*, 4(1), 51-62.
- [12] Kumar, A. and Nair, K. (2012). Wind characteristics and energy potentials at Wainiyaku Taveuni, Fiji. *Management of Environmental Quality: An International Journal*, 23 (3), 300-308.
- [13] Kumar, A. and Prasad, S. (2010). Examining wind quality and power prospects on Fiji Islands. *Renewable Energy*, 35 (2), 536-540.
- [14] Gosai, A.D. (2015). Wind energy potential and electricity generation at Rokavukavu, Rakiraki in Fiji. MSc Thesis, University of the South Pacific.
- [15] Sharma, K. and Ahmed, M.R. (2016). Wind energy resource assessment for the Fiji Islands: Kadavu Island and Suva Peninsula, *Renewable Energy*, 89, 168-180.
- [16] Pratap, R.D. (2016). Wind/Diesel hybrid micro-grid for a remote Fijian village. MSc Thesis, University of the South Pacific.

588 [17] Carrasco-Díaz, M., Rivas, D., Orozco-Contreras, M. and Sánchez-Montante, O. (2015).
589 An assessment of wind power potential along the coast of Tamaulipas, northeastern Mexico,
590 Renewable Energy, 78, 295-305.

591 [18] Aukitino, T., Khan, M.G.M and Ahmed, M.R. (2017). Wind energy resource assessment
592 for Kiribati with a comparison of different methods of determining Weibull parameters, Energy
593 Conversion and Management, 151, 641-660.

594 [19] Lima, L.A. and Filho, C.R.B. (2010). Wind energy assessment and wind farm simulation
595 in Triunfo – Pernambuco, Brazil, Renewable Energy, 35 (2), 2705-2713.

596 [20] Mortensen, N.G., D.N. Heathfield, O. Rathmann and Morten Nielsen (2014). Wind Atlas
597 Analysis and Application Program: WASP 12 Help Facility. Department of Wind Energy,
598 Technical University of Denmark, Roskilde, Denmark.

599 [21] Dayal, K.K. (2015). Offshore wind resource assessment, site suitability and Technology
600 selection for Bligh Waters Fiji using WindPRO. MSc Dissertation, Uppsala University.

601 [22] NREL, National Renewable Energy Laboratory - Wind, 2018. Available at:
602 www.nrel.gov. Accessed on October 25, 2018.

603 [23] Liu, B., Costa, K.B., Xie, L. and Semazzi, F.H.M. (2014). Dynamical Downscaling of
604 Climate Change Impacts on Wind Energy Resources in the Contiguous United States by Using
605 a Limited-Area Model with Scale-Selective Data Assimilation. Advances in Meteorology, vol.
606 2014, Article ID 897246, 11 pages.

607 [24] Patel, M. R. *Wind and Solar Power Systems: Design, Analysis and Operation*. Taylor &
608 Francis Group, Boca Raton, 2006.

609 [25] Smith, K., Randall, G., Malcolm, D., Kelly, N. and Smith, B. Evaluation of Wind Shear
610 Patterns at Midwest Wind Energy Facilities. National Renewable Energy Laboratory
611 NREL/CP-500-32492: Golden CO, USA, 2002.

612 [26] Bailey, B. H. et al. (1997) *Wind Resource Assessment Handbook: Fundamentals for*
613 *Conducting a Successful Monitoring Program*. Golden, CO (United States).

614 [27] Fiji Times Online. ‘\$34 M Failure: FEA admits lack of study in the wind farm project’.
615 Available at: www.fijitimes.com. Accessed on October 25, 2019.

616