Pre-feasibility Study of a Potential Wind Farm in Benau, Savusavu, Fiji

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Abstract

Wind characteristics and the Energy Potential of Benau, Savusavu is investigated using the Wind Atlas Analysis and Application Program (WAsP). It is established that Benau, Savusavu is a good site for wind power generation as it has a mean wind speed of 6.39 m/s and a mean power density of 322 W/m² at 50m height. The annual energy production, the mean wind speed and the mean power density of Benau is predicted using the WAsP software for potential sites for power production. Different wind turbines are selected and their annual energy production and mean wind speed is calculated using WAsP, on the basis of which an economic analysis is carried out.

Introduction

Energy is available in two different alternatives, non-renewable (coal, fuel, natural gas) and renewable (solar, wind, hydro, wave, biomass) sources. Coal and fuel oil are used as primary energy sources for the needs of modern communities. As known, fossil fuels have limited potential and at current rates of exploitation, are expected to deplete within the next century. This is one of the reasons why clean, sustainable and environmentally-friendly alternative energy resources are currently sought. The accumulation of carbon dioxide in the lower layers of the atmosphere gives way to climate change, floods, intensive rainfall and droughts. In order to reduce these dangerous effects, it is the responsibility of each country to improve the quality of energy resources, and if possible, to replace fossil fuels (coal and oil) with renewable alternatives.

Faced with energy crises in 1973, western countries began to search

for their own clean and renewable energy (RE) sources, which are effective but must inevitably compete against conventional energy sources. In this competition, energy sources with huge and renewable raw materials have the advantage in the long run. Atmospheric environment is polluted due to thermoelectric power plants and petroleum materials since the industrial revolution. The pollution crises are the catalysts for the search and development of RE sources. The environmental impact of fossil fuels, in the form of air pollution, acid rain and greenhouse effects, in addition to their limited availability, gave added importance to the use of conventional and renewable alternative energy sources such as solar, wind and solar-hydrogen energies. Recently, renewable and clean energy generation technological development facilities became available on the energy market. Among the renewable alternatives, wind energy has an important potential role, and wind-power farms are becoming widely used all over the world.

Wind energy can be utilized for a variety of functions ranging from windmills to pumping water and sailing boats. With increasing significance of environmental problems, clean energy generation becomes essential in every aspect of energy consumption. Wind energy is very clean but not persistent for long periods of time. Wind energy generation studies show that fossil fuels must be supplemented by wind energy. There are many scientific studies in wind energy domain, which have treated the problem with various approaches (Cherry, 1980; Justus, 1978; Troen and Petersen, 1980). General trends towards wind and other RE resources increased after the energy crises of the 20th century (Sayigh, 1999).

For over 2000 years, water and windmills powered the world's industries with new technologies and materials. Modern wind turbines are used to generate clean electricity needed for lighting, heating, refrigeration and other uses. Wind energy is a rather young industry, but one which already makes sense. It has been a proven success in some areas; its use is increasing, and the downward trend in its costs is expected to continue. Already over 20,000 turbines are producing electricity worldwide. Most are operating in 'wind farms' as groups of wind turbines, generating electricity on a significant scale. Single wind turbines are also used for generating electricity, charging batteries, driving pumps and producing heat.

The potential of wind power for electricity generation has been investigated extensively at several locations and in many countries. The general criteria of investment considered are weather data and the technical specification of wind energy conversion systems based on economic and financial analysis (Papadopoulos and Dermentzoglou, 2002). Investment strategies have been developed exclusively for low wind speed area (Kongnam and Nuchprayoon, 2008). Screening and ranking methods have been proposed to identify the most attractive investment plans. To account for the unpredictable nature of wind and minimize economic risks, various models have been proposed (Blanco, 2008; Montes, 2007 Ahmed and Abouzeid, 2001).

To determine the optimum capacity in a Fiji case, decision analysis techniques (Kongnam and Nuchprayoon, 2008) are proposed to evaluate generation capacity of a 25km^2 area in Benau, Savusavu, Fiji. The objective is to maximize the expected generation profit and minimize risks arising from uncertain wind speed distribution.

Wind Data and Site Description

Successful wind power development projects hinge on quality wind resource assessments and understanding of the variables affecting the wind resource. Wind power is strongly influenced by the wind resource behaviour that fluctuates with a host of variables including topology, altitude, meteorological conditions, and complex weather patterns. Obstructions and complex terrains complicate the measurement process and require careful analysis of quality wind data as well as correlation to historical data from an existing monitoring station. Urban settings can present some of the most complex terrains for wind assessment. Within urban settings, long-term wind data monitoring projects are essential to fully characterize wind patterns throughout the year and to account for interaction of wind, weather and building induced effects.

In order to gain success in these kinds of wind resource assessment projects, it is vital to implement a proper methodology. Before visiting any prospective monitoring site, various factors influencing urban wind energy resource need to be compiled. This was done for this project. The site selection criteria that proved particularly critical in the assessment of possible host sites were the degree of exposure to SE/NE prevailing winds during peak season, physical characteristics of existing and available instrument mounts, location with respect to prevailing winds, building or property manager interest and cooperation (equipment installation support, security/controlled roof access, and opportunities for promotion/education), ground mounted tower sites (land use, topography, and soil properties, security, controlled access to towers and data loggers, and zoning, aesthetics, and obstructions within 10 m), and proximity to turbulence-causing obstructions (buildings/structures, hills, ridgeline trees).

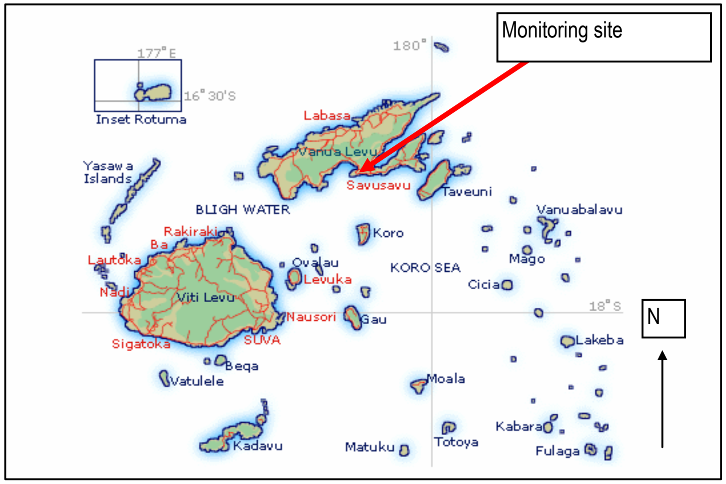
Time-series wind data was obtained from the government weather

monitoring centre in Benau, Savusavu located at 16.798° latitude south and 179.586° longitude north in Fiji. The average wind speed and direction data was recorded at 10-minute intervals at 30 meters above ground level.

Method

The wind speed and direction were measured using a NRG *Type 40 maximum* anemometer and NRG type 200P wind vane mounted at 30m on the tower. The anemometer had a measuring range of 0.5 to 50 m/s with an accuracy of ± 0.5 m/s and a resolution of less than 0.1 m/s. The NRG type 200P wind vane had a continuous rotation of 360° and a sensitivity of approximately 1 m/s. Wind data was collected by a NRG 2000plus data logger. Data intervals were calculated every 10 minutes over a period of 3 years and are written on the data logger. Data from the data logger was retrieved and analyzed using the Wind Atlas, Analysis and Applications Program (WAsP), a software developed by the RISØ National Laboratory, Denmark.

Figure 1: Map of Fiji showing the study area

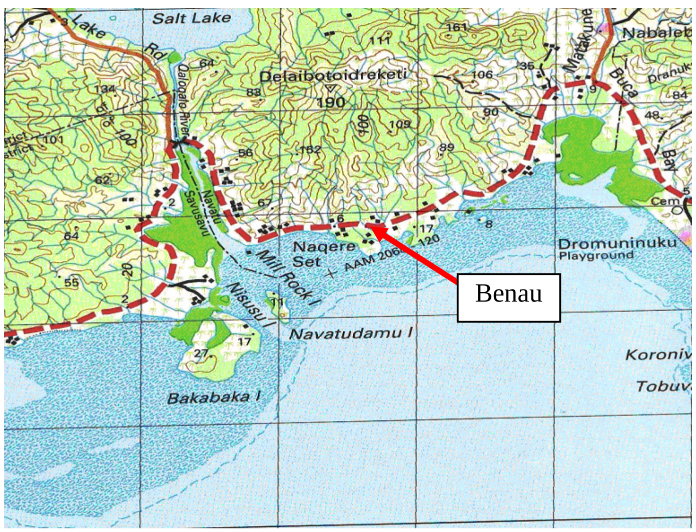


Source: http://www.scaruff.com/travel/fiji.gif

Firstly, the 10 minutes raw data from 1st February 2002 to 30th November 2004 was processed by the Observed Wind Climate (OWC) Wizard in the WAsP software to identify errors in the data which would not have been detected in data summaries. Wind speeds greater than 35 m/s and less than 0 m/s were rejected. Furthermore, wind directions that were above 360 degrees and below 0 degrees, were also rejected.

Secondly, the statistically analyzed wind data (OWC) obtained from the OWC Wizard was corrected to obtain a regional wind climate (wind atlas). Wind at the site of measurement is subjected to different flow depending on the complexity of the terrain, surface roughness and the obstacles around the site of data measurement. Hence the OWC was corrected with respect to the terrain, obstacles and the roughness. To correct the complexity of the terrain, a vector map was introduced. A vector map was prepared for the site by using the 1:50000 topography map as a background map (Figure 2). The vector map contained data of terrain complexity with appropriate height and roughness. The wind flow around the monitoring site was corrected by introducing the obstacle group. The obstacle group contained information about the obstacles around the terrain. 1:1600. Aerial photos were used to prepare the obstacle group. The OWC was corrected for terrain, roughness and obstacles by the WAsP software to obtain a regional wind climate (wind atlas); the roughness of the terrain was in-cooperated into the vector map.

Figure 2: 1:50000 topographic map of Benau, Tacilevu (R24)



The grid spacing is 1km and the heights are in metres.
Source: Dept of Lands, Government of Fiji.

Three available wind turbines (Vesta V27, Vesta V29, and Vergnet Gee 275 kW), with specifications shown in Table 1, were selected for assessment, which included performance analysis of the turbines in this terrain. The resource grid was introduced in WAsP software to locate areas of high wind speed, power density and annual energy output for each wind turbine. Since the turbine rating and the thrust coefficient of the wind turbines are different, the annual energy production (AEP) of the turbines are different. An economic analysis was carried out to evaluate the profitability of each wind turbine and to determine the optimum investment type of turbine for this area. Levelized cost of energy, NPV and cost to benefit ratio were used to assess the economic feasibility of the area. Estimates of the economic analysis of the wind energy system was performed based on the assumption that the project is fully funded and grid connected, together with other parameters which are discussed in the results and discussion sections.

Table 1: Specification of 3 Wind Turbines Considered for Installation at Benau with Basic Perimeters that Affect the AEP.

					Weibull perimeters		
	cut-in (m/s)	Rated power	cut-out (m/s)	AEP from Benau (GWh)	$\bar{U}$ m/s)	A m/s)	k
Vesta V27	4	225 kW	25.00	3.483	6.39	5.30	2.20
Vesta V29	4	225 kW	25	3.835	6.39	5.30	2.20
VergnetGev	3	275 kW	20	4.238	6.39	5.30	2.20

WAsP Software

WAsP is a PC program for predicting wind climates and power productions from wind turbines and wind farms. The predictions are based on wind data measured at stations in the same wind region. The program includes a complex terrain flow model, a roughness change model and a model for sheltering obstacles. WAsP modeling involves:

- analyzing observed wind data to calculate regional wind climate (wind atlases), and
- applying wind atlas to a particular turbine site to calculate an estimated wind climate and power output.

WAsP generalizes a set of surface wind observations into regionally representative wind climatology by modeling the wind flow across the landscape. In the analysis mode (Figure 3), the statistics derived from a set of long-term wind speed and direction data from a long-term reference site are extrapolated to the top of the boundary layer by fitting to a Weibull distribution and modeling the effects due to obstacles, terrain roughness and orography at the reference site. This distribution was used accordingly with Weibull probability density function where *k* is a shape factor and *c* is a scale factor. The Weibull probability density function and the cumulative distribution is given by the following:

$$p(U)=\left(\frac{k}{c}\right)\left(\frac{U}{c}\right)^{k-1}\exp\left[-\left(\frac{U}{c}\right)^{k}\right] \qquad (1.0)$$

$$F(U)=1-\exp\left[-\left(\frac{U}{c}\right)^{k}\right] \qquad (2.0)$$

The resulting wind speed and direction statistics are known as Wind Climate and are representative of the geostrophic wind over the region. In the application mode, a prediction of the wind resource at a candidate site is generated from the Wind Climate data by extrapolating down from the top of the boundary layer, effectively applying the reverse of the analysis process (Jimenez, et al, 2006).

Results / Discussion

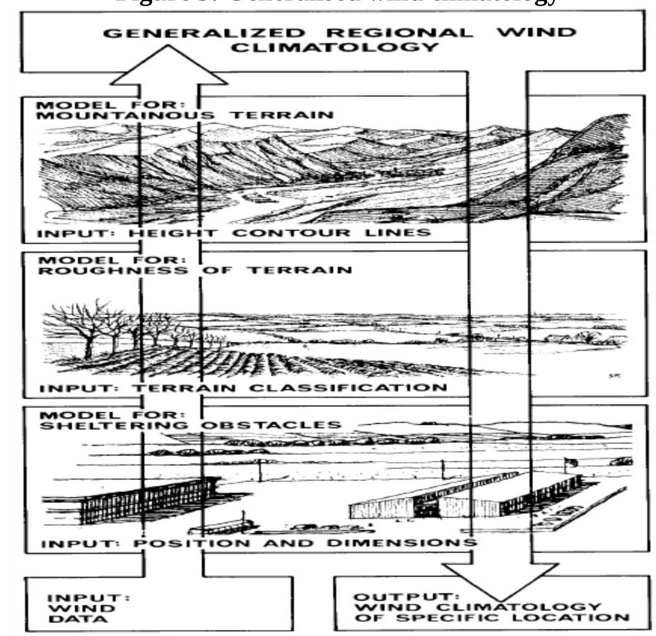
Observed Wind Climate at Benau

The OWC at Benau has a Weibull shape factor (*k*) of 1.33 and the scale factor of 4.1m/s. The mean wind speed and power density for the OWC with and without correction is shown in Table 1. Further analysis shows that there is negligible discrepancy in mean wind speed and power density between the corrected and the observed wind climate. However, there is a 10% discrepancy in predicting the direction of the wind in the south east region as shown in Figure 4. Figure 5 shows the south east as the most frequent direction of the wind with wind blowing from this direction 29% of the time. The pop-up yellow labels give the corresponding frequencies. Red and green sector segments show the differences between the observed wind climate and the self-prediction.

Table 1: The Observed Mean Wind Speed and the Power Density at 30m

	Unit	OWC	Corrected OWC	Weibull-fit	Discrepancy
Mean wind speed at 30m	m/s	3.74	3.81	3.75	1.35%
Mean power density at 30m	W/m²	106.74	104.00	107.18	2.56%

Figure 3: Generalised wind climatology



The Wind atlas methodology of WAsP was the meteorological model that was used to calculate the regional wind climatology from the raw data. In the reverse process of the application of wind atlas data, the wind climate at any specific site may be calculated from the regional climatology (after: Mortensen, et.al, 2004).

Wind Atlas

The wind atlas consists of the wind climate prediction for the whole area, while taking the roughness and complexity of the terrain into consideration. WAsP uses the corrected wind climate data as one of its standard reference conditions to predict the expected wind climate at every point in the terrain. The wind atlas obtained from WAsP contains results for 5 reference roughness lengths (0.000 m, 0.030 m, 0.100 m, 0.400 m, 1.500 m) and 5 reference heights (10 m, 25 m, 50 m, 100 m, 200 m) above ground level (a.g.l). The highest Weibull perimeters predicted for the site are 5.8m/s and 1.67 as the scale factor and shape factor respectively for the highest point in the 25 km^2 area, the power density is predicted to be 276W/m^2 assuming that all the trees were cleared in that area for a wind turbine installation. Thus, a possible choice of a turbine in this area has to have a cut-in speed less than 5m/s in order for the turbine to produce power most of the time. Previous studies (Kumar and Prasad, 2010) show that the average wind speed at a height of 50m in Fiji is between 4 to 6m/s and the predicted wind speed at this point is found to be 5.74m/s, which correlates well with the previous study.

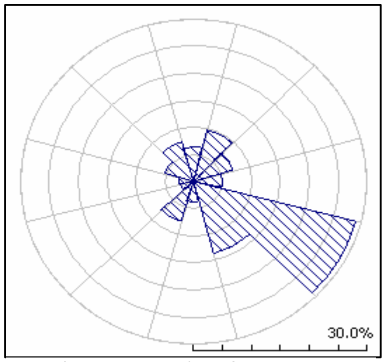


Fig 4: Wind Rose of the Observed Wind Climate at the Met Station

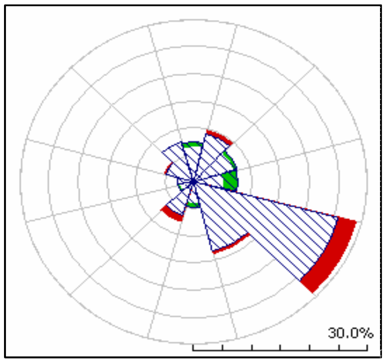


Fig 5: Wind Rose of the Corrected Observed Wind Climate at the Met Station

Resource Grid

Results from the resource grid were used to locate areas of high power density and mean wind speed at 50m around the area of study. The results of power density and wind speed are shown in Figures 6 and 7 respectively. The areas in red indicate areas of high power and wind density. Benau has a highest power density and wind speed of 322 W/m^2 and 6.39 m/s respectively.

The WAsP analysed data also shows that there are regions in the map that have a high wind speed but the power density at this location is not high. Figure 7 shows that there are high winds in the sea but Figure 6

shows that the power density at this location is marginal. Thus, an AEP map of the area was used to locate the areas of high wind energy production for each of the turbines as shown in Figure 8. For the purpose of reliability, two turbines were placed close to the shore with high wind speed whereas the other 6 turbines where placed in the regions of high power density.

Figure 6: The power density variation in Benau.

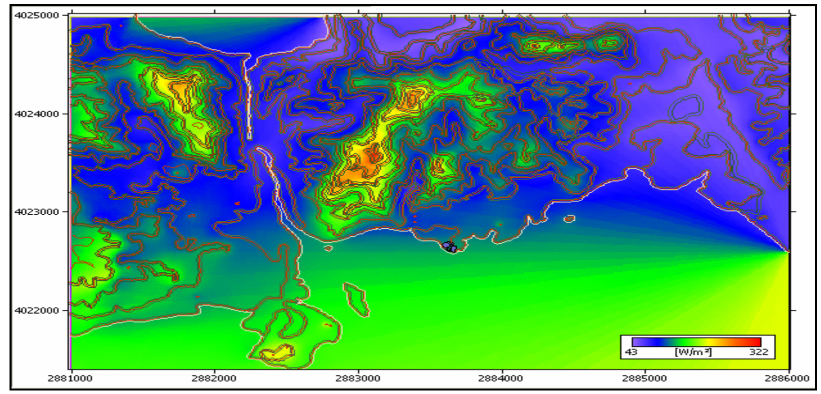


Figure 7: The wind speed variation in Benau.

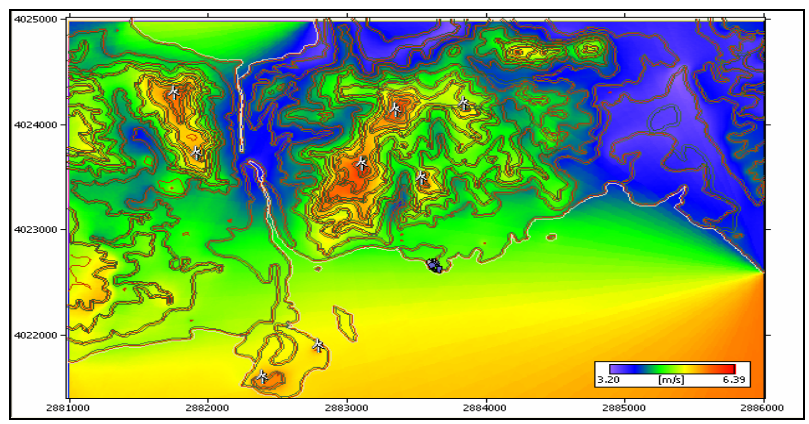
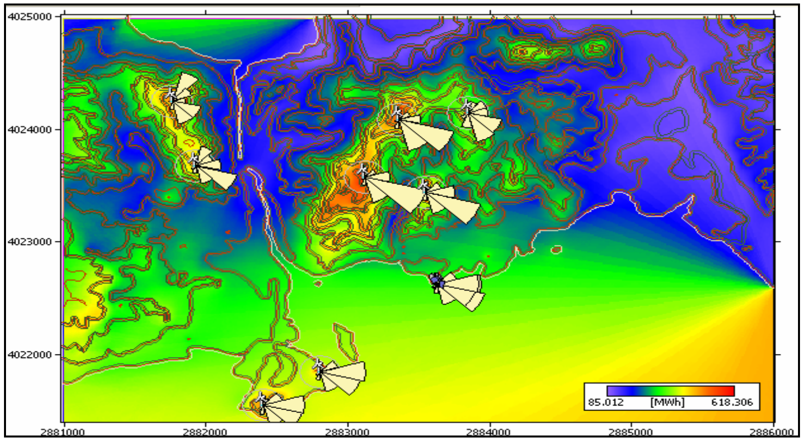


Figure 8 shows the direction in which most of the AEP production for each of the wind turbine sites occurs when using the Vesta V29 225 kW wind turbine generator.

Fig 8: Direction of AEP Production for Each of the Wind Turbine Sites (using Vesta V29 225 kW Wind Turbine Generator)



Benau has the highest power density and wind speed of 322 W/m^2 and 6.39 m/s respectively at 50 m above ground level at the highest point. Thus, as Table 4 shows, it can be said that the VergnetGev (275 kW) wind turbine is the best turbine for Benau. Since Vergnet wind turbine has a lower cut-in speed than Vesta wind turbine. The Vergnet wind turbine produces power when the wind speed is in the range of 3-4 m/s while the Vesta wind turbine does not produce any power. Based on the wind speed data, it can be concluded that the Vergnet wind turbine is better than Vesta wind turbine. However, this information is not enough to predict which turbine is best to use for a maximized energy output since the Vergnet wind turbine is rated at 275 kW and the Vesta wind turbines are rated at 225 kW. Thus a financial analysis needs to be performed to determine which turbine is best. Due to the high rating of the Vergnet turbine, the expected annual output from Benau is high.

An Economic analysis is carried out to determine which turbine optimizes the investment in this area. The economic analysis summary is given in Table 3.

The design and economic lifetime of the wind energy system was assumed to be 20 years (WEC, 1993). This follows the recommendation of the Danish Wind Industry Association (2006), which states that a 20 year lifetime is a useful economic compromise that is used to guide engineers who develop components for wind turbines.

The cost of energy, COE, is defined as the unit cost to produce energy in ($/kWh) from the wind energy system. That is

Cost of energy = (Total costs) / (Energy produced)

The capital recovery factor, CRF, is based on the lifetimes of the system, *L*, and the discount rate *r*. On this basis, the levelized cost of energy multiplied by the annual power production would equal the annual loan payment needed to amortize the net present value (NPV) of the cost of energy system. The benefit-cost ratio (B/C) is one of the economic performance factors that can be used for evaluation of the life cycle based performance of an energy system and is given by:

$$\text{B/C} = \frac{present\ value\ of\ all\ benefits\,(income)}{present\ value\ of\ all\ costs}$$

Generally, systems with a benefit-cost ratio greater than one are acceptable, and higher values of the B/C are desired.

Table 3: Summary Results of Financial Analysis (in FJD$)

	Financial perimeters					
	C_c ($ million)	COE_L (cents)	Payback time (yrs)	CRF	NPV ($ million)	Cost-to-benefit ratio
Vesta V27	7.2	28.8	9.710	0.118	8.496	2.247
Vesta V29	7.2	25.9	8.704	0.118	8.426	2.506
VergnetGev	8.8	28.9	9.627	0.118	10.383	2.266

(C_c – installed capital cost. (source: Berry and Jaccard, 2001)).

Table 3 shows that Vesta V29 wind turbine is the best turbine out of the three since it has the lowest levelised cost of energy with a payback time of 8.704 years and has the highest cost to benefit ratio out of the three turbines.

Thus, from an economic analysis, it can be said that Vesta V29 wind turbine has the potential of maximizing energy output from Benau. However, for investment security, further analysis has to be carried out in order to determine the sensitivity for each of the wind turbines in different economic conditions. The sensitivity of wind energy systems is important in relation to key technical and financial parameters.

Conclusion

In this study, assessments of wind characteristics and wind power potentials around Benau, Savusavu were investigated. The specific aims of the research were attained by constructing OWC at the Benau site, using WAsP model to predict the regional wind climate at Benau and was later verified using the measured on-site data. The economic analysis developed in this report shows that Vesta V29 wind turbines maximizes the energy output of Benau. The maximum cost of energy was found to be 25.8 cents with a cost to benefit ratio of 2.506.

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