AWES2020
20th Australasian Wind Engineering Society Workshop
8 – 9 April, 2021

Prefeasibility Study of Offshore Wind Energy to Support the National Electricity Grid in Fiji

Kunal K. Dayal[1, 2], Rajnish N. Sharma[1] and Sasan Sarmast[2]
[1]*Department of Mechanical Engineering, University of Auckland, Auckland 1023, New Zealand.*
Corresponding Author Email: kday202@aucklanduni.ac.nz.
[2] *Department of Earth Sciences, Uppsala University, Visby SE-621 57, Sweden*

ABSTRACT

This paper carries out a prefeasibility study of offshore wind energy to support the national electricity grid in Fiji in terms of energy output from model offshore wind farms and an economic analysis for Bligh Waters. The objectives were achieved by using reanalysis datasets in WindPRO to carry out energy calculations for a 10 MW and 11.5 MW model offshore wind farms using two different types of offshore wind turbines. The analysis showed that both model offshore wind farms have potential. The best model offshore wind farm was the 11.5 MW wind farm with Siemens wind turbines, which had an AEP of 40,327.5 MWh/year, a capacity factor of 40.0 %, park efficiency of 99.8 % and full load hours of 3507 hours/year. The wind farm has a payback time of approximately 9 years with an installation cost of USD $57,500,000 and AAR of USD $6,452,400. The COE per kWh is computed to be USD $0.11. Hence, comparing this to the COE generation by other renewable and conventional sources in Fiji, it can be concluded that offshore wind energy has potential to support the national electricity grid in Fiji.

Keywords: Model, offshore wind farms, WindPRO, energy and economics.

1. Introduction

Wind energy is a very useful renewable energy resource that is utilized in many developed and developing countries to assist in electrical power generation at large scale supporting the national electricity grid. It is also used at small-scale for stand-alone and hybrid power systems for homes, industrial and rural electrification applications [Mathew, 2006]. Wind energy is a fast-growing industry for power generation with a worldwide installed capacity of 651 GW as of the year ending 2019 and many more resource assessments, construction permits and installations are currently underway worldwide [REN21, 2019; GWEC, 2019].

Fiji is located in the Southwest 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 approximately 18,400 km^2, out of which only 110 islands are inhabited. Around 87 % of the total land area is taken up by the two largest islands of Viti Levu and Vanua Levu. The two islands are of volcanic origin, mountainous and with maximum peak of around 1300 m. The climate in Fiji is tropical with a dry and a wet season. The wet season extends from November to April while the dry season is from May to October.

Fiji has a 10 MW onshore wind farm in Butoni, Sigatoka which consists of 37 Vergnet wind turbines each rated at 275 kW to support its national electricity grid. The electricity generation statistics of Fiji for the year ending 2019 states that renewable energy-based power plants produced 58 % of electricity while fossil fuel-based power plants produced 42 % of electricity. The 10 MW wind farm contributed 0.25 % towards the total electricity generation from renewables while 53 % comes from hydro-power plants and 4.6 % from independent power producers (IPPs) [EFL Annual Report, 2019]. Wind energy research has been carried out around Fiji by using the data provided by NASA's MERRA reanalysis dataset and this, has outlined that the average onshore yearly wind speeds for Fiji is between 5 to 6 m/s with an average power density of 160 W/m^2 [Kumar and Prasad, 2010]. Figure 1 shows Bligh Waters by the highlighted grid area and the location of the micro-site for the model offshore wind farms denoted by "x". The wind farms are modelled 1 kilometer away from the shore of Viti Levu and in water depth of less than 30 meters.

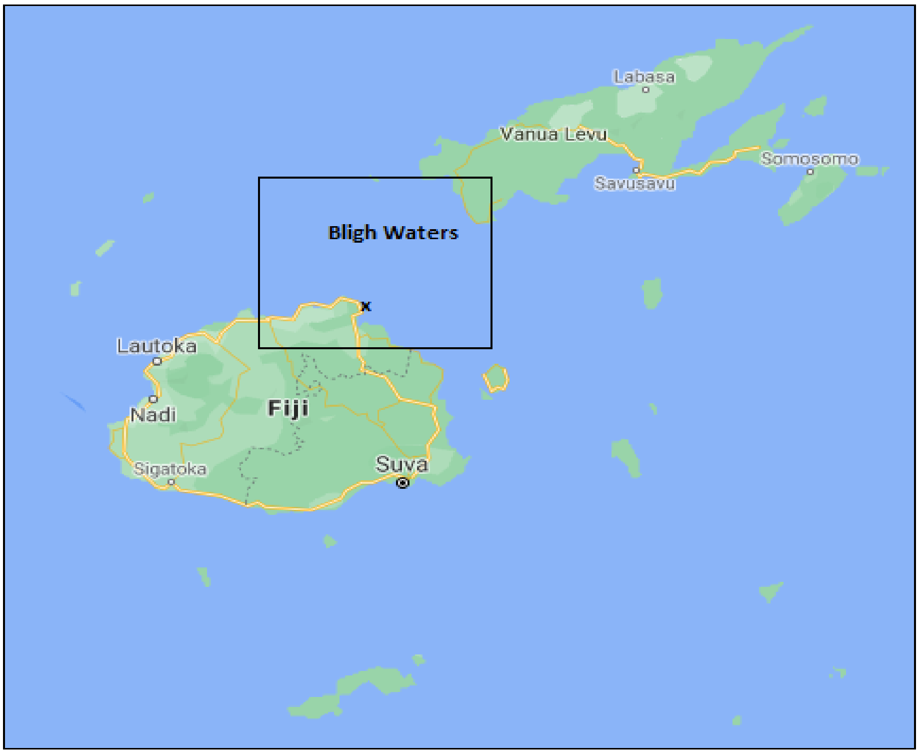


Figure 1. Map of Fiji showing Bligh Waters and the Micro-Site (x) for the Model Offshore Wind Farms.

A prefeasibility study is a preliminary study to explore the possibility of potential wind energy projects considering a number of factors which includes available wind resource, turbine selection, energy yield, foundations, cost of energy generation and payback time among others [Mathew, 2006]. Numerous wind energy related research has been carried out in Fiji using measured wind data from the Fiji Department of Energy onshore wind monitoring program [Fiji Department of Energy, 2020]. The Wind Atlas Analysis and Application Program (WAsP) have been used to carry out a prefeasibility study of wind resource in Vadravadra on Gau island [Singh, 2015], wind energy potential, resource assessment and economics in Qamu, Navua [Kumar and Nair, 2014] and wind characteristics and energy potential at Wainiyaku on Taveuni island [Kumar and Nair, 2013]. For these studies, the mean wind speed, power density, annual energy production (AEP) and the cost of energy (COE) generation ranges from 4.6 – 14.69 m/s, 300 – 1128 W/m^2, 677 MWh – 13.320 GWh, FJD \$0.08 – \$0.55 per kWh at heights of 30 – 55 m, respectively.

The economic viability of a wind power project includes installation costs, operation and maintenance costs and average annual return as per the feed-in tariff per kWh to supply electricity to the grid to determine whether the project is cost effective or not. According to the IRENA report (2020) on Renewable Power Generation Costs in 2019, the installation costs for offshore wind farms ranges from USD \$3000 - \$5000 per kW and this includes overall investment costs [IRENA, 2020]. The average operation and maintenance costs as a function of energy production from the wind turbines of offshore wind farms ranges from USD \$0.008 - \$0.027 per kWh of electricity generated [IRENA, 2020]. The feed-in tariff in Fiji for electricity supplied to the national electricity grid from renewable energy resources by IPPs is priced at FJD $0.30/kWh [Fiji Commerce Commission, 2020] ($0.16 USD/kWh using average exchange rates of 1 FJD = 0.5333 USD).

In a payback analysis computation, the revenue is compared with the costs and the length of time required for recovering the initial investment costs. The payback period in years equals to the total capital costs of the wind energy system divided by the annual revenue generated from the energy produced [Manwell et al., 2009]. In equation form the payback period is expresses as:

$$PP = \frac{C_c}{AAR} = \frac{C_c}{AEP \times P_e} \tag{1}$$

where: PP is the payback period, C_c is the total installation cost, AAR is the average annual return, AEP is the annual energy production (kWh/year) and P_e is the feed-in tariff for electricity ($/kWh).

The cost of energy (COE) is the unit cost to produce energy in $/kWh from a wind energy system [Manwell et al., 2009]. In the form of an equation it is given as:

$$COE = \frac{Total\ costs}{Energy\ produced} = \frac{[(C_c \times FCR) + C_{O\&M}]}{AEP} \tag{2}$$

where: $C_{O\&M}$ is the average annual operation and maintenance cost and FCR is the fixed charge rate. The fixed charge rate refers to the value of interest one pays and or an average annual charge used to account for debt, equity costs and taxes etc.

A study on assessing the impact of renewable technologies on costs and financial risk of electricity generation in Fiji by [Dornan and Jotzo, 2011] outlines the cost of electricity generation in Fiji by different technologies (sources). The cost of energy generation was reported to be FJD $0.20 (USD $0.10) for hydropower, FJD $0.39 (USD $0.21) for oil-power, FJD $0.28 (USD $0.15) for Bagasse, FJD $0.23 (USD $0.12) for biomass and FJD $0.93 (USD $0.49) for onshore wind [Dornan and Jotzo, 2011]. Looking at the COE generation in Fiji it can be stated that hydropower, bagasse, and biomass are amongst the cheapest sources of energy generation in comparison with oil and onshore wind.

This study aims to assess the prefeasibility of offshore wind farms to support the national electricity grid in Bligh Waters Fiji by performing energy calculations for a 10 MW and 11.5 MW model offshore wind farms using two different wind turbines and an economic analysis.

2. Methodology

This study utilized the WindPRO software. WindPRO is a wind simulation software package developed by EMD International A/S and is a very useful tool for wind resource assessment, site suitability assessment and energy calculations among many others.

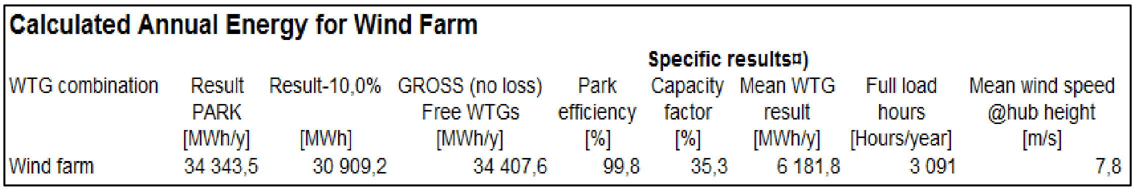
The wind resource data used in this study is from the WindPRO online database. The Climate Forecast System Reanalysis (CFSR) dataset and the CFSR-E dataset which is an extended version of the Climate Forecast System version 1 (CFSR v.1) dataset have been used. The datasets are available at a grid resolution of 0.3° and 0.5° respectively at a temporal resolution of 1 hour. The correlated results of two atmospheric reanalysis datasets mentioned above have been used to perform the AEP calculations for the model 10 MW and 11.5 MW offshore wind farms with two different wind turbine technologies in Bligh Waters, Fiji using WindPRO. WindPRO utilizes WAsP which is an analytical model for the AEP calculations. Wind Atlas Analysis and Application Program (WAsP) is a linear model developed by Risø laboratories in Denmark. The model considers the geostrophic balance, the modified logarithmic wind profile, a specific (but uniform) stability, roughness variations and height variations. WindPRO uses WAsP with wake models and advanced turbulence computation for wind farm AEP calculations.

The cost of investment and the operation and maintenance costs have been adopted from literature [IRENA, 2020]. Maximum costs have been used since Fiji is new to offshore wind so related costs will be high and as Fiji experiences on average two tropical cyclones per year. The procedure to calculate the payback period and the cost of energy generation is also adopted from literature [Manwell et al., 2009]. The cost of energy generation by the model offshore wind farms is compared with the current electricity generation costs from literature [Dornan and Jotzo, 2011] to carry out the prefeasibility of offshore wind to support the national electricity grid in Fiji. The average fixed charge rate of 5.69 % [Reserve Bank of Fiji, 2019] is taken, considering that renewable energy projects have a tax holiday of 5 years in Fiji and with the benefit of importing renewable energy equipment with zero percent fiscal tax [Fiji Revenue and Customs Authority, 2020].

3. Results and Discussion

The correlated mean wind speed of CFSR2 E178.363 S17.274 and CFSR-E E179.00 S17.00 datasets which are close to the micro-site is computed to be 6.5 m/s at a height of 10 m. The mean wind direction is 121.2°, the Weibull mean is 6.5 m/s and the Weibull A parameter which is used to indicate on average how windy the site is, is 7.35 m/s and the Weibull shape parameter k, which outlines how peaked the wind distribution is, is 2.2981 and these values correspond well with the research done in Fiji from literature [Kumar and Prasad, 2010; Singh, 2015]. The mean wind speed at the hub height of the wind turbines is approximately 7.8 m/s which clearly indicates that the site is a good site for wind power development in terms of wind resources [Mathew, 2006; Manwell et al., 2009].

The energy production from the model 10 MW and the 11.5 MW wind farms using different wind turbines with the correlated results from the linear regression MCP close to the micro-site in Bligh Waters is presented in Figures 2 and 3, respectively. The energy calculations have been done using the WindPRO Energy Park module at the hub height of 67 meters and 68.3 meters respectively using a wind shear of 0.10, which represents offshore and water areas.

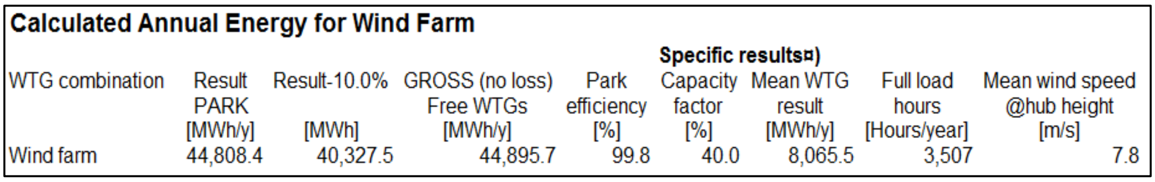


Calculated Annual Energy for Wind Farm

				Specific results¤)				
WTG combination	Result PARK [MWh/y]	Result-10,0% [MWh]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	34 343,5	30 909,2	34 407,6	99,8	35,3	6 181,8	3 091	7,8

Figure 2. 10 MW Model Wind Farm Annual Energy Production using Vestas Wind Turbines.

It can be reported that the 10 MW model offshore wind farm produces 30,909.2 MWh energy annually with a capacity factor of 35.3 %, park efficiency of 99.8 % and full load hours of 3091 hours/year. Each Vestas V80-2.0MW offshore wind turbine produces an average of 6,181.8 MWh annually at a mean wind speed of 7.8 m/s.



Calculated Annual Energy for Wind Farm

				Specific results¤)				
WTG combination	Result PARK [MWh/y]	Result-10.0% [MWh]	GROSS (no loss) Free WTGs [MWh/y]	Park efficiency [%]	Capacity factor [%]	Mean WTG result [MWh/y]	Full load hours [Hours/year]	Mean wind speed @hub height [m/s]
Wind farm	44,808.4	40,327.5	44,895.7	99.8	40.0	8,065.5	3,507	7.8

Figure 3. 11.5 MW Model Wind Farm Annual Energy Production using Siemens Wind Turbines.

The 11.5 MW model offshore wind farm produces 40,327.5 MWh energy annually with a capacity factor of 40.0 %, park efficiency of 99.8 % and full load hours of 3507 hours/year. Each Siemens SWT-2.3-93 2,300 kW wind turbine produces an average of 8065.5 MWh annually at a mean wind speed of 7.8 m/s.

The calculated AEP of the wind farms is a 10 % reduced value from the actual calculation to account for errors in the wind data, correlation calculations, power curve and losses due to wake interaction [WindPRO, 2020]. The energy calculated cannot be directly compared to the existing studies done in Fiji as those done so far are using few small-scale wind turbines. But comparing the AEP of the model offshore wind farms with the existing onshore wind farm it can be reported that the offshore wind resources have a higher potential compared to the onshore wind resources. The 10 MW onshore wind farm has an AEP of 3,150 MWh for the year 2019 [Manwell et al., 2009] while the model 10 MW and 11.5 MW offshore wind farms have an AEP of 30,909.2 MWh/year and 40,327.5 MWh/year respectively. There is a huge difference because the existing onshore wind farm has been poorly planned [The Fiji Times, 2009] with lower hub-height and smaller 2 bladed wind turbines and because offshore wind resources are much higher in comparison with onshore wind resources. Also, the capacity factor of both the model offshore wind farms is better than the operational capacity factor of existing wind farms [IRENA, 2020; Dornan and Jotzo, 2011].

The economic analysis of the 10 MW and the 11.5 MW model offshore wind farms using Vestas and Siemens wind turbines in Bligh Waters Fiji are presented in table 1 in terms of cost of installation, operation and maintenance costs (O&M), annual average return (AAR), payback period (PP) and cost of energy (COE). Note: all costs are in USD.

Table 1. Economic Analysis of the model offshore wind farms in Bligh Waters, Fiji.

Installed Capacity	10 MW	11.5 MW
Wind Turbines	5 × 2 MW	5 × 2.3 MW
Capital Costs	\$50 Million	\$57.5 Million
ARR	\$4,945,472	\$6,452,400
O&M Costs	\$834,548.4	\$1,088,843
PP	10.1 years	8.9 years
Cost of Energy	\$0.12	\$0.11

Performing an economic analysis of the 10 MW model offshore wind farm in Bligh Waters Fiji, it can be reported that the cost of installation is USD \$50,000,000 and AAR per annum is USD \$4,945,472, operational and maintenance cost per annum is USD \$834,548.4 and hence, the wind farm has a payback period of approximately 10 years and the COE generation is computed to be USD \$0.12/kWh. For the 11.5 MW model offshore wind farm in Bligh Waters Fiji, it can be reported that the cost of installation is USD \$57,500,000, AAR per annum is USD \$6,452,400, operational and maintenance cost per annum is USD \$1,088,843 and hence, the wind farm has a payback period of approximately 9 years and the COE generation is computed to be USD \$0.11/kWh.

Since the desired model wind farm is offshore, it is quite expensive in terms of installation costs compared to onshore wind projects in literature therefore, the COE is much higher when compared to the studies done by [Kumar and Nair, 2013] but it is less when compared to the study done by [Singh, 2015]. Also, comparing the COE generation with the present COE generation by other sources in Fiji [Dornan and Jotzo, 2011], it can be reported that both the model offshore wind farms are potentially competitive with sources like hydro-power which has a COE/kWh of USD \$0.10, Biomass USD \$0.12 and is better while comparing it with Bagasse USD \$0.15, Oil-power COE generation which is USD \$0.21 and onshore wind-power which has a COE of USD \$0.49.

Hence, both the model offshore wind farms are feasible but the best one is the 11.5 MW wind farm with Siemens wind turbines as it has a higher AEP, better AAR, higher capacity factor and a better payback period and COE generation in comparison with the 10 MW wind farm with Vestas wind turbines.

4. Conclusions

Energy calculations were performed for 10 MW and 11.5 MW model offshore wind farm using the two correlated datasets close to the micro-site. Both model offshore wind farms are feasible but the best model offshore wind farm was found to be the 11.5 MW wind farm, which had better AEP of 40,327.5 MWh/year with a capacity factor of 40.0 %, park efficiency of 99.8 % and full load hours of 3507 hours/year at the mean wind speed of 7.8 m/s. Each Siemens SWT-2.3-93 (2,300 kW) wind turbine of the 11.5 MW wind farm produces an average of 8,065.5 MWh annually. The wind farm has a payback time of approximately 9 years with an installation cost of USD $57,500,000 and AAR of USD $6,452,400. The COE generation per kWh is computed to be USD $0.11. Therefore, comparing this to the COE generation by other renewable and conventional sources in Fiji, it can be concluded that offshore wind energy is potentially competitive to support the national electricity grid in Fiji.

For further study, it is recommended to carry out mesoscale wind resource mapping of the islands in Fiji to identify appropriate wind resource sites for detailed wind resource and economic analysis.

Acknowledgement

This research was carried out as part of the Research Project for Master of Wind Power Project Management Program 2014-2015 at the Department of Earth Sciences of the Uppsala University, Campus Gotland and recommendations made are currently being carried out as a PhD project at the University of Auckland in New Zealand.

References

Dornan, M. and Jotzo, F. (2011). Electricity Generation in Fiji: Assessing the Impact of Renewable Technologies on Costs and Financial Risk. *Australian ARES 55th Annual National Conference*, Melbourne, Australia.

EFL, Energy Fiji Limited. Annual Report, 2019. Available at: www.efl.com.fj.

EMD International A/S, web: http://www.emd.dk.

Fiji Commerce Commission. Authorization of Independent Power Producer ("IPP") Rates-2nd Phase, 2014. Available at: www.commcomm.gov.fj.

Fiji Department of Energy. Renewable Energy - Wind, 2020. Available at: www.fdoe.gov.fj.

Fiji Revenue and Customs Authority. "Fiji Tax and Customs Incentives", 2012-2013. Available at: www.frca.org.fj.

GWEC, Global Wind Energy Council. Global Wind Statistics, 2019. Available at: www.gwec.net.

IRENA, International Renewable Energy Agency. Renewable Power Generation Costs in 2019. Available at: www.irena.org.

Kumar, A. and Prasad, S. 2010. Examining wind quality and power prospects on Fiji Islands. *Renewable Energy*, 35 (2), 536-540.

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.

Kumar, A. and Nair, K. 2013. *Wind power potential at Benau, Savusavu, Vanua Levu, Fiji. International Journal of Energy, Information and Communications,* 4 (1), 51-62.

Manwell, J.F., J.G. McGowan, and A.L. Rogers, (2009), "Wind Energy Explained: Theory, Design and Application", John Wiley & Sons, Chichester.

Mathew, S., (2006), "Wind Energy: Fundamentals, Resource Analysis and Economics", Springer-Verlag, Berlin, Germany.

REN21. Renewables 2019 Global Status Report (Paris: REN21 Secretariat); 2019.

Reserve Bank of Fiji. Economic Review – May 2019, Volume 35, Number 4, 1 – 3.

Singh, R.A. 2015. A Pre-feasibility Study of Wind Resources in Vadravadra, Gau Island, Fiji. *Energy and Environmental Engineering*, 3(1), 5-14.

The Fiji Times Online. $34 M Failure: FEA admits lack of study in the wind farm project, 2009. Available at: www.fijitimes.com.

WindPRO (2020). WindPRO 2.9 User Manual. Aalborg: EMD International A/S.