Resour Environ Econ, 2020, 2(1): 136-142
DOI: 10.25082/REE.2020.01.005

RESEARCH ARTICLE

Technical and economic prospect of wind energy at Lapaha, Tonga

Ajal Kumar[1] Sione Tausinga[1*] Kaushal Kishore[1] Krisnham Nair[1] Dinesh Rao[2]

Abstract: The wind at 50 m above ground level (a.g.l) was measured for 22 months. The mean wind speed predicted by Wind Atlas Analysis and Application Program (WAsP) at Lapaha was 6.39 m/s and the power density were 279 W/m^2. The prevailing wind direction at Lapaha site was East and Southeast direction with a low turbulence. The WAsP wind map indicated that Lapaha has a good wind potential for power production. A wind farm consisting of four Vergnet 275 kW wind turbines at Lapaha site is expected to pay itself back in 9 years with a Benefit to Cost Ratio (BCR) of 1.74, a Levelized Cost of Energy (LCoE) in Tongan Pa'anga (TOP) of 0.10/kWh compared to TOP 0.86/kWh presently charged to domestic consumers. The expected internal rate of return (IRR) would be 50% and with a life time of 25 years. The expected cost saved from the wind farm is TOP 1.3 million per year, which is equivalent to 1.3 million liters of diesel saved, resulting in 535 tons less CO_2 emitted annually. The proposed wind farm is expected to decrease diesel consumption by 20% annually.

Keywords: wind energy, WAsP, Weibull PDF, Rayleigh PDF, wind farm, Lapaha, Tonga

1 Introduction

The beginning of the 19th century the revolution of development emerged in our world which had driven the demand for energy and accelerated the power generation. It forced the people to dig more into the earth surface for adequate supply of fossil fuel. By the 20th century both development and population rapidly increased depleting the energy resource, consequently yielded in transition to Renewable Energy (RE). However, Kingdom of Tonga located in the midst of the South Pacific with a population of just over 100,000 people has all its grid connected electricity produced from diesel generators. Thus, it makes Tonga vulnerable to any world crude oil price shock. Kumar and Nair[1] stated, that there is a rapid depletion of the world's energy resources with a fast growing in energy demand. This had triggered nations like Tonga to put more emphasis on renewable energy resources and demand the introduction of Renewable Energy (RE) conversion systems in Tonga's main supply.

Wind power system is the most feasible, sustainable and suitable source of RE for Tonga despite the fact that it requires a lot of capital cost for its establishment. However, it demands a precise and quality assessment of the wind resource. Wind assessment and installation of wind farm in Tonga has long been hindered due to lack of reliable wind data. Consequently, Tonga has lagged in wind technology installation compared to other neighboring countries.

2 Background

2.1 Wind assessment in the Pacific

A number of studies have been carried out to assess the potential of wind energy in the South Pacific Countries, *i.e.* Cook Islands, Fiji, Kiribati, Tuvalu, Niue, Samoa and Vanuatu. Apart from Fiji, these countries depend heavily on imported diesel to generate electricity with a small portion of Renewable energy mix. Wind Resource Assessment (WRA) in Samoa conducted at two sites in Samoa found that were not feasible to drive commercial wind turbines. Even though, wind speeds beyond 5 m/s were present but the monthly variance were large and thus undesirable for wind turbines operation[2]. Wind measurement conducted in Cook Islands suggested a small scale wind farm with estimated mean wind speed between 6.1 and 7.5 m/s at 30 m a.g.l,[3]. Rarotonga Electricity Authority had installed four small wind turbines with total rated capacity of 11.2 kW. Thus, it indicates that wind energy capacity in Cook Islands is slowly building up compared to other Pacific Island Countries (PICs)[4]. Tuvalu has re-

Received: March 20, 2020 **Accepted:** April 10, 2020 **Published:** April 15, 2020

* **Correspondence to**: Sione Tausinga, School of Engineering and Physics, University of the South Pacific, Laucala Campus, Suva, Fiji; Email: sl_tausinga@yahoo.com
[1] School of Engineering and Physics, University of the South Pacific, Laucala Campus, Suva, Fiji
[2] School of Computing and Mathematics, University of the South Pacific, Laucala Campus, Suva, Fiji

Citation: Kumar A, Tausinga S, Kishore K, *et al*. Technical and economic prospect of wind energy at Lapaha, Tonga. *Resour Environ Econ*, 2020, **2**(1): 136-142.

cently embarked on wind energy technology assessment and Funafuti's data showed a mean wind speed of about 4.74 m/s at 20 m a.g.l[5]. The Republic of Kiribati measured wind at 34 m a.g.l from 2009 to 2011 on Kiritimati Island and found that wind was mostly from the Northeast, with an average annual wind speeds between 6.7 and 6.6 m/s. These magnitude of wind is considered good, but not an excellent wind resource[6]. Vanuatu is quite successful with a 3.025 MW wind farm at Devil's Point. The wind farm comprises of 10 × 55 m high de-mountable wind turbines. Fiji has a 10 MW Butoni wind farm installed in 2007. The Butoni wind farm consists of 37 wind turbines each with a generating capacity of 275 kW at a rated wind speed of 12 m/s[7].

2.2 Wind resource assessment in Tonga

A small 11 kW grid connected wind turbine installed at Nakolo operating efficiently. Palmer[8] stated, the prefeasibility study conducted by the SPC-GIZ under Coping with Climate Change in the Pacific Island Region (CCCPIR) program, predicted the availability of a long-term wind resource on the eastern side of Tongatapu, the main island of Tonga.

3 Methodology

Lapaha with a population of 7500 is located on the Eastern site of Tongatapu, about 20 km form Nuku'alofa[9]. It is one of the biggest villages in Tonga and their main income is export agricultural products. The dependence on agriculture determine their settlement allocation, the people are settled on the Western side leaving the Eastern side available for agricultural use. The terrain at Lapaha site is mainly flat (Figure 1) and is approximately 10 to 15 m above sea level (a.s.l).

Figure 1. Lapaha site with wind mast location[10] (175.6°W, 21.2°S)

The wind mast at Lapaha monitoring site consisted of six cup anemometers, mounted in pairs at 30 m, 40 m and 50 m above ground respectively, with wind vanes mounted at 37 m and 48 m and the temperature sensor mounted at 2 m height. Each sensor was connected to the NRG Symphonies PLUS data logger. Anemometer NRG#40 was used for measuring wind speed, the wind direction was measured using Wind Vane #200P and thermometer NRG 110S was used to measure temperature[11]. The measurement was carried out at 50 m a.g.l for 22 months from July 2010 to April 2012.

3.1 Wind statistics and economics

Wind is a very powerful natural phenomenon carrying an enormous amount of energy. This energy can be converted into useful electrical energy using a wind turbine[12–16]. The amount of energy available in wind on a selected site can be calculated using:

$$P = \frac{1}{2}\rho A v^3 \tag{1}$$

Where P (W) is the power, ρ is the air density (kg/m^3), A is the cross-sectional area (m^2) and v is the wind speed (m/s). The amount of energy that can be extracted by a wind turbine is

$$P = \frac{1}{2}\rho A v^3 C_p \tag{2}$$

where C_p is the power coefficient that determines the amount of power the wind turbine can extract from the selected site.

In WRA statistical analysis is used to determine the availability of the potential wind resources at a known site and to estimate the energy production from the wind turbines. Two probability distribution functions Weibull and Rayleigh distribution are generally accepted distribution used widely to study wind speed distribution and direction[17].

The energy production of the turbine is dependent on the mean wind speed and the statistical frequency of occurrence of the wind speed for a defined time period. Weibull probability distribution f (v) is used to statistically analyze the wind speed data is based on the two parameters, the shape parameter k and scale parameter c.

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} exp\left[-\frac{v}{c}\right]^k \tag{3}$$

The c and k values can be determined using the Methods of Moment based on the law of large numbers, thus:

$$\begin{aligned} &\overline{v} = c\Gamma\left(1+\frac{1}{k}\right), \; where \; \overline{v} = \frac{1}{n}\sum_{i-1}^{n} v_i \\ &and \; \sigma = \left[\frac{1}{n-1}\sum_{i-1}^{n}(v-\overline{v})^2\right]^{\frac{1}{2}} \end{aligned} \tag{4}$$

Here $\overline{v}$ and σ are mean and standard deviation for the measured wind speed data respectively. The Energy pattern factor E_{Rf} is the ratio between the average cube of the wind speed and the cube of the average wind is given by:

$$E_{Rf} = \frac{\frac{1}{n}\sum_{i-1}^{n} v_i^3}{\left(\frac{1}{n}\sum_{i-1}^{n} v_i\right)^3} \tag{5}$$

An approximation value of shape parameter k can be determined using:

$$k = 1 + \frac{3.69}{E_{Rf}^2} \tag{6}$$

and the scale parameter c can be determined using:

$$c = \left(\frac{1}{n}\sum_{i-1}^{n} v_i^k\right)^{\frac{1}{k}} \tag{7}$$

In probability theory and statistics, the Rayleigh Distribution (RD) is a continuous probability distribution for positive valued random variables. According to[18] the RD function is derived from the amplitude of sound resulting from many important sources. A random variable U is said to have a RD function then its probability density function (PDF) is given by:

$$p(U) = \frac{\pi}{2}\left(\frac{U}{\overline{U}^2}\right) exp\left[-\frac{\pi}{4}\left(\frac{U}{\overline{U}^2}\right)^2\right] \tag{8}$$

The economic feasibility of a wind farm is one of the important factors that should be considered when designing a wind farm. Sathyajith[19] stated that, the relevant question to ask is "At what cost can we generate electricity?" It means that the wind farm should operates at its maximum output with minimum cost as possible. The exorbitant capital cost of wind turbines has not allowed the South Pacific regional countries to make quick change to renewals.

The Net Present Value (NPV) cost includes the incurred cost in a wind energy project over its life time of n years such as the capital cost and the operation and maintenance costs is calculated using:

$$NPV\,(Cost) = C_A = C_1\left\{1 + m\left[\frac{(1+I)^n - 1}{I\,(1+I)^n}\right]\right\} \tag{9}$$

Where C_A is the annual operational cost, I real discount rate, n life time of the project, m is the percentage of operation and maintenance cost and C_I capital cost.

The benefits and profit from the wind farm then can be calculated using:

$$NPV\,(Benefit) = B_A\left[\frac{(1+I)^n - 1}{I\,(1+I)^n}\right] \tag{10}$$

Net NPV gives a preview of the economic viability of a wind farm. Gnatowska[20] stated, the net present value indicates the economic efficiency of any wind farm.

$$\begin{aligned} NetNPV &= NPV\,(Benefit) - NPV(Cost) \\ &= \left\{B_A\left[\frac{(1+I)^n - 1}{I\,(1+I)^n}\right]\right\} - \left\{C_I\left\{1 + m\left[\frac{(1+I)^n - 1}{I\,(1+I)^n}\right]\right\}\right\} \end{aligned} \tag{11}$$

Internal Rate of Return (IRR) is the discount rate when the NPV is equal to zero. The investment is profitable when the IRR is greater than the discount rate, thus (IRR $>$ r), the higher the IRR the better[20]. It is determined using:

$$IRR = \frac{NPV(Benefit)}{NPV(Cost)} \tag{12}$$

Wind[21] stated, the payback period is equal to the total capital cost of the system divided by the average annual return production of energy from the wind turbine. Thus:

$$PBT = \frac{Capital\ \cos\ t}{Averageannual\ Return} \tag{13}$$

The levelised cost of energy per kilowatt hour LCoE (Equation 14) is the term of interest for both the investor and consumer.

$$LCoE = \frac{Total\ \cos\ t}{Energy\ produced} \tag{14}$$

The avoided cost is mainly evaluated from the perspective of the amount saving from importing diesel. To do so the fuel cost needs to be assessed because saving this expense permits further investment in wind energy capacity building[22,23].

Wind turbine can significantly cut down the amount of CO_2 emitted to the atmosphere each year. This can be quantified using CO_2 conversion factor; one liter of Diesel emits 2.68 kg CO_2.

4 Results and Discussions

The wind speed variation (Figure 2) shows that all year round, the wind speed at Lapaha site in every 10 minutes intervals were mostly greater than the cut-in wind speed of Vergnet 275 kW wind turbine.

However, during March to end of May the wind speed is below the cut-in wind speed. The below average wind speed experienced may be due to thermal inversion effect that is prevalent on the island[24].

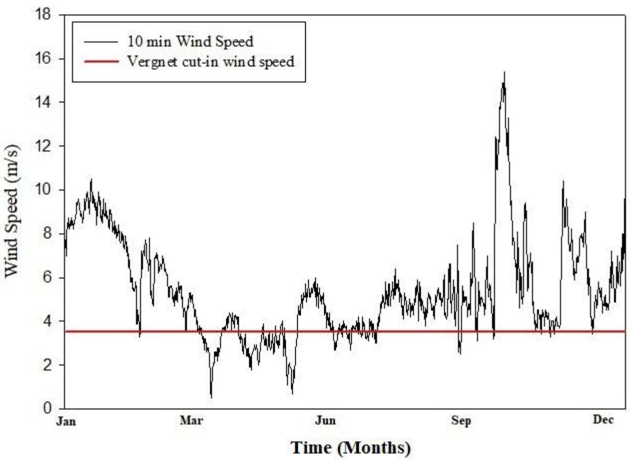

Figure 2. Annual wind speed variation (10 min averages) at Lapaha site

The diurnal mean wind speed variation for 22 months (Figure 3), shows how the hourly wind speed varied throughout the day at Lapaha site. The wind speed is generally stable at around 6.5 m/s during the night and early mornings. It starts to decrease after midday as the sun starts to set and increases slowly into the night. The 10 min averaged wind speed for the hour shows a dip around 3:00 pm. This may be due to the decrease in temperature differential and thus change of breeze after this[25]. The minimum mean wind speed of 6.01 m/s translates to 27 kW. It should bear in mind that the mean hourly wind speed in the 24 h cycle is greater than 3.5 m/s the cut-in wind speed of Vergnet 275 kW turbine. Hence, on an average Vergnet 275 kW would produce a minimum of 27 kW of power during the day.

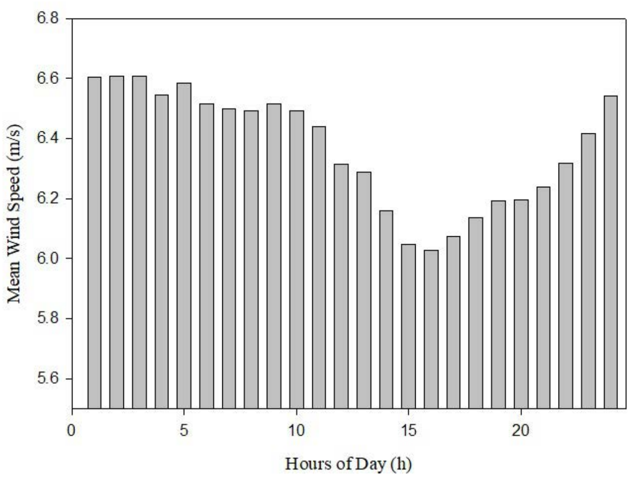

Figure 3. Diurnal hourly mean wind speed at Lapaha site at 50 m a.g.l

The turbulence intensity (TI) has a negative effect on the power output of a wind turbine. TI is associated with an increased wind shear which may reduce wind turbine performance[26]. Thus, with an increasing TI, the power output is overestimated at moderate wind speeds and underestimated at higher wind speeds. The variation in daily TI (Figure 4) shows that the wind at Lapaha site is less turbulent.

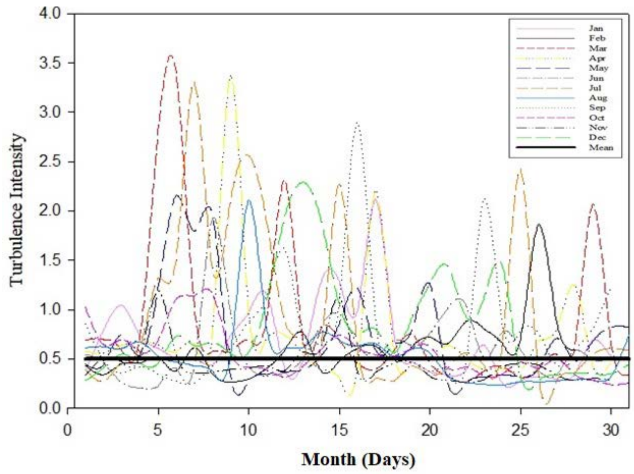

Figure 4. Daily and mean TI at 50 m a.g.l at Lapaha site

The Wind rose (Figure 5(a)) shows that the wind at Lapaha site is predominantly blowing from the East to South East. The mean wind at Lapaha site (Figure 5(b)) is 6.39 m/s at 55 m a.g.l (hub height of Vergnet 275 kW wind turbine) and with a mean power density of 279 W/m^2, a fair value for wind farm installation. Researchers[13, 25, 26] randomly carried out wind assessment in Chad, Fiji and Ethiopia determined the power density as 343.3 W/m^2, 160 W/m^2 and 287 W/m^2 respectively and declared as a fair site for wind farm.

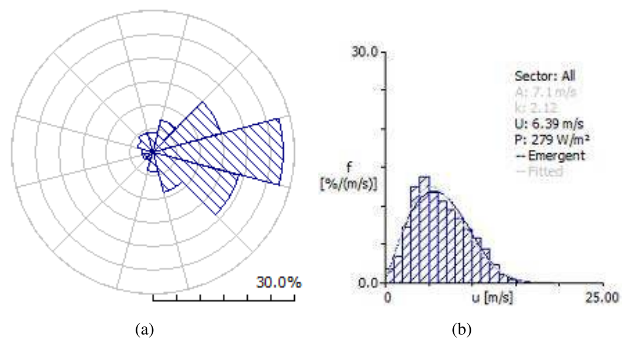

Figure 5. (a) Wind rose; (b) Wind speed distribution for the Lapaha site

The roughness map of Lapaha site within five kilometers radius from the wind mast (Figure 6) shows elevation differentials indicated by colors. The roughness map shows that the elevation ranges from 0 to 70 m a.s.l. The elevation surrounding the wind mast is approximately 30 m a.s.l, and is considered generally flat.

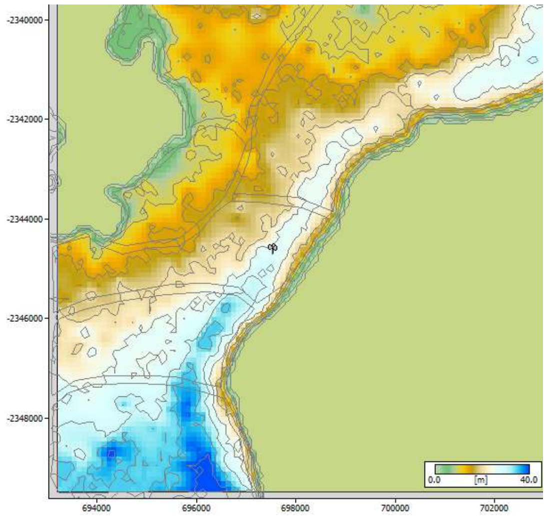

Figure 6. Lapaha site roughness map

The AEP map (Figure 7) shows an approximately 1001 MWh of annual energy can be produced using a 275 kW vergnet wind turbine at the measuring site. The AEP depends on the power density and the wind turbine characteristics. Therefore, inspecting the AEP map reveals that, the site has a promising wind resources available that could be utilized for electricity generation.

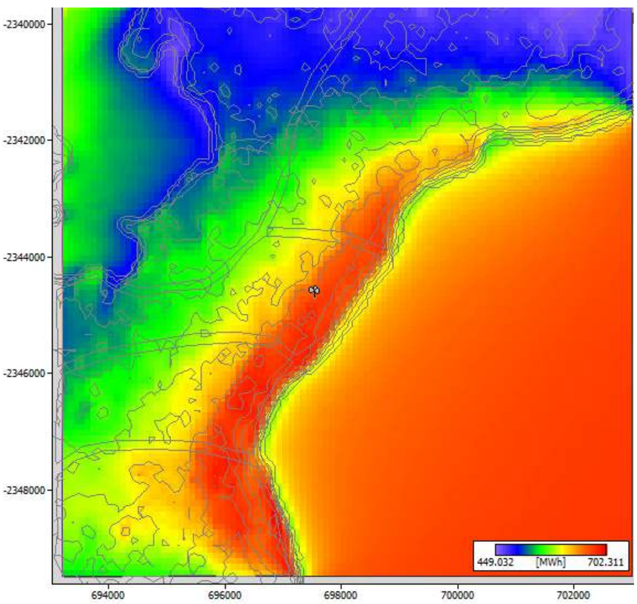

Figure 7. AEP map for a 275 kW Vergnet wind turbine for Lapaha

The proposed wind farm at Lapaha derived from Figure 8 consists of four Vergnet 275 kW wind turbines in a linear configuration perpendicular to the East to Southeast prevailing wind. The location of the suggested wind farm is approximately 3.5 km from the closest settlement area. According to[27,28], if the wind farm is normal to the wind direction than the distance between each wind turbine is four times the diameter of the rotor. Thus, the horizontal distance between turbines is 128 m (D = 32 m for vergnet wind turbine); However, a 50 m concession is allowed on both ends to avoid any naturally occurring obstacles that may affect the turbine's performance.

Figure 8. Lapaha wind farm outlook

From Table 1 it displays an economic analysis of a 5 different types of wind turbines. However, as from the table it shows clearly that Vergnet 275 kW is the best choice for a wind farm in Tonga.

Based on the Vergnet 275 kW, the BCR and the payback period were calculated to be 1.74 and 9 years respectively. The cost of energy was found to be Tongan Pa'anga (TOP) 0.10/kWh. The current cost of electricity in Tonga is TOP 0.86/kWh[29], which means that the proposed wind farm energy cost is comparatively lower. Moreover, the IRR was determined to be 50%. The payback period of 9 years indicates that it is feasible to develop a wind farm at Lapaha site (Table 1).

Using the Vergnet 275 kW, the proposed wind farm installed is expected to save a total 1.3 million liters of diesel per year which is equivalent to a total of TOP 2.90 million per year (Using the amount of TOP 2.40/L for diesel) and is estimated to save a total of 535 tons of CO_2 per year being added into the atmosphere. However, with wind farm the life time of 25 years a large amount of saving is expected. In addition, the Tonga Power Limited's (TPL) financial report[30], that a TOP 19.2 million was used to procure diesel for electricity generation. Also, the use of renewable energy, like wind in a particular has saved the country TOP 3.2 million in 2018.

The Table 2 shows the probability of wind at Lapaha site. It is a very important aspects of wind farm design, which can be able to predict or forecast the output of the wind farm installing at Lapaha site. Table 2 indicates that most of the wind at Lapaha site falls in the range of 3.5 m/s and 12 m/s. This is the productive range of Vergnet

Table 1. Technical and Economic analysis of wind turbines

Turbine's name	Vergnet	Vesta	Bonus	Power Wind	Enercon E33
Capacity per Turbine (kW)	275	250	300	225	330
Wind Farm Capacity (kW) 4 Turbines	1100	1000	1200	900	1320
AEP per Turbine (GWh)	0.49	0.48	0.54	0.36	0.72
Wind Farm AEP (GWh)	1.96	1.92	2.14	1.3	2.83
Cost for one Turbine (MFJD)	0.626	0.569	0.682	0.66	0.523
Cut-in Wind Speed (m/s)	3.5	4	3	3	3
Cut-out Wind Speed (m/s)	25	25	25	25	25
Rated Wind Speed (m/s)	12	14	13	12.5	11.5
Rotor Diameter (m)	32	29	33.4	56	33
Hub Height (m)	55	32	30	59	41
Number of Blade	2	2	3	3	3
Cost per kiloWatthour ($/kWh)	2276	2276	2273	2276	2274
Folding	Yes	No	No	No	No
BCR	1.74	1.72	1.59	1.12	2.78
Payback time (y)	9	9	10	19	5
LCoE ($/kWh)	0.1	0.09	0.08	0.15	0.06
IRR (%)	50	82	76	76	80
Life time (y)	25	25	25	25	25
Diesel saved (ML/y)	1.3	0.19	0.21	0.13	0.28
Amount saved (MFJD)	2.9	0.36	0.4	0.25	0.53
CO_2 saved (t/y)	535	515	573	348	758

Note: Cost of turbines was adopted from Butoni Wind Farm Installation cost (Fiji) FJD 3345/kW

275 kW wind turbine. However, it clarifies that Vergnet 275 kW is the most suitable turbine for Lapaha site.

Table 2. Lapaha site wind prediction

Probability	Values
$P(3<x\leqslant 3.5)$	0.051
$P(3.5<x\leqslant 4)$	0.056
$P(4<x\leqslant 12)$	0.696
$P(x\geqslant 12)$	0.048
$P(x\geqslant 14)$	0.015

5 Conclusion

The comprehensive economic analysis showed that the proposed wind farm at Lapaha is economically viable and will benefit the people and the nation of Tonga as whole. The wind farm will save a total 1.3 million liters of diesel per year which is equivalent to a total of TOP 2.90 million per year and avoid a total of 535 tons of CO_2 released annually. Compared to present cost of electricity the proposed farm is expected to provide a cheaper environmental clean and consistent alternative to diesel. The saving from the proposed farm can be used to build better infrastructure and improve health and education facility on the Island.

Acknowledgement

The author acknowledges the University of the South Pacific Engineering and Physics Department for allowing me to carry out this work and to the Tonga Energy Department MEIDECC for providing the wind measured data for Lapaha site.

References

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

[2] Monthly WP. Samoa gets first wind project — Windpower Monthly. 2014. https://www.windpowermonthly.com/article/1309994/samoa-gets-first-wind-project

[3] Isaka M, Mofor L and Wade H. Pacific Lighthouses: Kiribati. 2013.

[4] Zieroth G. Feasibility of grid-connected wind power for Rarotonga cook islands draft report feasibility of grid connected wind power for Rarotonga Cook Islands, 2006.

[5] Sarah H and Radanne P. Tuvalu Renewable Energy Study Current Energy Use and Potential for Renewable Energies, 2006.

[6] Services I. Wind energy feasibility study for kiritimati island republic of Kiribati client Energy Planning Unit, Ministry of Public Works, Republic of Kiribati, 2012.

[7] EFL. Wind Energy Projects — Energy Fiji Limited, 2018. http://www.fea.com.fj/about-us/renewable-projects/wind-electricity-projects/

[8] Palmer-Wilson AK, Matzarakis PA and Cheng PP. Report based on the master thesis for the partial fulfillment of the requirements to be awarded the Master of Science in Renewable Energy Management: A Pre-Feasibility Study on Wind Energy for Tongatapu Island , Kingdom of Tonga First Examiner: Second E, 2012.

[9] Tonga Department of Statistic. Tonga 2006 census of population and housing: Administrative report and basic tables, Vol. 1, 2008.

[10] Googlemap. Mua - Google Maps, 2018. https://www.google.com/maps/place/Mua,+Tonga

[11] ADB. Guidelines for Wind Resource Assessment Best Practices for Countries Initiating Wind Development. **2014**: 1-49.

[12] Topalo F. Analysis of Wind Data, Calculation of Energy Yield Potential, and Micrositing Application with WAsP and Huseyin Pehlivan. Advances in Meteorology, 2018, ID: 2716868. https://doi.org/10.1155/2018/2716868

[13] Waewsak J, Chancham C, Landry M, *et al*. An Analysis of Wind Speed Distribution at Thasala, Nakhon Si Thammarat, Thailand. Journal of Energy and Environmental Sustainability, 2011, **2**: 51-55.

[14] Carrasco-Diaz, Magdiel-Rivas D , Orozco-Contreras M, *et al*. An assessment of wind power potential along the coast of Tamaulipas, northeastern Mexico. Renewable Energy, 2015, **78**: 295-305. https://doi.org/10.1016/j.renene.2015.01.007

[15] Dawde OY. Wind Resource Data Analysis: The case of MYDERHU project site, Tigray regional state, Ethiopia, 2013.

[16] Khadem SK and Hussain M. A pre-feasibility study of wind resources in Kutubdia Island, Bangladesh. Renewable Energy, 2006, **31**(14): 2329-2341. https://doi.org/10.1016/j.renene.2006.02.011

[17] Venkata S and Krishnamurthy S. Wind energy explained: Theory, Design, and application. Power & Energy Magazine IEEE, 2003, **1**(6): 50-51. https://doi.org/10.1109/MPAE.2003.1243963

[18] Yahaya A and Yohanna AA. A Note on Generalized Weibull-Rayleigh Distribution with Its Applications. 2017, **1**(1): 174-178.

[19] Sathyajith M. Wind Energy: Funamentals, Resource Analysis and Economics. 2006.

[20] Gnatowska R and Was A. Wind Energy in Poland - Economic analysis of wind farm (E3S Web Conf.), 2017. https://doi.org/10.1051/e3sconf/20171401013

[21] Wind. The payback period, return on investment and cost per kilowat-hour of wind power, 2018.

[22] Knight J. Wind Power vs Diesel Power vs Solar Power (Comparison) Uprise Energy Portable Renewable Energy. Uprise Energy, 2012. http://upriseenergy.com/blog/2012/9/15/wind-power-vs-diesel-power-vs-solar-power-comparison

[23] AWEA. Wind Power Environmental Benefits, 2017. https://www.awea.org/wind-101/benefits-of-wind/environmental-benefits

[24] Kusiak A and Song Z. Design of wind farm layout for maximum wind energy capture. Renewable Energy, 2010, **35**(3): 685-694. https://doi.org/10.1016/j.renene.2009.08.019

[25] Werapun W, Tirawanichakul Y and Waewsak J. Wind Shear Coefficients and their Effect on Energy Production. Energy Procedia, 2017, **138**: 1061-1066. https://doi.org/10.1016/j.egypro.2017.10.111

[26] Jose L, Stival L, Guetter AK, *et al*. The impact of wind shear and turbulence intensity on wind turbine power performance O impacto do cisalhamento do vento e da intensidade de turbulência no desempenho da turbina eolica. 2017, **27**(27): 11-20.

[27] Soulouknga MH, Doka SY, Revanna N, *et al*. Analysis of wind speed data and wind energy potential in Faya-Largeau, Chad, using Weibull distribution. Renewable Energy, 2018, **121**: 1-8. https://doi.org/10.1016/j.renene.2018.01.002

[28] Kumar A and Prasad S. Examining wind quality and wind power prospects on Fiji Islands. Renewable Energy, 2010, **35**(2): 536-540. https://doi.org/10.1016/j.renene.2009.07.021

[29] TPL. Wind Power, Tonga Power Limited, 2013. http://www.tongapower.to/OurBusiness/RenewableEnergy/WindPower.aspx

[30] TPL. Solar Energy Projects — Tonga Power Limited, 2014. http://www.tongapower.to/OurBusiness/RenewableEnergy/SolarEnergyProjects.aspx