Economic and Financial Analysis for a Proposed Small Wind Turbine System: Case Study for Fiji

Ravita Prasad

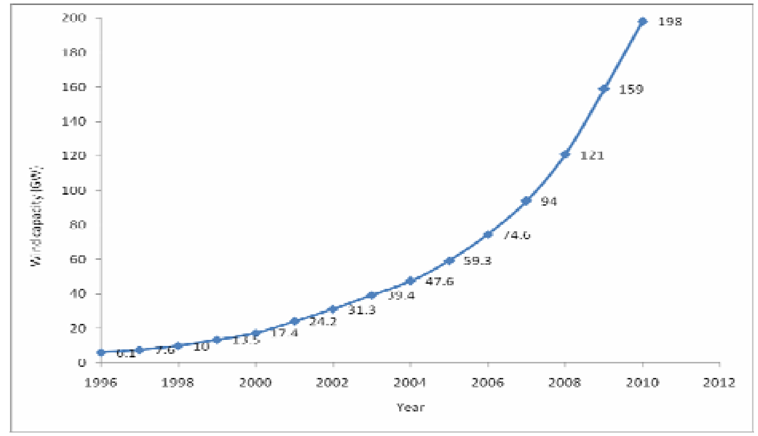
Abstract

For any wind energy conversion system, nearly 90% of all the life cycle costs (LCC) is during the initial stage. The economic and financial viability of electricity generation from wind energy is dependent on the level and extent of energy content in wind prevalent at a particular site, and on the payment expected for the power generated. This paper presents a brief overview on the economics of wind energy conversion systems (WECS) and a case study on economic and financial analysis for a proposed wind turbine at Vadravadra site in Gau Island in Fiji.

Introduction

Electricity from wind energy conversion system is claimed to be economical and environmentally sound since wind resource is free, clean, and renewable. Turbines are becoming cheaper and more powerful with larger blade lengths which can utilize more wind, therefore, producing more electricity and bringing down the cost of renewable energy generation (BWEA; Burton et. al, 2001; Hau and Renouard, 2006; Harrison et. al, 2000). According to REN21 (2011) as shown in Figure 1, the total wind power installed capacity globally till 2010 has been 198 Gigawatts (GW). On average there is a 28% annual increase in installed capacity of global wind power. It can, therefore, be hypothesized that the cost of wind power has been decreasing. REN21 (2011) reports that China is leading in total installed wind power capacity, followed by the United States and Germany respectively.

Figure 1: Existing Global Wind Power Capacity from 1996-2010



Source: REN21, 2011

There are two main influences which affect the cost of generating electricity from wind and the final price of the power generated: (i) technical factors, such as wind speed and the nature of the turbines, and (ii) the financial perspective of those that commission the projects, e.g. what rate of return is required on the capital, and the length of time over which the capital is repaid (BWEA, 2011). To be economically viable, the cost of generating electricity has to be less than its selling price.

Wind Turbine Systems Economic Components

The main factors involved in wind power economics are investing costs, operation and maintenance costs, wind regime of a site, availability of wind turbine, turbine life time, and the discount rate. In addition, another economic component of wind power is its market value.

Availability is the percentage of the time in a year that the wind turbine is able to generate electricity. The time when a wind turbine is not available includes downtime for periodic maintenance or unscheduled repairs. *Life-time* is the economic life of the system. It is common practice to equate the design life time with the economic life time of a wind energy system. In Europe, an economic life time of 20 years is often used for the economic assessment of wind energy systems (Manwell et. al, 2002).

Wind regime is the distribution of wind speed through a year, where the wind turbine is supposed to be commissioned. It can be presented in a wind speed duration curve or wind speed frequency curve. Wind speed duration curve shows the number of hours that wind speed exceeds a particular value while wind speed frequency curve shows the number of hours in a year that a particular wind speed will occur. For instance, the wind regime for Vadravadra site in Gau Island in Fiji is shown in Figure 2 and Figure 3. Wind regime determines the annual wind energy yield from a site by convolving a wind turbine's power curve. The annual energy yield determines the economic viability of a wind energy project; this will be discussed in Section 3 of this paper.

Figure 2: Wind Speed Duration Curve for Vadravadra

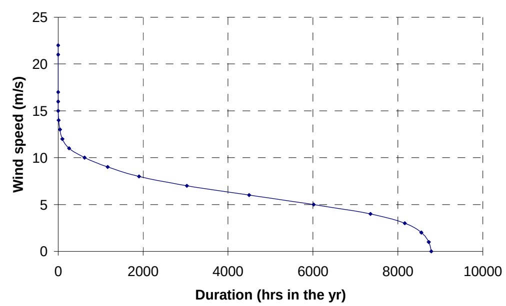
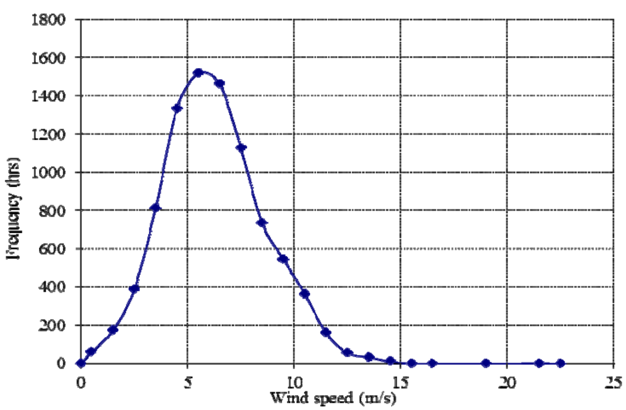


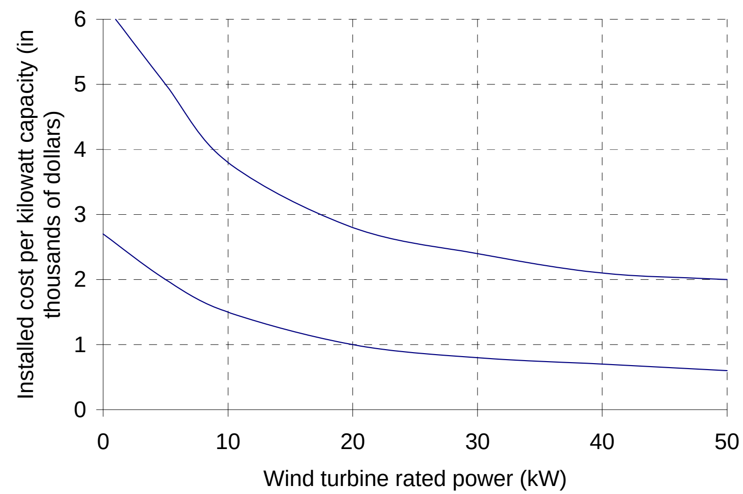
Figure 3: Wind Speed Frequency Curve for Vadravadra in 2004



Investment Costs

Investment cost of a wind turbine includes the cost of wind turbine and its auxiliaries. Wind energy projects require large investments during the initial stages of the project for the purchase and installation of equipment. Over the lifetime of the project, the cumulative interest can add up to a significant amount of the total costs. Auxiliaries include tower, wiring, utility interconnection or battery storage equipment, power conditioning unit, delivery and installation charges, and professional fees and taxes (Gipe, 2004). Figure 4 shows the typical installation costs of wind turbines in remote areas; these could be typically varying between the two curves depending upon siting conditions.

Figure 4: Installation cost of wind turbines (US Currency)



(Source: Iowa Energy Centre)

Operations and Maintenance (O&M) Costs

O&M costs are related to a limited number of cost components, including insurance, regular maintenance, repair, spare parts and administration. The relative compositions are given in Table 1 (Iuga, 2009). The

Danish Wind Industry Association states that O&M costs are very low when the turbines are brand new but increases as the turbines get older. The O&M costs generally range from 1.5% to 3% of the original turbine cost.

Table 1: Different Categories of O&M Costs for German Wind Turbines

Component	% of total cost
Service and spare parts	26%
Administration	21%
Land Rent	18%
Insurance	13%
Power (grid)	5%
Misc	17%

(Source: Iuga, et. al (2009))

Environmental Value of Wind Energy

The primary environmental value of electricity generated from wind energy systems is that the wind offsets emissions that would have been caused by conventional fossil-fueled power plants. These emissions include sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon dioxide (CO_2), particulates, slag and ash. The amount of emissions saved via the use of energy depends on the types of power plants that are replaced by the wind system and the particular emission control systems currently installed on the various fossil-fired plants.

Market Value of Wind Energy

The market value of wind energy is the total amount of revenue one will receive by selling wind energy or will avoid paying through its generation and use. The value that can be 'captured' depends strongly on three considerations - the market application, the project owner or developer and the types of revenues available (Gipe, 2004; Mathew, 2006; Ghahremanian; Marafia and Ashour, 2003).

Methods of Economic Analysis

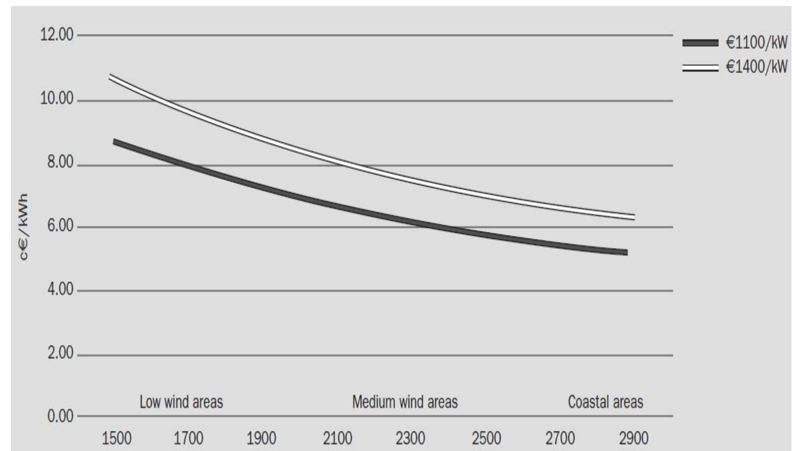
Any investor for a wind energy project would be interested to know the cost of wind energy generation (COE), i.e. dollars per kilowatt hour

($/kWh). This is calculated by dividing the sum of investment cost and O&M costs over the lifetime of the wind turbine by the annual wind energy yield in kWh as given in equation (1).

$$\left[\text{COE}(\$/\text{kWh}) = \frac{\text{Investment cost} + (\text{O\&Mcost/year} \times \text{project lifetime})}{\text{Annual wind energy}(\text{kWh}) \times \text{project lifetime}} \right] \quad (1)$$

It is clearly seen from equation (1) that the factor which will decrease the COE is the annual wind energy yield from the selected site. Hence, it is vital that the site selected for wind turbine installation is of a good wind regime which matches the selected wind turbines speed characteristics to increase the profitability of a wind turbine project. Figure 5 shows the calculated costs per kWh of wind-generated power as a function of the wind regime at the chosen sites in Germany.

Figure 5: COE of Wind Energy as a Function of Wind Regime (number of full load hours)



(Source: Iuga, et. al, 2009)

The independent axis in Figure 5 has wind regime which is given by the full load hours. It can be calculated as follows:

$$\text{Full load hours} = \frac{\text{Annual wind energy yeild (kWh)}}{\text{Rated power of wind turbine (kW)}} \quad (2)$$

The two lines on the graph represent the total investment cost per kilowatt. This figure clearly shows that the better the wind regime the less the cost of energy.

A cost benefit analysis is normally done to carry out an economic analysis of a wind energy project. This includes calculation of one or more of the following:

- Benefit-cost ratio
- Net present value
- Internal rate of return
- Payback period.

Appendix I provides brief descriptions of these measures.

Economic Analysis of Small Wind Turbine System, Vadravadra

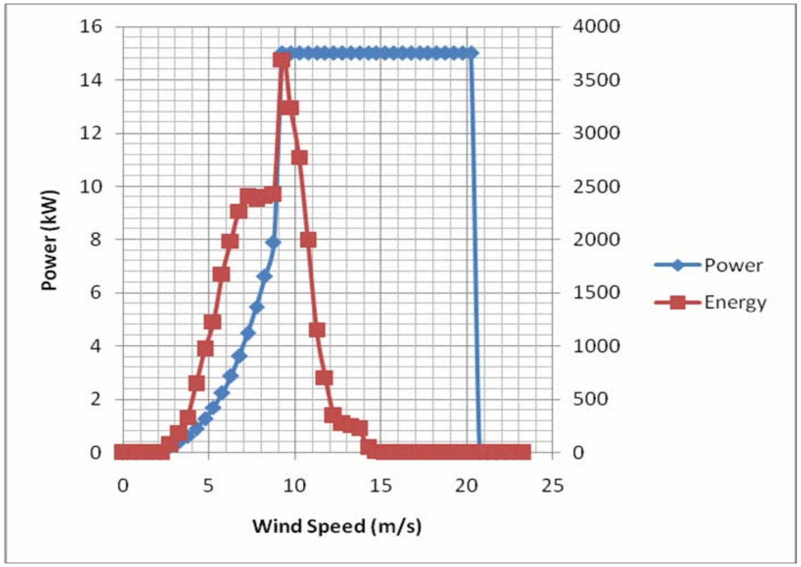
Energy Demand and Supply at Vadravadra

Vadravadra village has a population of 174 individuals, with a total of 44 households, a church, a community hall, a postal agency, a shop, a nursing station and a nursing house. The houses are mostly made of concrete, iron and timber. The village currently has an 18.5 kVA (15 kW) DG set that was installed in 1999, assisted by the Government of Fiji under the Rural Electrification (RE) programme of the Department of Energy (DOE). This generator operates 4 hours every evening with fuel consumption of approximately 2.2 litres per hour. Hence, in a month 264 litres of fuel is consumed. The unit cost of generation for this generator is \$0.85 per kWh assuming that specific fuel usage is 0.34 litres/kWh and fuel cost is \$2.50/litre. The electrical load is mainly used in lights, followed by radios, TV sets, refrigerators, washing machines and mixers. Currently, these loads are only used in the evenings for 4 hours. However, electricity consumption is bound to increase if it is provided for 24 hours.

Potential for Wind Energy

Considering the wind speed characteristics at the site, the electrical demand and the fact tat once electricity is provided for 24 hours electrical demand will increase, Hannevind 15 kW wind turbine is chosen for the Vadravadra site. Its power curve is shown in Figure 6.

Figure 6: Power and Energy Output Curve for Hannevind 15 kW Wind Turbine



When the wind turbine power curve and the wind speed frequency curve (Figure 3) are convolved and the overall power coefficient of the wind turbine is taken as 0.25, the estimated annual wind energy output comes out to be 33,700 kWh.

Possible Costs Involved in Commissioning a 15 kW Wind Turbine

All the costs given in this paper are in Fijian dollars. The turbine and installation cost (\$140,000) is according to the manufacturer of the wind turbine (Better Generation, online). Transportation cost is taken as \$75,000, since the site is at a remote island and it would cost this sum to transport equipment from mainland to the site. Other cost details are summarized in Table 2.

Table 2: Costs for Economic Analysis

Description	Cost (F$)	
Initial Investment (one-time cost)		
Wind turbine and installation	140,000*	
Transportation	75,000**	
Wind survey	50,000**	
Total Initial Investment	***265,000***	
Recurring Costs (per year)	**% of total investments**	**Per year (F$)**
O&M	3	7,950
Insurance	1	2,650
Total Recurring Cost		***10,600***

Notes: * Hannevind wind turbine manufacturer [16]
** estimated

Financial Benefits of WECS

Financial benefit (income) is calculated from the product of annual energy yield from the site and cost of electricity per kilowatt hour (COE). For the analysis, the annual wind energy yield is 33700 kWh, while the COE depends on the targeted NPV.

Cost of Energy

The cost of energy is $0.708/kWh. That is,

$$\mathrm{COE}(\$/\mathrm{kWh}) = \frac{\text{Investment cost} + (\text{O\&Mcost/year} \times \text{project lifetime})}{\text{Annual wind energy}(\mathrm{kWh}) \times \text{project lifetime}}$$

$$= \frac{\$265000 + (10600 \times 20yrs)}{33700 \times 20yrs}$$

$$= \underline{\underline{\$0.708 / kWh}}$$

This value of cost of energy does not take into account the discount rate of future cash flows.

Cost Benefit Analysis

Scenario 1: Total cost incurred by the investor

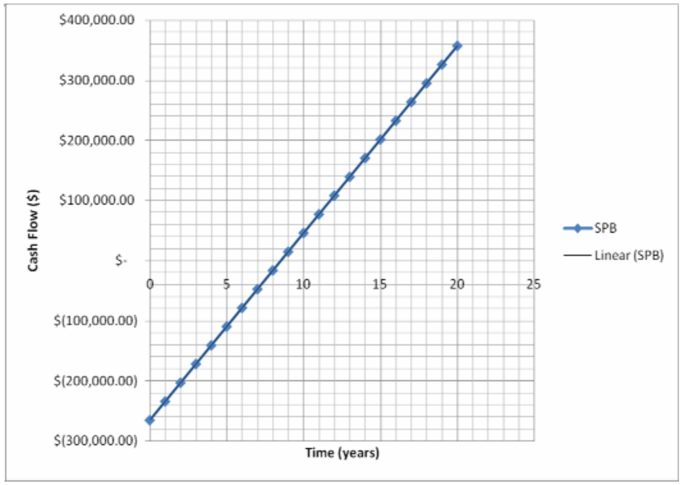
Cash flow analysis has been done to carry out cost benefit analysis for the proposed 15 kW wind turbine system. For the cash flow analysis,

the discount rate is taken as 10 %. For residential areas the COE charged by FEA is 0.34/kWh. At this rate the project will be unviable.

A COE of $1.24/kWh would produce a cumulative NPV of $0. In this situation the discounted BCR is 1. When NPV = 0, the IRR is 10%. This means that consumers would need to pay $1.24/kWh for the investor to breakeven.

Hence, the simple payback period will be between 8-9 years as shown in Figure 7. The place where the graph cuts the x-axis is the point of SPB.

Figure 7: Cash Flow (non-discounted)



Sensitivity Analysis for IRR

For this analysis, the discount rate was changed and the COE at which the NPV would be zero was found. In this case (where NPV = 0), the discount rate would be the internal rate of return (IRR). It is seen from Table 3 that as the IRR is increased the COE also increases; when IRR is increased by adding another 2%, the COE increases by 9-12%. In addition, from the SPB it is seen that doubling the IRR value decreases the SPB value by half.

Table 3: Variation in COE and SPB period as a function of IRR

IRR (%)	COE ($/kWh)	SPB (years)
6	1.00	11-12
8	1.12	9-10
10	1.24	8-9
12	1.37	7-8
14	1.50	6-7

Sensitivity Analysis for COE

Sensitivity analysis was done to see how variation in COE (the cost of energy that consumers pay) affects the NPV, SPB and discounted BCR, which is of interest to the investor of wind project. For this analysis, the discount rate is taken as 10%.

Table 4: Variation in NPV, SPB and Discounted BCR as a function of COE

COE ($/kWh)	NPV ($)	SPB (years)	Discounted BCR
1.24	0	8-9	1
1.26	5000	8-9	1.01
1.27	10000	8-9	1.03
1.29	15000	8-9	1.04
1.31	20000	7-8	1.06
1.33	25000	7-8	1.07

Table 4 shows that when the COE increases by 9 cents, the NPV of the project comes to $25,000. Payback period decreases and the discounted BCR increases as NPV increases. .

Sensitivity Analysis for Discount rate, i.

This sensitivity analysis was done to see the effect of how different discount rates affect NPV, SPB and discounted BCR. COE is taken as $1.24/kWh.

Table 5: Variation in NPV, SPB and discounted BCR as a function of discount rate, *i*.

Discount rate (%)	NPV ($)	SPB (years)	Discounted BCR
11	-17,127	*	0.95
10.5	-8,798	*	0.98
10	0	20	1.00
9.5	9,301	18	1.03
9	19,142	17	1.05
8.5	29,563	16	1.08
8	40,607	15	1.11

* The initial investment is not recovered during the project lifetime of 20 years.

As Table 5 shows, when discount rate is more than 10%, the net present value is negative. The NPV rises as the discount falls. At 8%, the NPV is $40,607 while the payback period is 15 years.

Scenario 2: Partial funding provided by Donor agencies

The initial cost of investment in any wind project is high. Such projects gain from external funding. Donor funding reduces the COE that consumers have to pay. A grant of $50,000 reduces the COE to $1.00/kWh at a discount rate of 10% and NPV of 0. This means that consumers pay $1.00/kWh for electrical energy consumed and the investor is able to recover all its costs without making any profit. Table 6 shows some sensitivity analysis on partial funding.

Table 6: Variation in COE as a function of Grant Funding

% funding of total investment	COE ($/kWh)	Discounted BCR	SPB (years)
10	1.11	1	8-9
20	0.99	1	8-9
30	0.87	1	8-9
40	0.74	1	8-9
50	0.62	1	8-9

When 10% of the total investment cost is provided by a donor agency, there is a 10% decrease in COE. Similarly, for all other donor funding ratios, the COE decreases by the same percentage.

Conclusion

Before implementation of any renewable energy project, economic and financial viability of the project should be studied. This paper carries the results of an economic analysis for a proposed 15 kW wind turbine system at Vadravadra site in Gau Island. When energy price is $0.34/kWh for the project lifetime of 20 years, costs are not recovered. At a discount rate of 10%, a rate of $1.24/kWh produces zero NPV. There is a significant difference between the cost of energy supplied by the Fiji Electricity Authority and that which can be generated from a 15kW wind turbine plant. However, when partial funding is provided as grant, unit cost falls; for a 50% grant funding, costs fall to $0.62/kWh. The comparative cost of utilising a diesel plant is $0.85/kWh. On this basis wind turbine energy conversion is viable for the site when grant funding covers more than 40% of the total investment cost for the project.

Appendix 1: Feasibility Study Indicators

Benefit to Cost Ratio (BCR)

For this, a time period is chosen and then the sum of all discounted costs and benefits in that period is determined. The quotient of benefit and cost gives the benefit to cost ratio.

$$\text{BCR} = \frac{\sum(\text{benefits})}{\sum(\text{costs})} \quad (3)$$

For a project to be acceptable, the ratio must have a value of 1 or more.

Cash flow Analysis

One of the most flexible and powerful ways of analyzing an energy investment is the cash-flow analysis. This technique easily accounts for complicated factors such as fuel escalation, tax-deductible interest, depreciation, periodic maintenance costs, and disposal or salvage value of the equipment at the end of its lifetime. The cash flow is calculated as follows:

$$\sum cash\ flow_n = \sum benfits_n - \sum costs_n \qquad (4)$$

where n is the number of years of operation from start system operation.

Net Present Value (NPV)

This discounted cash flow analysis, uses time value of money to convert a stream of annual cash flow generated by a project to a single value at a chosen discount rate, *i*. In simple terms, NPV determines today's value of future cash flow at a given discount rate.

$$\Sigma\ \text{Discount cash flow}_n = \frac{\sum benefits_n - \sum costs_n}{(1+i)^n} = \text{NPV} \qquad (5)$$

where i = the discount rate which is the interest rate used in calculating the present value of future cash flows and n = the years from start system operation. The present worth factor in the above formula is $1/(1+i)^n$. The value of i is chosen based on the government's long term bond rate.

If the NPV of a prospective project is positive, it should be accepted. However, if NPV is negative, the project should be rejected because cash flows will also be negative implying that no profit is made.

Internal Rate of Return (IRR)

This is perhaps the most persuasive measure of the value of an investment project. The IRR allows the return on investment to be directly compared with the return that might be obtained for any other competing investment. IRR is the discount rate that makes the NPV of the investment equal to zero.

$$IRR \Rightarrow NPV = 0\text{; i.e. } \frac{\sum benefits_n - \sum \cos ts_n}{(1+i)^n} = 0 \quad (6)$$

Simple Payback Period (SPB)

Payback considers the initial investment costs and the resulting annual cash flow. The payback time (period) is the length of time needed before an investment makes enough to recoup the initial investment. The payback period reflects the length of time required for a project's cumulative revenues to return its investment through the annual (non-discounted) cash flow (Owens, 2002). A more attractive investment is one with a shorter payback period.

However, the payback does not account for savings after the initial investment is paid back from the profits (cash flow) generated by the investment (project). This method is a 'first cut' analysis to evaluate the viability of investment. It does not include anything about the longevity of the system. For example, two wind turbines may both have the same 5-year payback periods, but even though one lasts for 20 years and the other one falls apart after 5 years, the payback period makes absolutely no distinction between the two. The formula for the layback period is:

$$\text{SPB (in years)} = \frac{\sum(\text{investment costs})}{(\text{yearly benefits} - \text{yearly costs})} \quad (7)$$

References

Better Generation, 'Hannevind 15 kW wind turbine'. Retrieved from: http://www.bettergeneration.com/wind-turbine-reviews/hannevind-15kw-wind-turbine.html [Accessed: 28/09/11].

Burton, T., Sharpe, D., Jenkins, N., and Bossanyi, E. (2001) 'Wind Energy Handbook,' John Wiley & Sons Ltd., England.

BWEA.: 'The economics of wind energy'. Retrieved from: http://www.bwea.com/ref/econ.html, [Accessed: 05/10/11].

Danish Wind Industry Association. Retrieved from: http://www.windpower.org/ (Accessed: 27/09/07).

Ghahremanian, S.: 'Wind Energy: Economical aspects and project development with real best practice projects data'. Retrieved from: http://www.exergy.se/goran/hig/ses/06/**wind**%202.pdf (Accessed: 25/04/08).

Gipe, P. (2004) 'Wind Power: Renewable energy for home, farm and business,' Chelsea Green Pub. Co, White River Junction, Vt.

Gunasekra, D. 'Query on discount rate', [email correspondence 14/10/11, Don.Gunasekera@csiro.au]

Harrison, R., Hau, E and Snel, H. (2000) 'Large wind turbines: design and economics,' Wiley & Sons Ltd., England.

Hau, E., and Renouard, H. (2006) 'Wind Turbines: Fundamentals, technologies, applications and economics,' Springer-Verlag Berlin Heidelberg, Germany.

Iowa Energy Centre, 'Wind Energy Manual-Wind Energy Economics'. http://www.energy.iastate.edu/Renewable/wind/wem/economic_issues.htm [Accessed: 05/10/11].

Manwell, J. F., McGowan, J., and Rogers, G. (2002) 'Wind energy explained: theory, design and application,' John Wiley & Sons Ltd., England.

Marafia, A. H., and Ashour, H. A. (2003) 'Economics of off-shore/on-shore wind energy systems in Qatar**,'** *Renewable Energy*, **28,** (12), pp 1953-1963.

Mathew, S. (2006) 'Wind Eenrgy: Fundamentals, resource analysis and economics,' Springer-Verlag Berlin Heidelberg, Netherlands.

Owens, G. (2002) 'Best Practices Guide: Economical and financial evaluation of renewable energy projects', United States Agency for International Development.

REN21 (2011) 'Renewables 2011: Global status report'. Retrieved from: http://www.ren21.net/Portals/97/documents/GSR/GSR2011_Master18.pdf [Accessed: 04/10/11].

Iuga, D. et. al. (2009) *Wind energy-The facts: Part III-The economics of wind power'*. European Wind Energy Association. Retrieved from: http://www.wind-energy-the-facts.org/documents/download/Chapter3.pdf [Accessed: 04/10/11].

Author:

Ravita Prasad, teaches renewable energy courses at the College of Engineering, Science and Technology, Fiji National University. Email: ravita.prasad@fnu.ac.fj or Prasad_ravita@yahoo.com