Feasibility Study for the Installation of Wind Energy Conversion Systems in Pakistan

Saif ur Rehman[1], Muhammad Shoaib[1,*], Shamim Khan[2] and Muhammad Jahangir[3]

[1]Department of Physics, Federal Urdu University of Arts Science and Technology, Karachi Pakistan

[2]Islamia College Peshawar Pakistan

[3]Government National College, Karachi Pakistan

Abstract: Wind generated electricity is one of the most attractive methods of electric power generation in a third world country like Pakistan. This paper presents the economic and technical viability of wind energy generation in remote and rural areas of Sindh (Pakistan). In light of this, Three wind turbines with power ratings of 660 kW, 1,000 kW and 18,00 kW are chosen. The economic analysis has been carried out by four economic indexes that are: cost benefit analysis (CBI), Net Present Value (NPV), Pay Back Period (PBP) and the Cost of Energy (COE $/kWh). The wind speed data for this study was obtained from the Pakistan meteorological department, measured at heights of 10m and 30 m, that span from 2002 to 2005.The outcome of the study showed that, the highest annual average energy of 5396 MWh/yr could be generated by Vestas V80 (with power capacity of 1.8 MW). Furthermore, the baseline economic evaluation of all the selected turbines, indicted that V80-1.8 MW gave the least cost (0.043 $/KWh) of electricity production at 80m hub height while the Sensitivity of the selected parameters showed that NPV is more sensitive to retail price of local electricity cost.

Keywords: Wind generated electricity, economic indexes, Rural electrification, wind turbines, Sindh (Pakistan).

1. INTRODUCTION

It is fairly clear that energy is a vital factor in the initiation of the development process and to maintain ongoing development. Current electricity generation facility in the country is about 19,566MW, of which 30% is acquired from Hydel, 67% of fossil fuels (35.3% of oil and 32.3% from natural gas) and nuclear energy provides remaining share [1]. In order to become self-sufficient Pakistan needs to use alternative energy resources such as wind power.

Several studies have been carried out to estimate wind energy potential. Shahnawaz *et al*. [2] conducted a study for the estimation of wind energy potential at Hawksbay, Pakistan. Ahmed *et al*. [3] studied the southern coasts of Sindh (Pakistan) to investigate wind energy potential and wind characteristics of Hawks bay, Ketibander, and Shahbunder. Regarding the feasibility studies for wind projects, few studies have been carried out for the cost analysis of wind energy projects in Pakistan [2, 4]. Beside theses local studies many studies have been conducted all over the world for the assessment and evaluation of wind energy potential [5-8].

Present research work focused on economic and technical assessment of medium-scale wind energy conversion systems (WECS) and selection of the most appropriate wind turbine for the site. So far most of the work in wind energy development has been relied mostly on large wind farm developments. The importance of present work is that it is intended to encourage community wind projects in Pakistan.

2. METHODOLOGY

2.1. Study Area

KetiBundar is located at a distance of about 200 km south east of Karachi in Thatta district, of Sindh (Pakistan) province. It is located on the South Shore of Sindh province, at Latitude 24.13^{o}N & Longitude 67.43^{o} E. Figure **1** shows the study site in the map.

2.2. Wind Resource

The wind speed data used in current study is the result of three years study project that was conducted by Pakistan Meteorological Department, for comprehensive wind power potential assessment of coastal areas of Pakistan [9]. The monthly average wind speeds at the heights of 10 m and 30 m and the extrapolated wind speed at 80m hub height are shown in Figure **2a**.

The vertical extrapolation is carried out by WINDOGRAPHER® [15] software using power law. The average value of power law exponent α (0.321) is determined by analyzing the wind data at the heights of 10 m and 30 m. Figure **2b** shows the Wind speed

*Address correspondence to this author at the Department of Physics, Federal Urdu University of Arts Science and Technology, Karachi Pakistan; Tel: (0092-91)99244141-9; Fax: (0092)021-99244272;
E-mail: profmshoaib@fuuast.edu.pk

ISSN: 1814-8085 / E-ISSN: 1927-5129/16

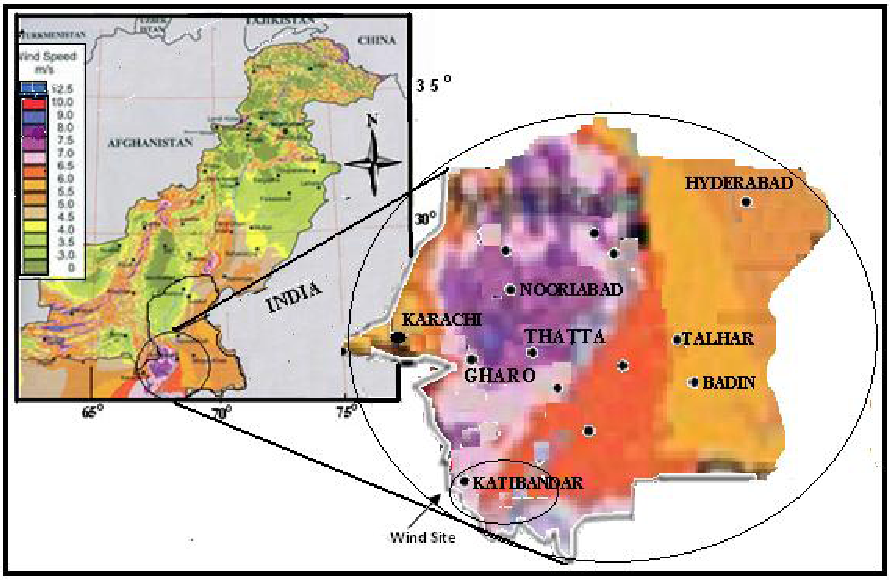
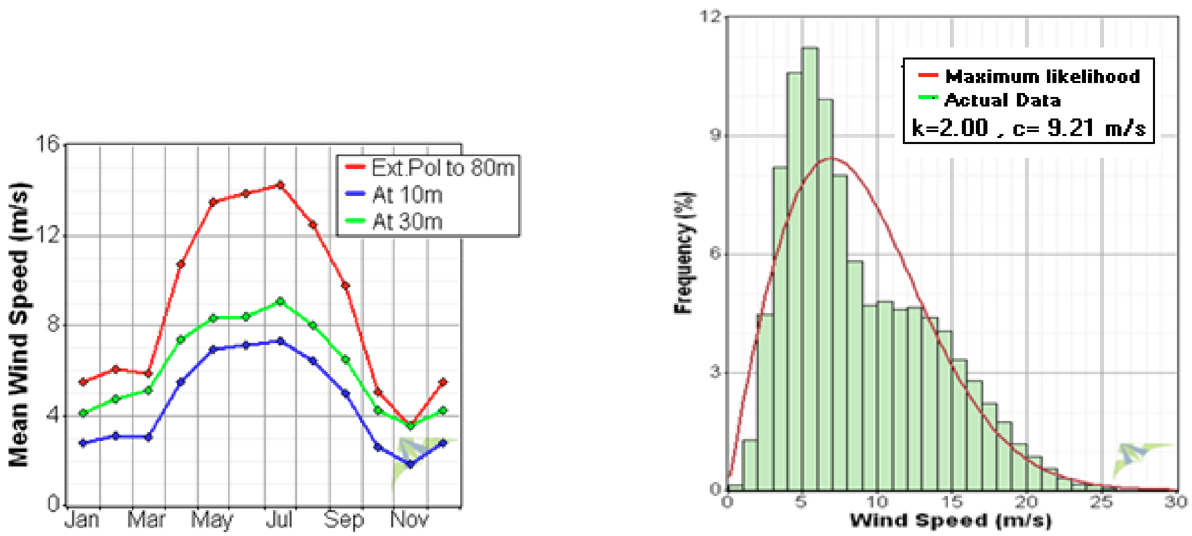


Figure 1: Wind map of Pakistan showing the steady site of KatiBandar (Resource: NREL).



(**a**) (**b**)

Figure 2: (**a**) Monthly mean observed wind speeds at 10m, 30m and extrapolated mean speed at 80m. (**b**) Frequency distribution at 80m for the KatiBandar.

probability distribution. A best-fit Weibull distribution shape parameter k is 2.0 and scale factor c is 9.21 m/s. The two-parameter Weibull distribution (the probability density function) is given by the following equation

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

3. CANDIDATE WIND TURBINES

Present research focused on GE [11] and Vestas [10] series turbines (V80, V47 and GE1.5sl) turbines for annual electricity production. Prices were obtained from similar projects [12,13,14]. Table **1** gives some Characteristics of Candidate Wind Turbines.

4. ENERGY PRODUCTION ESTIMATE

A comparison of power curves for the selected wind turbines to estimate the energy production estimates is shown in Figure **3**. Energy production is estimated by matching the obtained wind speed frequency distribution with a wind turbine power curve that can accommodate wind speeds in the desired regions. WINDOGRAPHER® software [15] is used for the process of energy output estimates of a wind turbine in the measured wind regime.

Table 1: Characteristics of Candidate Wind Turbines with Probable Project Cost for Single Wind Turbine Plant at KatiBandar

Manufacturer (Model)	Rotor Diameter	Rated Power	Cut-in Wind Speed (m/s)	Cut-out Wind Speed (m/s)	Hub Height
GE 1.5sle	77 m	1.5 MW	3.5	25	80 m
Vestas (V47)	47 m	660 kW	4	25	65 m
Vestas (V80)	80 m	1.8 MW	3.5	25	80 m

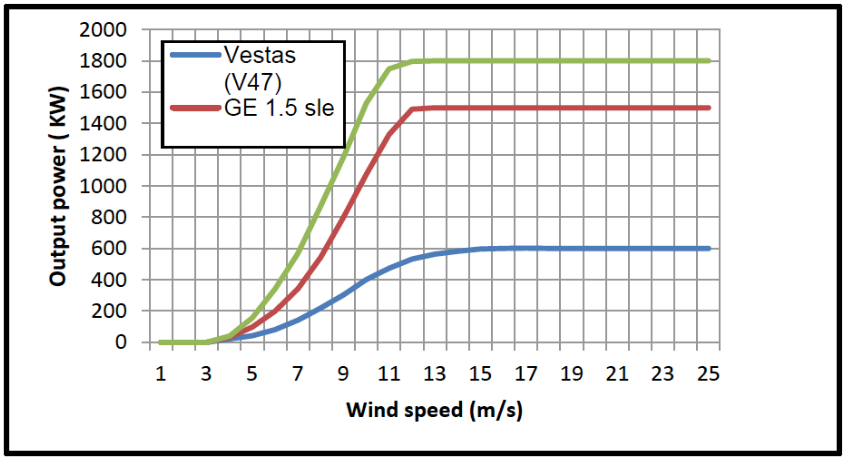


Figure 3: Wind turbine Power Curve Comparison [20,21].

4.1. Capacity Factor

It is defined as the ratio of the energy actually produced by the system to the energy that would be produced by it, if the machine operated at its rated power during whole year. Thus

$$C_F = \frac{E_T}{T\ P_R} \quad (2)$$

C_F depends upon the turbine as well as on the characteristics of location.

4.2. Energy Losses

The energy losses given in Table **2** are normally expected percentage of losses for energy calculations [15].

Table 2: The Table Below Specifies how the Losses were Derived [15]

Item	Loss
Power curve degradation	0.50%
On-site electrical losses	3%
Long-term WTG availability loss	6%
total loss	9.5%

5. ECONOMIC AND COST ANALYSIS

The specific assumptions employed in this paper for economic analysis is given in Table **4**. Probable project cost for single wind turbine plant at KatiBandar is given in Table **5**.

5.1. Cost of Energy Generation

The cost of energy generation of the WECS is the ratio of the entirety yearly cost of the wind energy conversion system to the annual electricity generated by this system. Cost of generated electricity (COE) is given by equation 3 [16].

$$COE = \frac{C_I}{n\ E_I}\left\{1 + m\left[\frac{(1+I)^n - 1}{I(1+I)^n}\right]\right\} \quad (3)$$

E_I, C_I, I and m are annual energy production, capital investment and percentage of C_I, real rate of discount respectively.

5.2. Payback Period

Payback period is the number of years it takes for the energy savings to offset the initial investment. The common assumption is the shorter the payback period, the more economical the investment. If the project

Table 3: Estimated Annual Power Production and Capacity Factors at 80-m hub Height

Month	Hub Height Wind Speed (m/s)	Vestas V47		GE 1.5sle		Vestas (V80)	
		Mean Net Energy Output (kWh/yr)	Net Capacity Factor (%)	Mean Net Energy Output (kWh/yr)	Net Capacity Factor (%)	Mean Net Energy Output (kWh/yr)	Net Capacity Factor (%)
Jan	5.59	80,366	16.4	154,479	13.8	199,009	14.9
Feb	5.95	86,590	19.5	170,404	16.9	215,662	17.8
Mar	6.32	111,737	22.8	224,240	20.1	279,789	20.9
Apr	8.99	215,640	45.4	469,629	43.5	556,242	42.9
May	11.42	291,330	59.3	648,986	58.2	764,627	57.1
Jun	11.3	279,767	58.9	622,932	57.7	733,818	56.6
Jul	11.05	284,049	57.8	631,604	56.6	744,046	55.6
Aug	10.69	274,832	56	609,506	54.6	718,193	53.6
Sep	9.47	231,907	48.8	508,444	47.1	600,700	46.4
Oct	5.41	70,197	14.3	130,213	11.7	172,481	12.9
Nov	4.5	40,331	8.5	72,608	6.7	97,474	7.5
Dec	5.47	75,443	15.4	143,761	12.9	186,451	13.9
Annual	8.13	2,090,500	36.2	4,497,792	34.2	5,396,291	34.2

Table 4: Financial Assumptions Used in This Project

Parameter	Electricity cost	inflation rate	Electricity inflation	Life time	O&M Cost (% of installed cost)	Discount Rate
Assumed values	$ 0.093/kWh	3%	2%	20 year	3%	10%

Table 5: Probable Project Cost for Single Wind Turbine Plant

Item	GE 1.5 sle	Vestas V47	Vestas V80
Turbine Rating (MW)	1.5 MW	0.66 MW	1.8 MW
Turbine Costs	$2,263,500	$936,250	$2,660,530
Transportation	$255,000	$205,000	$300,000
civil/site work	$522,500	$500,000	$540,000
electric system	$80,000	$80,000	$80,000
Total estimated project cost	$3,121,000	$1,721,250	$3,580,530

delivers a benefit of B_A annually through electricity Sales (B_A=E_I C_E) the payback period is given by equation 4 [16].

$$n = -\frac{\ln\left(1 - \frac{I\ C_I}{B_A - mC_I}\right)}{\ln(1+I)} \tag{4}$$

5.3. Net Present Value

A more flexible and meaningful calculation for evaluating renewable energy projects is net present value (NPV). As a general rule, a project makes economic sense if the NPV is positive and greater than the NPV of other alternatives. Investments with a negative NPV value would be unacceptable

The net present value (NPV) is given by equation 5 [16].

$$NPV = E_I\ C_E\left[\frac{(1+I)^n - 1}{I(1+I)^n}\right] - \left\{1 + m\left(\frac{(1+I)^n - 1}{I(1+I)^n}\right)\right\} \tag{5}$$

C_E is electricity price, other variables are defined in section 5.1.

5.4. Benefit Cost Ratio

Benefit cost ratio (BCR) is the ratio of the accumulated present value of all the benefits to the accumulated present value of all expenses, including the initial investment is given by equation 6 [16]. A plan is acceptable if BCR is greater than 1.

$$BCR = \frac{NPV(B_A)_{1-n}}{C_I + NPV(C_A)_{1-n}} \tag{6}$$

6. RESULTS AND DISCUSSION

6.1. Optimization

Three types of commercially available wind turbines (0.66MW, 1.5MW, 1.8MW) are used. The features of the selected wind turbines with particular hub heights are given in Table **1**. The annual energy production and turbine capacity factors are listed in Table **3**. The trend of capacity factors with the variation of wind speed of three chosen wind turbines is almost alike. Capacity factors range from 13% to 58%. Hhigher values of capacity factors corresponds to comparatively higher values of mean wind speeds similar to the results of [17]. The highest and lowest capacity factor is in May and in November respectively. The computed values of cost of energy (COE), payback period, net present value (NPV) and benefit cost ratio (BCR) are based on previously listed assumptions Table **4**. Baseline economic evaluation is given in Table **6**. the results are similar to [5,8,14]. It can be seen that, Vestas V80 (1.8 MW) wind turbine at 80-m hub generates 5396MWh average energy annually with capacity factor of 34.2% and COE is 0.043$/kWh. It can be seen that V47 turbine produces the least energy 2090MWh/yr with payback period of 37 Yrs, negative NPV of -$445,050 and BCR less than one makes this option invalid under the assumptions. The study also showed that, turbine GE1.5sle could be a good choice for wind power generation with positive NPV of $222,427 but has relatively more COE(0.053$/kWh) than V80 .The results for the small size turbine showed that these projects do not expected to have a strong net benefit. The shortest payback, of 12.2 years, is found for the Vestas V80 at 80-meter tower height the most suitable wind turbine on the basis of payback or cost benefit ratio appears to be a single V80, 1.8 MW.

6.2. Sensitivity Analysis

Table **7** gives the results from different sensitivity investigations that were conducted other than the base case expressed above. The results of sensitivity

Table 6: Baseline Economic Evaluation

Turbine Model	Installed Cost	Benefit of generated electricity ($/year)	Net Present Value	Benefit Cost Ratio (BCR)	Cost of Energy ($/kWh)	Simple payback (years)
Model GE 1.5sle (80m tower)	$3,121,000	$418294.7	$222,427	1.057049	0.053	17.9
Vestas v47 (65m tower)	$1,721,250	$194416.5	-$445,050	0.793025	0.071	37.6
Vestas V80 (80 m tower)	$3,580,530	$501855.1	$1,395,531	1.3	0.043	12.2

Table 7: The Sensitivity Analysis Vestas V80 (80 m Hub Height)

Assumption	NPV ($)	Cost of Energy ($/kWh)	Simple payback	Benefit Cost Ratio (BCR)
Original assumptions	1395531	0.043	12.2	1.3
All costs (except Turbine) are increased by 50%	271212	0.053	18.2	1
All costs(except Turbine) are increased by 100%	-853108	0.064	27.7	0.9
Electricity prices $0.05	-1212685	0.043	58.4	0.7
Electricity prices $0.2	8568128	0.043	4.2	2.9
10% more electricity is produced	2068491	0.038	10.3	1.5
10% less electricity is produced	834732	0.047	14.4	1.2

analysis under given cases are quite robust. Variation in electricity prices demonstrates large variations in the NPV and payback period. Reduction of electricity prices has negative impact on the feasibility of the project whereas most fevarable condition is a 100% increase in electricity prices. It is worth noting that if all costs (except Turbine cost) are raised by 100%, it results in the negative value for the 20-year NPV and, 27 years of payback period and 50% increase in COE.

7. CONCLUSIONS

In this study the wind data of KatiBandar (Sindh, Pakistan) has been analyzed. Under given conditions it is suggested that the investigated system is useful for rural regions and remote parts which do not access to electricity transmission lines. Wind turbine V80 at 80 m hub height is most suitable choice under given conditions. Results of sensitivity analysis depict that NPV and COE is not much vulnerable to the reasonable variations in the economic parameters, except for two assumptions in sensitivity analyses, payback period is within the allowed range.

REFERENCES

[1] Economic Survey of Pakistan, 2009-10. Available from http://www.finance.gov.pk/ finance_economic_survey.aspx

[2] Shahnawaz FK, Amir MS, Kavita T, Lei D. Assessment of wind power potential at Hawksbay, Karachi Sindh, Pakistan. Telkomnika 2013; 11(7): 3479-3490.

[3] Ahmed MA, Ahmed F, Akhtar MW. Wind characteristics and Wind power potential for southern coast of Sindh, Pakistan. Journal of Basic and Applied Sciences 2010; 6(2): 163-168.

[4] Commercial Wind Power Plant of 18MW at Gharo – Sindh, Pakistan Meteorological Department, Technical Report 2004 No. PMD- 11/2004.

[5] Wagner SO, Antonio JF. Economic Feasibility Applied to Wind Energy Projects. Int J Emerg Sci 2011; 1(4): 659-681.

[6] Rehman S. Wind energy resources assessment for Yanbo, Saudi Arabia. Energy Conversion and Management 2004; 45(3): 2019-32. http://dx.doi.org/10.1016/j.enconman.2003.11.009

[7] Vogiatzis N, Kotti K, Spanomitsios S, Stoukides M. Analysis of wind potential and characteristics in North Aegean, Greece. Renewable Energy 2004; 29: 1193-208. http://dx.doi.org/10.1016/j.renene.2003.11.017

[8] Gökçek M, Erdem HH, Bayülken A. A techno-economical evaluation for installation of suitable wind energy plants in Western Marmara Turkey. Energ Explor Exploit 2007; 25: 407428. http://dx.doi.org/10.1260/014459807783791791

[9] A study of wind in Sindh,Pakistan. Available from URL: http://www.met.gov.pk/Projectsl

[10] Vestas, Available from http://www.vestas.dk

[11] GE Wind Energy, Available from www.gepower.com/ dhtml/wind/en_us/index.jsp

[12] María IB. The economics of wind energy. Renewable and Sustainable Energy Reviews 2009; 13: 1372-1382. http://dx.doi.org/10.1016/j.rser.2008.09.004

[13] European Wind Energy Association, EWEA. No Fuel: wind power without fuel, EWEA Campaign 2006.Available at: http://www.no-fuel.org

[14] Massachusetts Clean Energy Center Town of Marion , Wind Turbine Feasibility Report Study, Renewable Energy Research Lab 201, Department of Mechanical Engineering University of Massachusetts Amherst, MA 01003 USA

[15] Mistaga Engineering inc Windographer Ver 1.52 Accessed April 2014. Available from www.windographer.com

[16] Mathew S. Wind Energy: Fundamentals. Resource Analysis And Economics, ISBN-10 3-540-30905-5 Springer Berlin Heidelberg New York, 2006; pp. 209-233.

[17] Tsang-Jung C, Yu-Ting W, Hua-Yi H, Chia-Ren C, Chun-Min L. Assessment of wind characteristics and wind turbine characteristics in Taiwan. Renewable Energy 2003; 28: 851-871. http://dx.doi.org/10.1016/S0960-1481(02)00184-2

Received on 08-02-2016 Accepted on 20-04-2016 Published on 20-06-2016

http://dx.doi.org/10.6000/1927-5129.2016.12.39