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Financial Analysis of PV-Wind Cogeneration for a Remote Village in Gwadar - Pakistan

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Abstract. The consumption concern and financial thought of fossil fuel assets around the world have required a basic seek for elective vitality sources to meet up the show vitality requests. Electricity has become a basic need of life for education, medical, transportation etc. In developing countries, the remote villages still have no access to electricity as it is uneconomical for utilities to provide electricity in geographically dispersed load centers. Kappar, a remote village in Gwadar city of Baluchistan province, is taken as a case study that has abundant solar and wind power potential. In this study, a hybrid power generation scheme is proposed for remote villages in Gwadar, Pakistan. A comprehensive study of the technical, economic and financial analysis including Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PP), Debt Service Coverage Ratio (DSCR), Benefit-Cost Ratio (BCR) for a hybrid PV-Wind system of said location have been calculated using clean energy management software called RET screen Expert, developed by Natural Resource Canada (NRC). The study of this paper renders an insight to auspicious configuration of PV capacity and wind turbines accessibility needed to meet the energy demand of posit location and their mutual technical, economical, financial and environmental parameters for future decision makings and best manipulations. The annual energy generated by the proposed hybrid system is computed, and an energy economic analysis is carried out based on demand. Using the RET screen tool, the main purpose is to create a hybrid system with an appropriate Levelized Cost of Electricity (LCOE).

Keywords: RET Screen, Hybrid PV, Wind System, Cost Analysis, Financial Analysis.

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1. Introduction

The development of a country is directly linked to the accessibility of power supply to every citizen from education to health facilities (Aqeel & Butt, 2001). Energy has become a basic need of the day for every citizen to be able to contribute to the development process. Pakistan is an energy deficient nation facing a severe electricity deficit of approximately 4000 MW in supply and demand. A huge amount of the population is living in the south of scattered villages which makes the grid connection even harder and economically unviable. It is also a fact that the country has the indefinite potential for renewable energy resources such as solar, wind, hydro, biomass etc. (Amer & Daim, 2011; Mirza et al., 2009). It has solar PV potential of producing 45 MW to 83MW per hundred-meter squares of area (Adnan et al., 2012). It encompasses an average daily global range of 19 to 20 MJ per day with an annual mean sunshine duration (Potential of Renewable Energies in Pakistan). There is adequate wind energy to power every coastal village in the country. According to wind resource calculation of Pakistan developed by NREL (National Renewable Energy Laboratory) in collaboration with USAID and Alternative Energy Development Board (AEDB), Pakistan contains a potential of more than 300,000 MW of wind vitality (Potential of Renewable Energies in Pakistan).

Over the years, using RET screen toolkit different scrutinizes have been regulated to discover more about the performance of the renewable energy resources to intuit the profitability and the performance of a projected system. Among these studies, it is worth mentioning the work by MN. Romero et al. (2014), compares the prognostic potential of the wind demonstrated in RET screen with the compelling generation of wind ranches found within the locale of Ontario, Canada, to roll components influencing the quality of these forecasts and thus, to comprehend what aspects of the demonstrate may be upgraded (Romero & Rojas-Solórzano, 2014). The investigation performed by A. Mehmood et al. (2014), conducts the data of six major cities (Islamabad, Karachi Lahore, Multan, Peshawar and Quetta) of Pakistan to fulfill the energy demand domestically by modeling standalone 5kW solar photovoltaic systems on RET screen.

Technical parameters like part of solar irradiance and resultant solar fraction are also observed along with evaluating the system viability based on economic determinants like NPV, IRR, and simple payback period. Software calculations are conducted for how much electric power load reduction is possible and how much Green House Gas (GHG) emission reduction is made authentic (Mehmood, Shaikh & Waqas, 2014). Mufti et al. (2015) searches out the potential and viability of standalone 380watts (0.38kW) solar photovoltaic systems on RET screen for Six major cities (Abbottabad, Chitral, Dera Ismail Khan, Dir, Mardan, and Peshawar) of K.P.K province of Pakistan. In which cost, financial analysis is done to select the optimum location for installation of said system (Akbar, Mufti, & Khurshid, 2015).

With data from measurement stations and the use of Geographic Information System (GIS) software, Zhou et al. (2011) examined the wind resource in Juangsu, a coastal province of China, to choose viable locations for building wind turbines and determine an array of features (Zhou, Wu & Liu, 2011). The study of cost analysis and emission analysis for grid-connected solar photovoltaic systems using RET screen by D. Dwivedy et al. (2015) is also a precedent.

In this simulation, the goal is to determine how much of a decrease in energy consumption cost this hybrid system can achieve, as well as the total cost and environmental impact of the reduction in greenhouse gas emissions (Dwivedy et al., 2015). In this paper,

- Cost analysis of an anticipated hybrid PV-Wind system i.e., 230kW for a proposed location (Kappar Village near Gwadar, Baluchistan) is studied based on climatic conditions to fulfill domestic energy requirements, through RET screen tool.
- Modeled system viability is estimated by relying on technical as well as financial and economic determinants like NPV, IRR, equity payback period and simple payback period. Technical parameters like solar irradiance and wind speed availabilities are also determined.
- Software calculations also revealed how much base case electric power load reduction is possible and how much GHG emissions can be reduced leading

toward green growth hinged on the results of the RET screen.

2. Systems and Methods

2.1. Kappar Village

Kappar village, Gwadar, is a coastal village in the south of Pakistan with the coordinates 25.317342, and 62.753221. It has abundant solar and wind resource potential which is discussed in Sec. 3A. There is only one weather station available for the village which is in Gwadar city. The RET screen Expert can load the required geographical and weather parameters datasheets from NASA (National Aeronautics and Space Administration) stations.

In hybrid PV-wind multi-technology, solar irradiance and wind speed are the main parameters among climatic conditions. A tabulated form of meteorological data measured at 10m is shown in Table I. The environmental data succors the feasibility of the obligation of PV-wind hybrid system installation.

Table 1. Meteorological Data for Kappar village, Gwadar, Pakistan

Months	Average Insolation Incident on A Horizontal Surface ($kWh/m^2/day$)	Average Direct Normal Radiation ($kWh/ m^2/day$)	Average Clear Sky Insolation Incident on A Horizontal Surface ($kWh/ m^2/day$)	Average Daylight Hours (hours)	Average Daylight Cloud Amount (%)	Wind speed (m/s)	Average Atmospheric Pressure (kPa)	Average Surface Albedo (0 to 1.0)
January	3.92	5.62	4.44	10.7	40.4	3.5	98.7	0.13
February	4.61	5.75	5.13	11.3	40.3	4.2	98.6	0.12
March	5.22	4.49	5.95	12	47.8	3.9	98.3	0.12
April	6.1	6.05	6.54	12.7	43.6	4	97.9	0.13
May	6.4	6.03	6.53	13.3	41.2	4.7	97.5	0.13
June	6.46	5.98	6.65	13.6	43.9	4.9	97	0.15
July	5.88	5.04	6.35	13.5	53.5	4.9	97	0.16
August	5.58	4.9	6.12	13	51.3	4.6	97.2	0.16
September	5.36	5.35	5.61	12.3	39.2	4.5	97.7	0.13
October	5	6.11	5.09	11.6	26.9	3.6	98.2	0.12
November	4.19	5.91	4.38	10.9	29.1	3	98.6	0.12
December	3.59	5.24	4.01	10.6	39.4	3.5	98.8	0.12

2.2. PV-wind Hybrid Configuration

The PV-wind crossover framework is well suited where daylight and wind have regular shifts (Subrahmanyam, Sahoo & Reddy, 2012).

Fig. 1 appears the schematic chart of the proposed PV-wind half-breed vitality framework setup. The power generated by the PV modules is DC voltage, which is subsequently converted to AC via a DC-AC inverter.

Through an AC/AC cyclo-converter, the inverter's output sinks with the power provided by wind turbines. A step-up transformer, which is attached to the supply system, boosts the collected power.

In an excess of energy production during a lower demand period, the transformer can feed the excess produced power to the storage (as an option) rather than dump the load. For analyzing the system performance these components are typified individually in section 3B.

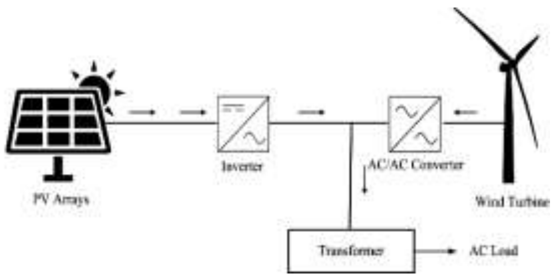

Figure 1. Schematic diagram of the hybrid power generation system

2.3. RET Screen Expert

There are various hybrid renewable energy tools available in the market for designing micro grid hybrid renewable energy systems including the famous Hybrid Optimization of Multiple Energy Resources (HOMER) energy, HYBRID2, System Advisor Model (SAM) developed by the National Renewable Energy Laboratory

(NREL) and RET screen Expert developed by NRC. These software tools are used for technical design, performance and financial modeling to facilitate decision-making for designing hybrid renewable energy systems. Among these tools, HOMER energy and RET screen Expert are the most flexible and user-friendly tools that have the capability of standardized measurements and economic calculations (Li, et al., 2022). The HOMER software programming tool is widely used by many researchers for direct optimization, emission, and economic analyses of all types of designed systems. However, the performance prediction of the designed system is a limitation (Khatib, Mohamed & Sopian, 2012). The study RET screen is preferred for this study

$$NPV = \sum_{t=1}^{T} \frac{Ct}{(1+r)^t} - C_0 \quad (1)$$

because it is provided free of charge by the Canadian Government and to explore its capabilities to design renewable energy schemes for far away loading centers. RET screen Expert analysis is based on five steps; accredit for the comprehensive identification, optimization and assessment software algorithm which is capable of computing technical, economic and environmental viability of different renewable energy, energy-efficient and cogeneration projects in terms of resultant solar irradiance, NPV, IRR, payback periods, GHG emissions reduction and backup fuel savings (Thevenard, Leng & Martel, 2000; Rets, T. ICEDSC).

2.4. Cost Analysis Methodology

The key to the project (PV-wind system) under study is to evaluate the economic viability using RET screen tool

$$DSCR = \frac{Net\ Operating\ Income}{Total\ Debt\ Service} \quad (3)$$

which has the option of an embedded products cost database. Costs associated with the proposed PV-wind system incorporate costs with feasibility analysis, development, engineering and commissioning of the power system.

2.5. Financial Analysis Methodology

One of the important benefits of using RET screen expert tool is it assists the project valuation process for decision-makers. RET screen expert simulation tool investigates the financial parameters including NPV, the interest rate

$$BCR = \frac{D_b}{D_i} \quad (4)$$

on debt, IRR, pre-tax IRR, cumulative cash flow, DSCR, BCR etc. Simple definitions and mathematical formulas of these financial parameters are given below.

Net Present Value (NPV): The show esteem of cash inflows short the display esteem of cash outpourings is utilized to calculate the net show esteem (NPV) of expected speculation or extension (Khatib, Mohamed & Sopian, 2012). The formula for calculating NPV is calculated by using the equation (1);

C_t delineates net cash influx amid the period t, Co is added up to starting venture costs whereas r limns intrigued rate and t informs number of periods.

Internal Rate of Return (IRR): The inside rate of return (IRR) may be a metric utilized in capital arranging to decide the productivity of arranged ventures, as appears in equation (2) (Khatib, Mohamed & Sopian, 2012). Inside rate of return could be a markdown rate that makes the NPV of all cash streams from a specific venture break even with to zero.

$$IRR = \sum \left(\frac{After\ Tax\ Cash\ Flow}{(1+r)^t} \right) - Initial\ Investment \quad (2)$$

DSCR is a measure of cash flow available to pay current debt obligations, as described in eq. (3).

BCR is a pointer, utilized in an investigation that endeavors to summarize the by and large esteem for cash of a venture or proposition. Acknowledge all ventures with a BCR more prominent than one. The modus operandi of BCR is in equation (4).

D_b depicts the discounted value of incremental benefits and D_t is discounted value of incremental costs.

$$P = \frac{1}{2} k \rho C_p A V^3 \qquad (5)$$

3. Results and Discussions

RET screen software has been developed to shape the possibility of a system in expressions of its technical parameters, economic factors and environmental control (like GHG emission reduction). The annual inflation rate of Pakistan is assumed to be 2%. RET screen conclusions are convoluted in four approaches as shown in Fig. 2.

Figure 2. The maneuver of RET screen analysis

3.1. Feasibility Analysis

Figure 3 shows the data of solar radiation kWh/m²/day VS each month of the year. The average value lies at 5.91 kWh/m²/day of each month. The maximum solar irradiance takes place during April, May, June, and July. As the power generated by a wind turbine is directly proportional to the wind speed m/s (equation below) shows mathematical inference (Rets, T. ICEDSC). A climatic data of projected location produced by RET screen is weighing up the consequences of wind speed in m/s over the year on monthly origin made known in Fig. 3. The power output of wind turbine is given as:

P is power output (kW), k is 0.000133 constant to yield power in kWs, ρ is air density (lb/ft^3), Cp is maximum power coefficient (from 0.25 to 0.45), A is rotor swept area and V is wind speed (mph).

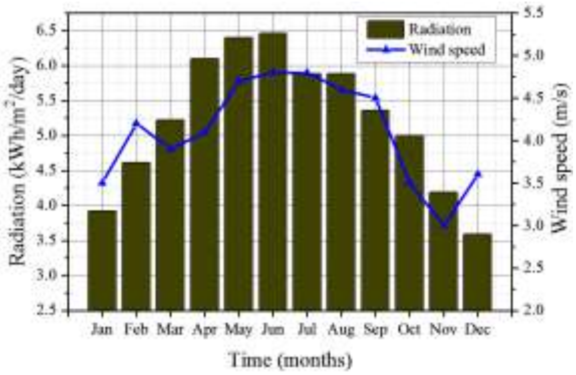

Figure 3. Solar and wind annual resources of Kappar village, Baluchistan

3.2. Technical Analysis

In monetary terms, the specialized examination could be a security examination state of mind of checking the changing in past costs with the expected of estimating future cost and volume (Brealey et al., 2012). But an engineering perspective, technical analysis cop with the restriction of equipment on which the efficiency and efficient consumption depend.

Results show that 484 units of PV (150kW) and 1 unit of wind (80kW) multi-technology are sufficient to provide more than 100% essential power capacity. Tables 2, 3, and 4 compromises the introductory technical parameters of the under-study hybrid power station for inferred capacity.

3.3. Cost Analysis

The initial cost is estimated to be CAD (Canadian dollars) 241,022. Operating and maintenance cost is predicted to be CAD 2795. Grand initial cost includes feasibility study, development, engineering, and power system costs.

Table 5 limns the database cost values in Canadian dollars which the RET screen produced against input parameters of the energy analyzer.

Costs are predicted to be in CAD with 3% contingencies. In the development contract negotiation and permit, approval is included with a per-unit cost of 800 CAD and 1000 CAD respectively. Table 6 shows the detail of the cost calculated in the feasibility study.

Table 2. Precursory Parameters of Proposed System

Base Case PV-Wind Electricity	
Parameters	***Values***
1. Power demand	Stand Alone Load
2. Contracted capacity of PV system	150kw
3. Contracted capacity of wind system	80kw
4. Contracted total capacity	230kW
Proposed Case PV module	
5. Solar PV power plant	150kW
6. Grid type	Hybrid, Stand Alone
7. PV panel type	484 units, 310 W
Proposed case Wind System	
8. Wind power plant	80kW
9. Grid type	Hybrid
10. Wind turbine (horizontal axis)	1 units, 80kW
11. Wind power plant	80kW

Table 3. Characteristics of Selected PV Module

Parameters	Values
PV type	Poly-Si
Module	Fixed
Manufacturer	Yingli Solar
Model	poly-Si - YL310P-35b
Capacity	310W
Maximum power (V_{mp})	36.9 V
Maximum current (I_{mp})	8.41 A
Open circuit voltage (V_{oc})	46.4
Short circuit current (I_{sc})	8.98 A
Power tolerance (%)	0~+2 %
Efficiency (%)	16%
No. of units used	484
Nominal operating temperature	- 40°C - +85°C
Frame area	1.94 m²
PV type	Poly-Si

Table 4. Characteristics of Selected Wind Turbine

Parameters	Values
Supplier/manufacturer	Wind Energy Solutions BV
Model	WES 18 - 40m (< 2012)
Type	Tubular
Rated power	80 kW
No. of Units	1
Hub Height	40m
Rotor Diameter	18m
Swift Area	254m²
Cut in wind speed	<3 m/sec. (6.7mph)
Cut out wind speed	25 m/sec. (56mph)
Operating temperatures	From -20°C up to +40°C
Degree of protection	IP55

Table 5. Precursory Parameters of Proposed System

Type of Cost	Cost (CAD)	Relative Costs (%)
Feasibility study	45,000	8.8
Development	40,000	7.8
Engineering	57,000	11.1
Power system		
Photovoltaic	81,022	15.81
Wind turbine	160,000	31.22
Road construction	25,000	4.87
Transmission line	25,000	4.87
Balance and miscellaneous		
Transportation	50,000	9.75
Contingencies	14,491	2.82
Interest during construction	14,925	2.91
Total cost	512,438	100%

Table 6. Feasibility Cost Analysis

Feasibility study	Unit	Unit cost CAD
Site investigation	p-d	1,600
Resource assessment	Project	15,000
Environmental assessment	p-d	800
Report preparation	p-d	800
Project management	p-d	800
Travel & accommodation	p-trip	300

3.4. Financial Analysis

In the proposed system electricity exported to grid is 437 MWh. We also suppose that the plant receives no government subsidies. Table 7 shows the important financial parameters.

Table 7. Financial Parameter Input

Input parameters	Values
Electricity Export rate	CAD 0.15 kW
Electricity export Escalation Rate	2%
Inflation Rate	2%
Discount rate	7%
Gross GHG reductions	73 t CO_2/yr.
Projected life	25 years

Input parameters	Values
GHG reduction cost	CAD - 228/tCO_2

DSCR is 3.2 which means the income generated is enough to cover the operating expenses and payments. With a 25-year expected lifetime, the NPV of the PV facility is CAD 460,816. Similarly, if the beginning cost was reduced from CAD 310,670, the NPV would be positive.

The Net Benefit-cost ratio is projected to be 4.7 which is a positive indicator. We can conclude that the benefits would outweigh the costs. The annual life cycle savings (ALCS) represents the PV plant's annual benefit, based on net present value, project lifetime, and discount rate. The project's yearly ALCS is expected to be CAD 46,914.

$$Payback\ Period = \frac{Cost\ of\ project}{Annual\ cash\ flows} \quad (6)$$

The interest collected by the project over its lifetime is represented by the internal rate of return on return. The internal rate of return (IRR) is expected to be 38.7%. The project is financially worthwhile if the IRR exceeds the investor's necessary return on investment.

Given a positive annual income from the PV-Wind system, the simple payback period illustrates how many years it will take to recoup the initial and annual costs, as shown (6) (Devarakonda, 2019). This power plant has a payback period of 4.9 years. Table 8 tabularizes the financial cost.

Table 8. Financial indicator for Plant

Parameters	Values
NPV	CAD 460,816
BCR	4.7
ALCS	CAD 46,914
IRR	38.70%
Payback period	4.9 years

A positive number of cash flows signify that a project generated more cash beneficially. By the use of RET screen analysis, we have negative cumulative cash flows for the first 3 years then we move to positive cash flows for the next 22 years as shown in Fig. 4. which recompenses a good scheme for investment as we generated more cash than we spent.

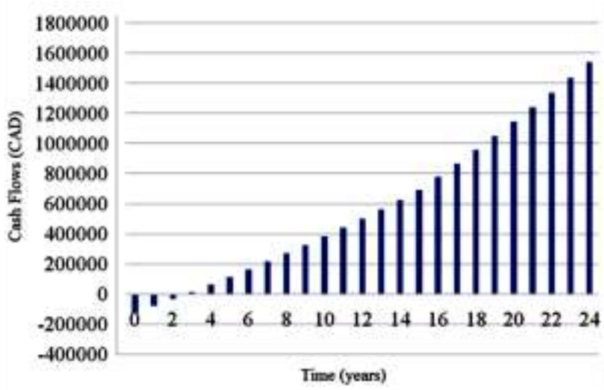

Figure 4. Cumulative Cash Flow

3.5. GHG Emissions

For GHG emission reduction required input data are the transmission and distribution (T&D) losses which are taken as 7% for a proposed location as a developing part of the country and scrutinized fuels are selected as ‘‘All fuel types’’.

GHG emission factor is assumed to be 0.472 tCO2/MWh. Fig. 5 shows the 93% GHG emission reduction possible by the proposed system.

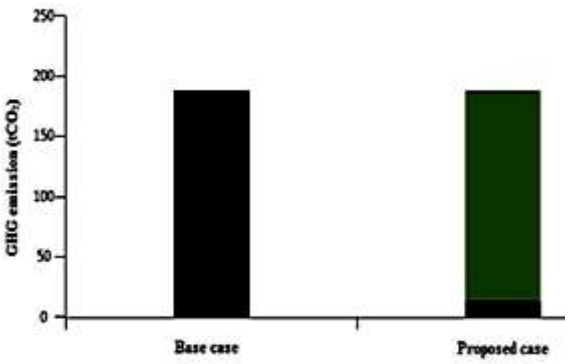

Figure 5. Gross annual GHG emission by RET screen

4. Conclusions

This proffered paper manifests the unit sizing and an economical appraising of a PV-Wind hybrid generation system and its cost acquisition for a typical assumed location by RET Screen software.

In terms of power delivered to the load, net present value, internal rate of return, benefit to cost ratio, simple and equitable payback times, and GHG emission reduction analysis, an extravagance and utilitarian assessment of the solar system is devised.

The research provides evidence to support an appropriate configuration of PV capacity and wind turbines to suit the energy demand of the area, as well as their mutual cost analysis findings.

This study abets the Government to make certain access to modern and infallible information on the costs and execution of renewable energy resources like hybrid PV-wind systems.

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