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A Techno-Economic Viability Analysis of Wind-Powered Power Plants in Panjgur, Balochistan †

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Abstract: This research paper explores the potential of wind turbine power plants as a sustainable energy solution for addressing energy deprivation in the Panjgur region of Balochistan. Balochistan, an area with limited access to traditional energy sources, suffers from chronic electricity shortages, hindering its socio-economic development. This study examines the feasibility of harnessing wind energy through establishing wind turbine power plants. This paper discusses the technical aspects of wind turbine technology, including turbine designs, capacities, and power generation potential. The findings highlight the viability of wind turbine power plants as a renewable energy source to alleviate the energy crisis in the region and promote sustainable development at a very reasonable price.

Keywords: wind energy; sustainable energy; renewable energy; techno-economic analysis

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1. Introduction

Pakistan's energy issue has become a recurring headline, as power usage surges due to electronic devices, advancing technology, and population growth. The country's electricity consumption of 89,361 MW surpasses its generation capacity of 41,557 MW [1], predominantly fueled using coal, natural gas, and petroleum products. However, the environmental risks associated with fossil fuels necessitate a shift towards cleaner and more sustainable energy sources. Pakistan must explore its significant potential for renewable energy to overcome its worst ever crisis and improve the living standards of its citizens.

Among the provinces, Balochistan stands out due to its severe energy deprivation despite being the largest province with minimal industry and population. This study concentrates on the rural areas of Balochistan, aiming to enhance the quality of life by proposing a steady supply of clean, green energy and empowering the local population.

The fuel-wise breakdown of electricity generation in recent times reveals shifts in the energy mix. Hydropower's contribution declined to 24.7%, while RLNG's (Degasified Liquefied Natural Gas) share increased to 23.8%. Coal remained constant, although total installed capacity increased. Natural gas intake decreased from 12.15% to 8.5%, highlighting the transition towards renewable energy [2].

Utilizing renewable energy sources is crucial for several reasons. Firstly, it addresses the urgent need for environmental protection and the fight against global warming caused by greenhouse gas emissions from fossil fuels.

The literature survey indicates the importance of renewable energy generation resources and their incremental share in the energy mix of Pakistan. The most important globally employed renewable energy resources are solar energy, wind energy, hydropower, geothermal energy, bioenergy and ocean thermal energy conversion cycles (OTEC) [3]. This research project aims to evaluate the techno-economic viability of the building wind power plants in Panjgur (a rural area of Balochistan) by using relatively novel tools and an energy consumption data collection methodology.

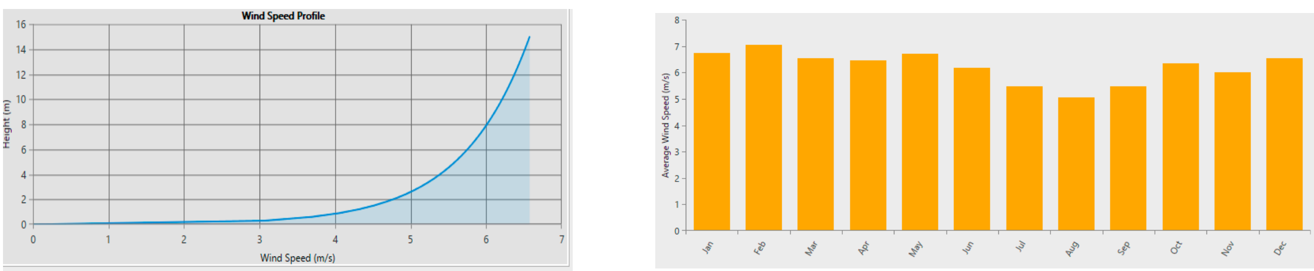
2. Materials and Methods

This study utilizes several analytic frameworks used by different authors in previous works [4]. Wind speed data were collected from various sources, such as NASA and Globalwindatlas.info [5]. A sample of power consumption-related data of the region was collected through a questionnaire, which included load shedding duration, number of energy savers and 100-watt bulbs, tube lights, mobile phones, celling and table fans, water pumps, computers/laptops, electric geysers, washing machines, refrigerators, etc. This type of data collection provided an estimate of electricity consumption monthly/per day. The data were then analyzed to determine the wind energy potential for the project. Factors like elevation and geographical variables were considered, and wind speed data were analyzed to calculate maximum, minimum, and mean wind speeds. Different locations were assessed, and Panjgur, at a height of 10 m, was found to have the most suitable wind potential based on monthly variations and simulation using Homer Pro software and RET Screen; manual calculations were also performed. Financial modelling tools were used to assess the wind energy project's financial and economic viability, considering capital costs, operational and maintenance costs, energy tariff rates, financing alternatives, and social and environmental aspects.

Qblade software was used to calculate the power produced by different speeds using a NACA 4415 blade profile. This data were then fed to RET screen, which in turn created a power curve and an estimate of the total energy produced by a turbine in KWh. The lifespan of the plant was set at 20 years, and total production in this lifetime was used for economic calculations. The cost of the plant included purchase cost, shipping, and maintenance. The levelized cost of electricity (LCOE) was calculated using Equation (1).

$$\text{LCOE} = \text{Total Cost of the plant}/\text{Total Electricity Produced} \tag{1}$$

At various heights of 50, 10, and 80 m above ground level, wind speed measurements were taken. It was discovered after a careful comparison of these observations that wind speed tended to climb with height (Figure 1a). A height of 10 m was determined to be the best option, considering the project's nature and modest size. Figure 1b presents average wind speed variations for Panjgur during the whole year at a 10 m height. This figure is generated through Homer Pro software (version 3.15.2).



(a) (b)

Figure 1. (**a**) Incremental wind speed against height (**b**) Average yearly wind speed variations for Panjgur at a 10 m height.

A load profile divided the load into four phases. A design considered the load demand and load calculation to obtain the daily maximum consumption.

- 2 to 3 houses (3 KW);
- 4 to 6 houses (6 KW);
- 6 to 8 houses (10.5 KW);
- 15 to 20 houses (25.5 KW).

The details of the hardware suggested in this work along with the purchase cost, shipping, installation, and maintenance cost are tabulated in Table 1. Similar calculations were conducted for all plants, but Table 1 presented here is only for the 6 KW plant.

Table 1. Economical and Technical Specifications of a 6 KW plant.

Item	Turbine	Battery	Controller	Invertor
Type	M2-2 (1500) HAWT for Home	Li-ion Battery 48 V 200 ah lifepo4	Automatic MPPT Charge Controller Wind Charge Controller	Pure Sine Wave Power Inverter
Unit Price (PKR)	84,000	72,000	50,700	13,800
Quantity	4	1	1	1
Life Span (Years)	20	6.7	5	10~15
Annual Maintenance cost (Excluding Consumables)	2–3% of initial cost	2–3% of initial cost	2–3% of initial cost	2–3% of initial cost
Shipping Cost	336,000 PKR	432,000 PKR	202,800 PKR	27,600 PKR
Total Cost (20 Years)	806,400 PKR	921,600 PKR	42,5880 PKR	60,720 PKR
Total Cost of the Plant/ Net Present Cost (NPC)	2,214,600 PKR			
Energy Production	13,140 KWh (Annual) and 262,800 KWh (20 years)			
Payback period (N)	9.36 years (Cost/Annual earning)			
LCOE	8.42 PKR			

3. Results and Discussion

Selected turbines, controllers, batteries, and inverters were chosen based on their cost-effectiveness, efficiency, and low maintenance. Shipping charges were calculated based upon the supplier's estimates. All four power plants with loads of 3 kW, 6 kW, 10.5 kW, and 25.5 kW were simulated using QBlade and RET software. The analysis included both economic and technical aspects. For the 6 KW load, calculations are provided in Table 1. Efficiency was calculated at 25% for the power production capacity of the turbines. Prices for different turbines were acquired and the most economical option was chosen. The lifespan of all equipment was not the same. Some equipment needed to be purchased twice or thrice to meet the requirements of twenty years for the whole plant. The power production capability of the turbine against different wind speeds is presented in Figure 2 (for the 6 KW plant only).

It can be observed from Figure 2 that both energy (MWh) and power (KWh) show an incremental trend for incremental wind speed variation (m/s). Power shows steep and smooth variations as compared with energy, which shows the importance of wind speed for power generation. On the other hand, the incremental trend of energy is nonlinear. This includes two types of wind speeds, namely cut-in and cut-off speeds.

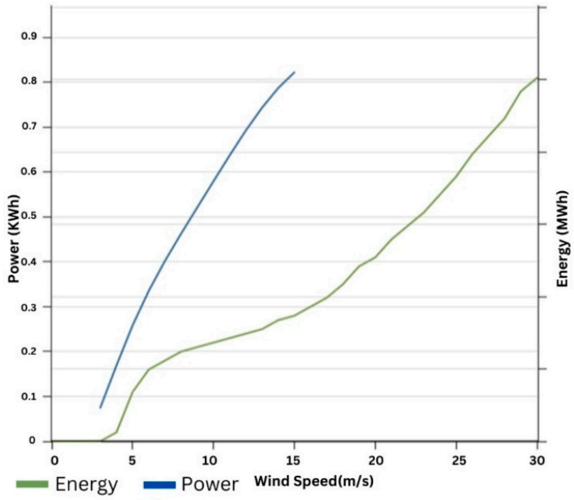


Figure 2. Power and energy variations for varying wind speeds.

4. Conclusions

This study was simulated for four different capacity projects (i.e., 3 KW, 6 KW, 10.5 KW, and 25.5 KW) in Panjgur (Balochistan) using Homer Pro and RET Screen tools. Analysis was performed at different turbine heights, i.e., 10 m, 50 m, and 80 m. A 10 m height measurement was found to have the most suitable wind potential based on monthly variations as per small-scale project standards. Variations in power and energy were also investigated for 0 to 30 m/s wind speed spans. A minimum power of 0.06 KWh and maximum energy of 0.8 MWh was achieved at 2.75 m/s and 30 m/s wind speeds, respectively.

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Conflicts of Interest: The authors declare no conflict of interest.

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