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Wind Energy Potential Assessment in Four Cities of Libya

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Abstract

Driven by the need to diversify Libya's energy portfolio and explore sustainable alternatives, this study investigates the wind energy potential of four cities in western Libya: Gharyan, Nalut, Asabah, and Alraiyna. Utilizing long-term wind data from representative meteorological stations and employing the Weibull distribution, we assess the feasibility of harnessing wind energy using the Siva 850 kW wind turbine model. Our analysis reveals that Alraiyna possesses the most promising wind energy potential among the four cities, boasting an annual energy output of 1.275861 MWh and a capacity factor of 17.14%. These findings indicate that Alraiyna's wind resource is suitable for power generation, offering a viable solution to supplement Libya's energy needs and promote sustainable development. Further studies are recommended to explore the economic viability and environmental impact of implementing wind energy projects in Alraiyna.

Keywords: *wind assessment; annual energy; wind power; wind energy; Weibull distribution.*

الملخص

يبحث هذا البحث في إمكانية استخدام طاقة الرياح لتوليد الكهرباء في مدن غريان ونالوت والاصابعة والرياينة في المنطقة الغربية من ليبيا. تتميز ليبيا بموقع جغرافي مناسب لاستغلال طاقة الرياح، حيث تتمتع بمناخ صحراوي جاف مع هبوب رياح قوية غالبًا. البحث يدرس إمكانات طاقة الرياح في مدن شمال غرب ليبيا غريان ونالوت والاصابعة والرياينة. تم استخدام بيانات الرياح في فترات زمنية طويلة المدى من محطات الأرصاد الجوية لتقدير إمكانات طاقة الرياح في كل مدينة. تم استخدام توزيع وبيل لتحليل بيانات الرياح وتقدير سرعة الرياح المتوسطة وكثافة الطاقة وعامل السعة. تم استخدام نموذج توربينة الرياح Siva 850 kW لتقدير إنتاج الطاقة السنوي. تشير النتائج إلى أن الرياينة لديها أفضل إمكانات طاقة الرياح بين المدن الأربع، حيث يبلغ إنتاج الطاقة السنوي لتوربينة الرياح 1.275861) Siva 850 KW) ميغاوات في الساعة. يبلغ عامل السعة 17.14%، مما يشير إلى أن مصدر الرياح مناسب لإنتاج الطاقة. تشير النتائج إلى أن الرياينة لديها إمكانات كبيرة لتوليد الكهرباء باستخدام طاقة الرياح. يمكن أن توفر طاقة الرياح مصدرًا نظيفًا ومستدامًا للطاقة في ليبيا، مما يساعد في تقليل الاعتماد على الوقود الأحفوري. تحث الدراسة بإجراء دراسات إضافية لتقييم الإمكانات الاقتصادية والبيئية لمشاريع طاقة الرياح في الرياينة.

Introduction

Throughout the past century, humanity has harnessed wind energy for a diverse range of applications, including air conditioning in deserts, firefighting, smelting raw materials, guiding sailboats, and agricultural practices such as irrigation and grain processing. The consistently blowing winds in Earth's subtropical belts, known as trade winds, continue to serve as a valuable source of renewable energy [1].

Harnessing the power of wind has been a practice dating back at least three millennia. before the Industrial Revolution., wind power was primarily employed for mechanical tasks such as water pumping and grain grinding. However, with the advent of modern industrialization, the inconsistent nature of wind energy led to its replacement by fossil fuel-powered engines and the electrical grid, which offered a more reliable and consistent power source [2].

The resurgence of interest in wind power in the early 1970s, triggered by the oil crisis and, marked a shift in focus from mechanical energy to electrical energy generation [3]. This strategic move enabled wind power to complement other energy sources through the electrical grid, ensuring a reliable and consistent power supply.

The development of wind turbines for electricity generation had commenced in the early twentieth century, and advancements continued steadily from the 1970s onwards. By the late 1990s, wind energy had emerged as a crucial sustainable energy source. This period witnessed a remarkable tripling of global wind capacity every three years, while the cost of wind-generated electricity plummeted to one-sixth of its early 1980s level. This positive trajectory is projected to persist, with experts anticipating a 25% annual growth in cumulative capacity and a further 20-40% reduction in costs by 2005 [4]. Wind energy technology itself has evolved at an unprecedented pace. In 1989, a 300kW wind turbine with a 30-meter rotor diameter represented the pinnacle of innovation. Just a decade later, 2000kW turbines boasting rotor diameters of around 80 meters were readily available from multiple manufacturers. The turn of the millennium heralded the installation of the first demonstration projects featuring 3MW wind turbines with 90-meter rotors, paving the way for today's commercially available 5MW turbines.

1. Historical Context

The utilization of wind energy can be broadly divided into the generation of mechanical power and the production of electricity. This historical overview traces the evolution of wind power technology across these two domains.

1.1 Mechanical Power Generation

The earliest documented windmills were vertical axis mills, characterized by their simple drag mechanism. These rudimentary devices A decade later in the Afghan highlands for grain grinding since the seventh century BC [5].

Historical records from around a millennium ago indicate that Persia and China pioneered in the development of horizontal axis windmills. These windmills gradually gained popularity, spreading to the Middle East by 1150 AD, England by 1180 AD, France by 1180 AD, Germany by 1222 AD, and Denmark by 1259 AD. The windmill industry flourished between the twelfth and nineteenth centuries, with windmills being employed for a variety of purposes beyond grain grinding, including water pumping from lakes and other sources. By the year 1800, France had an estimated 20,000 windmills, while the Netherlands derived approximately 90% of its energy from wind power (Figure 1).

Human fascination with wind energy dates back to ancient times, driven by a desire to harness its power for practical applications. Indeed, the windmill industry experienced significant progress and widespread adoption. However, the discovery of oil led to a decline in the use of of wind energy, as oil emerged as the world's primary energy source.

Figure (1) Timeworn wind-powered structure in the British archipelago

The early twentieth century saw the emergence of American windmills, characterized by their self-regulating mechanism, unlike their European counterparts that required manual intervention or blade furling during high winds. This distinction, coupled with Europe's rapid industrialization, contributed to a gradual decline in windmill usage in the region. For instance, in 1904, wind power accounted for 11% of industrial energy in the Netherlands, and Germany boasted over 18,000 installed units. This shift created a favorable market for American windmills, leading to a boom in their export to Europe between 1920 and 1930, with an estimated 600,000 units installed. As a result, American windmills became synonymous with agricultural applications, as shown in Figure 2, which illustrates their global distribution.

Figure (2) an ancient Spanish wind farm

2.2 Present Status of Wind Energy in Libya

Despite being a leading oil exporter, Libya has recognized the potential of renewable energy sources. Consequently, Libya aims to increase the contribution of renewable energy sources to 10% of its total energy production in the foreseeable future. This initiative is driven by the objective of substantially reducing national electricity production costs.

Figure (3) Wind farm in Darnah

Libya's electricity production is primary reliant on fossil fuels, with natural gas serving as the primary source due to its abundance in the country. Recognizing the need for diversification, Libya's electricity provider, GECOL (General Electric Company of Libya), has actively pursued wind energy development since the year 2000. This initiative aims to establish Libya's first commercial wind farm, with the dual purpose of generating electricity from a renewable energy source in a cost-effective manner and educating local engineers about the technical requirements and interconnected aspects of wind farm development.

Libya's geographical location offers unique advantages for the widespread utilization of various renewable energy resources. Considering this potential, Libya should strive to harness its renewable resources, including wind, solar, and geothermal power, not only to meet the increasing demand for energy but also to fulfill its environmental obligations .

3.Study Locations

The present study focuses on four selected sites in Libya: Nalut, Alraiyna, Gharyan, and Asabah. The locations of these sites are depicted in Figure(4).

Figure (4) Distribution of speed measurement stations over Libya [17]

Continuous wind speed data is collected at all stations using the EKO 21B data logger. The specific locations of these stations are provided in Table 1. It is noteworthy that all data originates from the meteorological center.

Table (1). Physical features of the meteorological stations

station	Elevation above sea level (m)	Latitude $N°$	Longitude $E°$
Nalut	**705**	**31 52**	10 58
Garrin	**715**	**32 10**	13 01
Asabah	**583**	**31 30**	11 50
Alraiyna	724	31 37	11 4

4. Analysis of Wind Data

4.1 Mean Wind Speed Calculation

A comprehensive statistical analysis of wind speed data was conducted to determine the mean wind speed and standard deviations for all stations. The results, presented in Table 2, provide valuable insights into the wind resource characteristics at each location.

Table (2) Mean monthly, annual wind speed (m/s) and standard deviation for whole years

Station	Months - wind speed(m/s)												AM (m/s)	SD
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**		
Gharyan	**6.88**	**7.03**	**6.88**	**7.57**	**6.93**	**6.28**	5.38	**5.66**	**5.81**	**6.35**	**6.20**	**7.13**	**6.51**	3.68
Nalut	**6.12**	**6.13**	**5.96**	**6.18**	**6.28**	**5.82**	5.55	**5.27**	**5.56**	**5.11**	**5.89**	**6.22**	**5.84**	2.73
Asabah	**7.97**	**8.64**	**8.03**	**11.54**	**7.64**	**9.06**	6.78	**7.68**	**5.99**	**8.17**	**7.40**	**7.62**	**7.92**	5.01
Alraiyna	6.58	8.28	7.95	10.90	7.89	8.48	6.88	7.40	7.38	8.18	7.17	7.24	7.67	3.65

AM: Annual mean, SD: Standard deviation

4.2 Diurnal Wind Speed Variations

4.2.1 Diurnal Variations

The diurnal variation of wind speed for all stations is depicted in Figure 6. This figure clearly demonstrates a near-constant wind speed throughout the night, followed by a gradual increase reaching its maximum value at 3:00 PM, indicating wind speeds ranging from 8 m/s in the morning to 11 m/s in the afternoon. Figure 6 further reveals a slight decrease in wind speeds during the early morning and evening hours.

4.2.2 Monthly Variations

Daily wind intensity variations, directly correlated with daily temperature variations, are low in the mornings, reaching their maximum in the afternoons, and commence a decline in the evenings. As evident from Figure 6, hourly wind speeds vary from 4.19 m/s in Nalut to 8.45 m/s in Asabah, with a peak occurrence in the afternoon. Figure 7 illustrates the monthly mean wind speed for all stations.

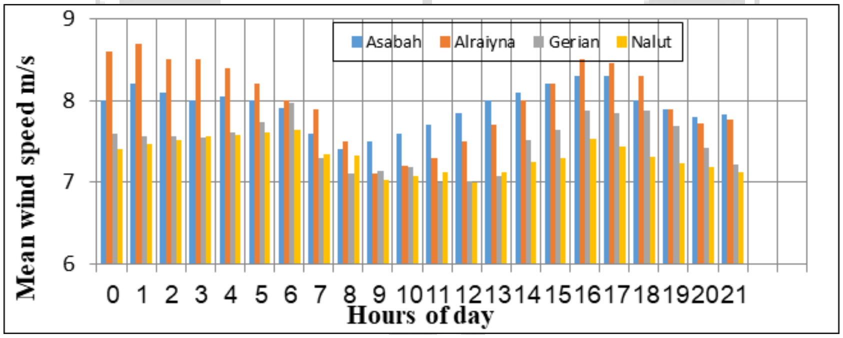

Figure (5) Diurnal variation of wind speed for all stations

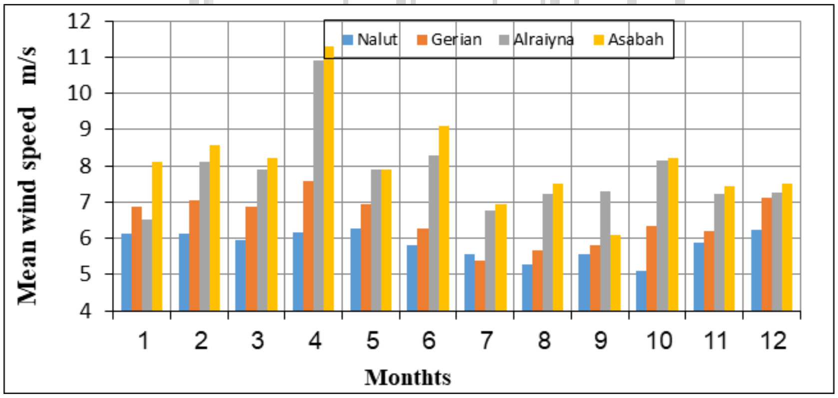

Figure (6) Monthly mean wind speed for all stations

4.3 Analysis of Wind Speed Variations

Figure (5) clearly illustrates the seasonal fluctuations in wind speed throughout the year, with August and October exhibiting the lowest wind speeds and April and June recording the highest values.

Additionally, Figure (6) reveals the spatial distribution of wind speed, with Asabah recording the maximum value of 11.29 m/s and Nalut the minimum value of 5.11 m/s.

Figures (7), (8), (9), and (10) depict into the mean wind speed patterns across different seasons. During the winter season, wind speed levels at all four stations exhibit substantial wind speed levels, ranging from 6.123 m/s to 8.12 m/s. Notably, Asabah experiences the highest mean wind speed of 8.12 m/s in February.

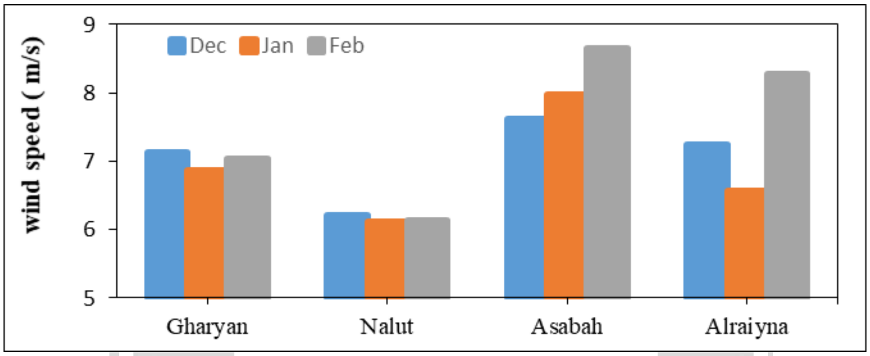

Figure (7) winter variation of wind speed for all stations

4.3.1 Seasonal Variations in Wind Speed

4.3.1.1 Spring Season

During the spring season, four stations exhibit high wind speeds ranging from 5.9601 to 11.29 m/s. Asabah records the maximum wind speed of 11.29 m/s in April.

4.3.1.2 Summer Season

The wind speed peaks at 9.11 m/s at Asabah during June in the summer season.

4.3.1.3 Autumn Season

Asabah records the highest mean wind speed of 8.23 m/s in October during the autumn season.

4.3.2 Observations

Based on Figures 7, 8, 9, and10, the following conclusions can be drawn:

a) The highest mean monthly wind speeds for all stations occur during the winter and spring seasons. This can be attributed to the temperature decrease observed during these seasons. This decrease induces thermal convection, transferring some of the momentum from the high-velocity upper atmosphere to the surface layers, resulting in the observed increase in mean monthly wind speed.
b) Nalut exhibits the lowest monthly wind speeds for three seasons, with the minimum value occurring in spring.
c) The monthly wind speed pattern remains consistent across all seasons.

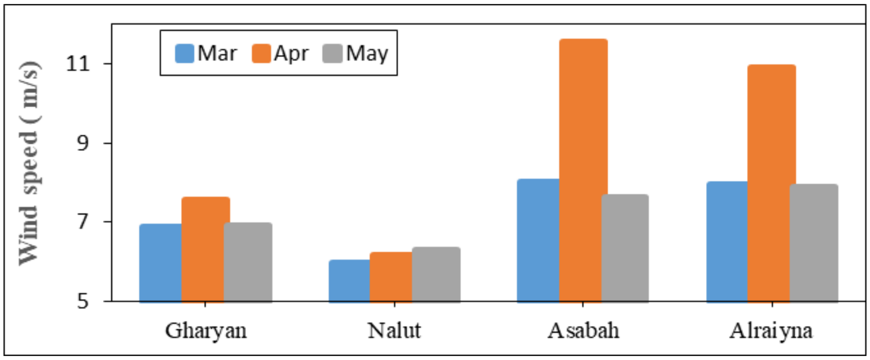

Figure (8) spring variation of wind speed for all stations

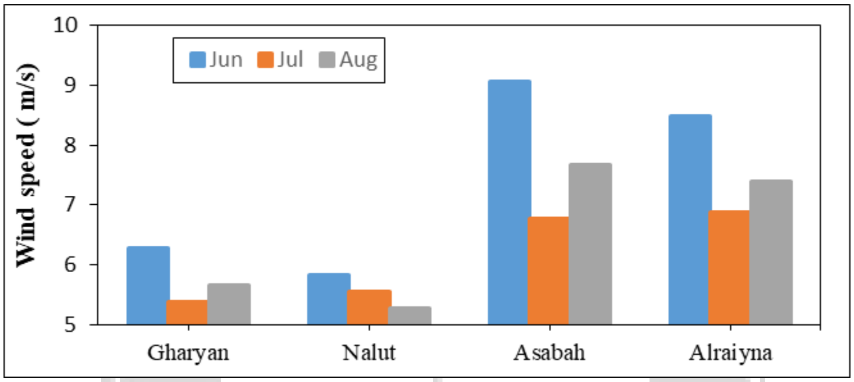

Figure (9) summer variation of wind speed for all stations

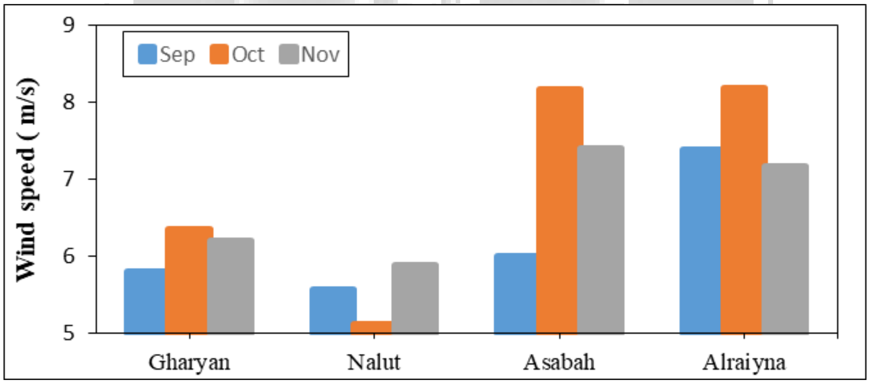

Figure (10) autumn variation of wind speed for all stations

4.4 Calculation of Weibull Frequency

The determination of Weibull frequency distribution and Weibull cumulative distribution requires the calculation of the scale parameter "C" and the shape parameter "k". The parameters C and k for all the stations are calculated using two methods.

Method 1:

The results of "C" and "k" for all stations using the first method are illustrates in Fig.11. The values of ln(-ln(P(U))) are plotted on the y axes, and the values of lnU are plotted on the x axes. A straight line is fitted through the points, and the best equation is determined, which is shown in each figure. Comparing these equations provides the values of "C" and "k".

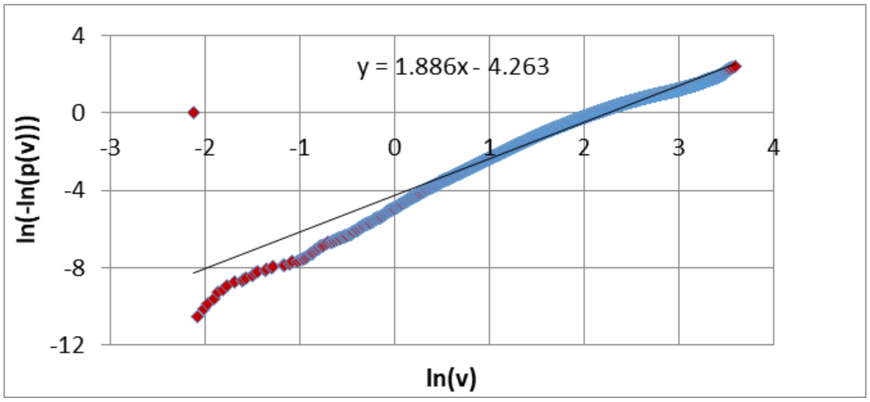

Figure (11) Graphical determination of Weibull parameters for Asabah city

Method 2

The results of "C" and "k" using the second method are obtained using equations where the values of Γ(1+1/k) are presented. The parameter "C" is then calculated by using equations. The final results of two methods are presented in table 3.

Table (3) gives the estimation of parameters "C" and "k" by two methods

station	Method 1		Method 2		Error (%)	
	C	**k**	**C**	**k**	**C**	k
Gharyan	**3.9151**	**1.6057**	**6.1302**	**1.5506**	**36.135**	3.4369
Nalut	**4.5885**	**1.6406**	**4.3**	**1.733**	**6.287**	5.331
Asabah	**9.6**	**1.886**	**8.8636**	**1.6437**	**7.6705**	12.846
Alraiyna	8.967	2.365	8.6688	2.2432	3.3317	5.1498

Comparison of Methods

It is clear from the results in table 3 that both methods give identical estimates of the parameters "C" and "k". Fig. 12 illustrates the value of "C" and "k" parameters for both methods.

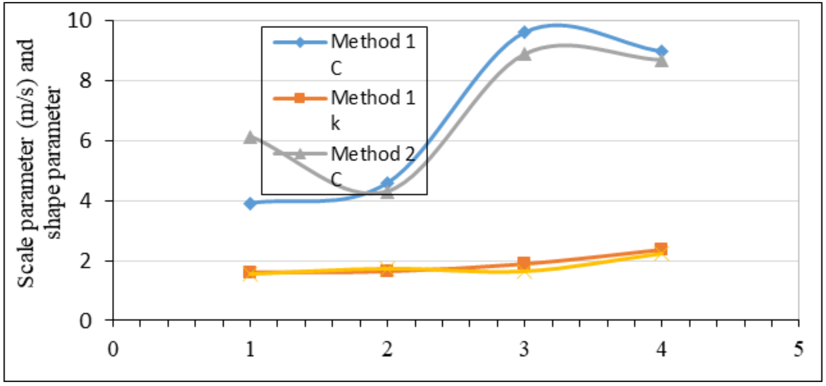

Figure 12: Scale and shape parameters

Fig. 13 illustrates the histogram for the probability of wind speed, which is drawn using the values of scale and shape parameters. From these histograms, it is clear that the highest wind speed of maximum frequency is 7 m/s at Asabah and ALraiyna with probabilities of 8.45 and 10.32%, respectively, and the lowest is 2 m/s at Gharyan with a probability of 16.1%. The annual mean wind speed can be estimated from the histogram of probability of wind speed by taking the summation of multiplying each wind speed by its probability.

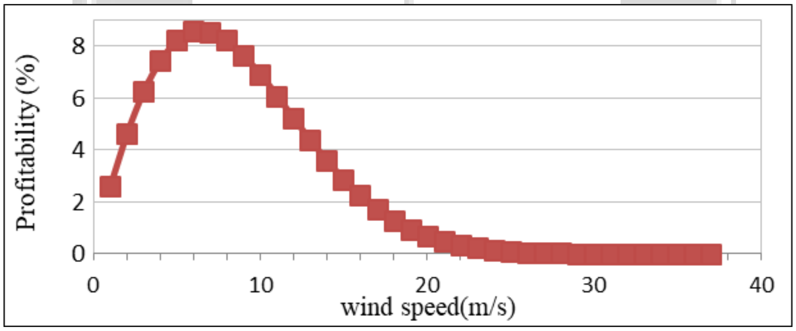

Figure 13 Histogram and wibull function for the probability of Asabah city

Fig. 14 illustrates the values of mean wind speed and wind speed of maximum frequency for all the stations. It is clear from this figure that the highest wind speed was 7.924 m/s in Asabah and the lowest was 5.841 m/s in Nalut, as indicated in table 4. Fig. 16 illustrates the Weibull cumulative distribution, which gives the probability of wind speed exceeding the value of any given wind speed.

Table 4 Annual mean wind speed and wind speed of maximum frequency

station	Wind speed of maximum frequency(m/s)	Annual mean wind	Profitability (%)	Hours/year

		speed(m/s)		
Gharyan	**2**	**6.50719**	**12.82**	1123.032
Nalut	**3**	**5.84135**	**19.513**	1709.339
Asabah	**6**	**7.924**	**13.69**	1199.244
Alraiyna	7	7.67	15.303	1340.543

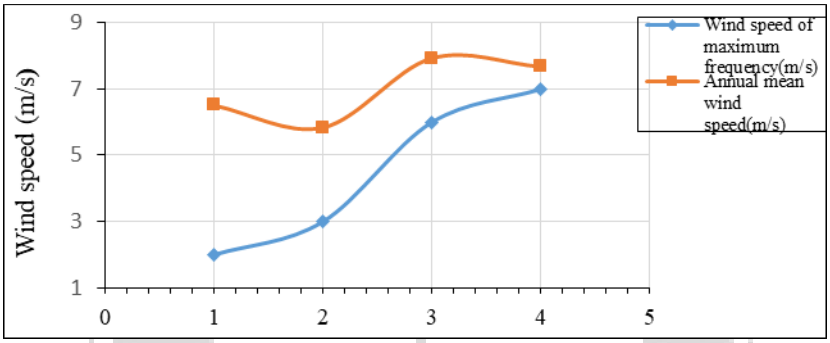

Figure 14 Mean wind speed and wind speed of maximum frequency

The Weibull distribution is a useful tool for modeling wind speed data. The two methods presented in this paper provide identical estimates of the Weibull parameters, which can be used to estimate the probability of wind speed exceeding a given value.

4.5 Calculation of power density

Table 1.5 summarizes the wind power density values for the different stations. It is evident from this table that the highest power density of 313.6W/m is observed in Gharyan, while the lowest power density of 97.456W/m is recorded in Nalut.

Table 5 Maximum power density for all stations

Station	Mean power density (W/m^2)	Maximum power density (W/m^2)
Gharyan	**76.56**	313.6
Nalut	**57.988**	97.456
Asabah	**90.12**	304.28
Alraiyna	81.32	276.37

4.6 Calculation of annual energy

The computation of annual energy for each site is based on the data provided by Vestas (V60-850kw) wind turbines.

Table 6 Annual energy values for all the stations

Station	Annual energy (kWh) for Turbine 850kW
Ggaryan	**1089566**
Nalut	**1008521**
Asabah	**1228378**
Alraiyna	**1275861**

Table 1.7 illustrates the total annual energy output of wind turbines of varying sizes. The maximum energy of 1275861 kW is generated by the 850-kW wind turbine at Alraiyna, whereas the minimum value of 1008521 kW is produced by the 850 kW wind turbine at Nalut.

4.7 Calculation of annual capacity factor

The energy output data is utilized to determine the capacity factor of the 850 kW wind turbines. The turbines share similar cut-in and cut-out speeds, but their rated wind speeds differ.

Table 7 Capacity factor values for all the stations

Station	**Capacity factor (%) for turbine 850kw**
Gharyan	**14.632**
Nalut	**13.55**
Asabah	**16.5**
Alraiyna	**17.14**

Table 7 displays the capacity factor values for selected sites. It is apparent from Table 7 that the highest capacity factor of 17.14% in Alraiyna was achieved by the 850-kW turbine, followed by Asabah, with Gharyan ranking third.

5. Conclusions

This project presents the findings of an assessment study of wind energy potential in four selected areas: Nalot, Alraiyna, Gharyan, and Asabah, located in Libya. The findings demonstrate the viability of harnessing wind energy in these areas and integrating it into the national electricity grid. Additionally, wind energy could be utilized for other applications, such as battery charging and water pumping.

Key Findings

The wind data utilized in this study relies on human observations, which may not be as precise as measurements obtained using modern automated data loggers. Furthermore, wind speed values were rounded to the nearest knot, potentially introducing a cumulative error in meter per second values.

An analysis of the available wind power density data, with a value of 313.6 W/m2, suggests that the Gharyan area possesses favorable wind power density characteristics. This site is deemed suitable for grid-connected applications.

Existing data sources indicate that Asabah exhibits a mean annual wind speed exceeding 7.924 m/s, with a theoretical capacity factor surpassing 16.5%. These values imply that Alraiyna has the potential to generate 1.275861 MWh annually.

Overall Significance

The findings of this study demonstrate the promising potential of wind energy in the selected areas, particularly in Gharyan and Asabah. Further investigations utilizing more precise wind data and advanced modeling techniques are recommended to refine the assessment and identify the most suitable locations for wind energy installations.

Recommendations

Enhancing Wind Energy Research

Extend the current study to encompass wind energy potential across various locations, deepening our knowledge and promoting the use of this resource.

Data Collection and Analysis

- Launch nationwide wind speed data collection initiatives, covering a significant portion of the country, to lay the groundwork for a comprehensive wind atlas.
- Conduct thorough investigations into the implications of integrating wind energy systems into the national electricity grid.

Resource Identification and Development

- Conduct a nationwide survey to pinpoint suitable locations for wind turbine farms. Subsequently, launch public initiatives to establish wind energy farms in these designated areas.

  Implementing Pilot Wind Energy Projects
- Implement one or more pilot projects to demonstrate feasibility and cultivate expertise. Careful planning and preparation are crucial for the success of such projects. Essential components of a pilot project include:
  - Cost and performance data from wind turbine manufacturers
  - Information about current electricity generation
  - Preliminary and final project objectives
  - Site data-driven decision-making regarding pilot project implementation

Future Research Directions

The proposed future research endeavors aim to enhance our understanding of wind energy systems and optimize their performance. Key considerations in this regard include:

- Underscoring the significance of renewable energy's contribution to Libya's energy balance, particularly in meeting energy demands.
- Promoting and supporting the adoption of wind energy across universities and educational programs through textbooks, DVDs, and study guides.
- Raising public awareness through various media platforms to encourage rational energy consumption in buildings.
- Encouraging the establishment of renewable energy research centers, particularly within universities and scientific institutions, to foster the localization and development of renewable energy technologies.

  Titles
- Harnessing Libya's Wind Power: A Comprehensive Assessment and Evaluation
- Libya's Wind Energy Potential: Unveiling Opportunities for Sustainable Development
- Unearthing Libya's Wind Energy Wealth: A Multi-City Assessment and Evaluation
- Wind Energy in Libya: A Promising Pathway to Sustainable Electricity Generation
- Optimizing Wind Energy Utilization in Libya: A Data-Driven Assessment and Evaluation

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