

# Analyzing the Monthly and Annual Wind Speed Characteristics of the Kilwa Offshore Zone Using Rayleigh Probability Distribution

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## Abstract:

This study analyses the wind speed characteristics in the Kilwa offshore zone, situated along Tanzania's southern coast. The Rayleigh probability distribution model, which only has one parameter the scale parameter was used for analysing the wind speed characteristics since it is simpler to estimate and work with. In order to match the hub heights used in modern offshore wind turbines, wind speeds were initial measured at a height of 10 meters and then projected to higher heights of 50 and 70 meters using standard wind profile equations. Analysis of monthly and annual wind speed distributions revealed that average wind speeds ranged from 9 to 10 m/s. They show a high potential for energy generation because they are within the ideal operating range for modern offshore wind turbines. The region's feasibility for the utilization of sustainable offshore wind energy is further demonstrated by the consistent and advantageous wind conditions that are seen throughout the year. The study highlights Kilwa's potential for offshore wind farm development, which serves the broader goal of generating sustainable offshore wind energy solutions and enhancing energy sources. The study not only identifies Kilwa as a potential location for offshore wind generation but also establishes a foundation for more comprehensive feasibility and investment analyses in the future.

**Keywords:** Offshore energy resource, Offshore wind energy, Kilwa offshore zone, Rayleigh probability distribution, Wind speed characteristics

## 1.0 Introduction:

Offshore wind energy is now at the forefront of sustainable energy generation due to the global transition to offshore energy resources. With regard to climate change, various countries are looking for more efficient methods of using sustainable offshore wind energy (Ahmad et al., 2022; Costoya et al., 2021). The use of turbines, which are located on different water bodies such as seas and oceans, offers an opportunity to use

the more powerful and reliable offshore wind energy prevailing in these areas. (Allouhi et al., 2017; Chitteth Ramachandran et al., 2022; Michael et al., 2021).

One of the main benefits of offshore wind energy is the higher efficiency resulting from the stronger wind speeds available along the offshore zone compared to terrestrial environments. The direction and speed of offshore winds are generally more consistent. Together with the

larger areas available at offshore locations, these more stable winds provide the perfect conditions for offshore wind energy generation (Costoya et al., 2021; Shu et al., 2015). This consistency not only promotes the reliability of power generation, but also improves the attractiveness of offshore wind energy as a sustainable energy source worldwide. (Adedipe et al., 2018; Ahmad et al., 2022; Rae & Erfort, 2020)

Offshore activities such as fishing, tourism, and recreational vessels will benefit from offshore wind energy, which is very important in light of the escalation of clean energy (Rae & Erfort, 2020). Advances in turbine technology have shaped the global growth of offshore wind energy and enabled offshore wind farms to use more energy (Rae & Erfort, 2020). Deeper oceans and stronger offshore winds are two extreme conditions to which commercial turbines have been adapted. This enabled larger plants and increased energy generation capacities. In addition, due to advances in offshore grid infrastructure and installation procedures, it is now more feasible to build larger offshore wind farms and connect them to the current energy system.

However, Africa has a wide offshore zone and strong winds, particularly along the Indian Ocean, but Tanzania could diversify its energy sources by taking advantage of the region's steady and strong winds along the Indian Ocean coast. Investigating offshore wind energy would not only improve the country's energy security but also support international initiatives to transition to offshore energy (Michael et al., 2021).

Reliable offshore wind energy has a lot to offer Tanzania's offshore sectors such as shipping, tourism and fishing. The growing electricity demand of these industries could be met by this offshore energy source while reducing its impact on the environment. Tanzania could become a regional pioneer in offshore energy development by focusing on sustainable offshore energy solutions. This would not only boost economic growth but also serve as a model for the more

extensive integration of renewable offshore energy technologies across Africa (Michael et al., 2021).

Understanding local wind conditions is essential to maximizing Tanzania's offshore wind potential. Statistical methods such as Rayleigh, Weibull, Gamma, Beta, Gaussian, and Lognormal distributions facilitate this process. Because of its simplicity and accuracy, the Rayleigh distribution provides a more accurate understanding of wind speed distributions than other models such as Weibull (Olaofe, 2017; Ongaki et al., 2021; Pallikonda & Rsr, 2020).

## **2.0 Literature Review:**

### **2.1 Offshore energy resources:**

Offshore energy resources are energy derived from natural resources located beneath the ocean's surface. These resources include wind, waves, natural gas, and oil, as well as innovative technologies like tidal and ocean thermal energy. Offshore energy is essential to addressing the global need for sustainable energy. The most established offshore energy source is still oil and gas production, although wind and wave energy are rapidly gaining popularity due to their sustainability and low adverse environmental impacts (Chen et al., 2020; Costoya et al., 2021; Li et al., 2020).

Offshore energy resources have been crucial in satisfying global energy demands, particularly in regions where land-based resources are limited. The North Sea, which includes parts of the UK, Norway, and the Netherlands, is one of the most advanced offshore energy zones. Its oil and gas resources have been significant for a long time. Offshore wind energy is another rapidly growing firm, especially in countries like the US, Germany, and Denmark. For example, the UK is host to the Hornsea Project One, the world's largest offshore wind farm with a capacity exceeding 1.2 gigawatts (GW) (Pallikonda & Rsr, 2020). Brazil's pre-salt reserves and the deepwater fields in the Gulf of Mexico are two significant projects that contribute significantly to the world's energy supply, demonstrating the continued

importance of offshore oil and gas exploitation (Chen et al., 2020) Africa's energy future is increasingly dependent on offshore energy resources. The West African region contains significant offshore oil and gas reserves, particularly in countries like Ghana, Nigeria, and Angola. These nations are significant contributors in the global energy market and supply a portion of the world's oil. (Olaofe, 2017)

Large-scale offshore wind farms are being researched in nations like South Africa and Morocco as part of the growing interest in offshore wind energy. The government of South Africa, for example, has recognized the potential of the country's 2,000 km of offshore line to produce renewable energy and has set out to incorporate offshore wind into its future energy portfolio. (Rae & Erfort, 2020) East Africa is also considering offshore wind possibilities; Kenya is investigating the feasibility of offshore wind power along its vast offshore zone. East Africa is putting itself in a position to access offshore resources for sustainable energy generation as renewable energy gains popularity globally. (Ongaki et al., 2021) Tanzania is leading the way in the development of its offshore energy industry. Additionally, the government has shown interest in offshore wind energy and is investigating research to determine its viability. Tanzanian offshore energy has a bright future because to efforts to expand capacity and diversify energy sources, which will support both domestic energy security and global energy markets. (Bishoge et al., 2018; Laurent et al., 2024; Michael et al., 2021)

## **2.2 Kilwa region and its potential geographical location:**

Kilwa, which is situated along the Indian Ocean in southeast Tanzania, is a historically significant area with new offshore wind energy production potential. Kilwa's strategic offshore zone positioning, at 8.95° S latitude and 39.53° E longitude, make it a perfect place for a various maritime activity, such as shipping, fishing, and offshore wind development. Being the center of

the Kilwa Sultanate, the region has a rich cultural history that is reflected in UNESCO World Heritage sites like the Kilwa Kisiwani ruins, which show how African, Arab, and Persian influences blended together. Kilwa is rapidly becoming known for its huge potential in renewable energy, especially in the fields of offshore wind power, despite its rich cultural legacy. Kilwa's location to the Indian Ocean, which has been suggested as a potential future site for Tanzania's offshore wind energy, makes it an ideal location to utilise offshore wind energy. With steady offshore wind speeds between 9 and 10 meters per second, the offshore zone of the region provides perfect conditions for the production of wind energy. Kilwa and other shore regions like Dar es Salaam, Zanzibar, and Mtwara are ideal sites for massive offshore wind farms because of these factors.

The increasing interest in onshore and offshore wind energy is another indication of Tanzania's drive to develop its renewable energy infrastructure. With average wind speeds of 9 to 10 meters per second, onshore locations like Mwenga, Singida, and Shinyanga offer ideal wind conditions for the construction of wind farms. These onshore locations can provide a substantial contribution to the national grid, lowering dependency on fossil fuels and assisting Tanzania's to shift to sustainable offshore wind energy generation, as can offshore areas like those surrounding Kilwa.

In particular, offshore wind energy is widely acknowledged as a reliable and sustainable energy source. Through the use of rotors and blades that transform kinetic energy into mechanical energy, this energy is created as air moves from high-pressure to low-pressure regions. Electricity can then be produced from this energy, providing a more economical and environmentally friendly substitute for fossil fuels. Offshore wind farms are a great option for large-scale energy generation since they offer the extra advantage of greater and more steady wind speeds than onshore areas (Argin et al., 2019; Chen et al., 2020; Rae & Erfort, 2020; Salvação & Guedes Soares, 2018).

Furthermore, Tanzania's growing dedication to sustainability is in line with the environmental advantages of wind energy, such as its zero emissions and capacity to lower greenhouse gas emissions (Bishoge et al., 2018; Michael et al., 2021).

Kilwa's offshore zone and the national energy strategy makes the region essential for the development of both offshore and onshore wind energy initiatives. The offshore regions of Tanzania, particularly Kilwa, have the potential to

make substantial contributions to the national electrical grid as technological advancements and industry investments increase. This expansion benefits Kilwa and the larger East African region by promoting local economic growth, job creation, and energy security in addition to assisting the nation's transition to sustainable offshore energy generation. Kilwa's offshore energy potential is expected to be crucial in determining Tanzania's offshore energy landscape going forward as the world's transition to renewable energy picks up speed. (Laurent et al., 2024; Michael et al., 2021)

**Figure 1.1 Geographical location of Kilwa Region**



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<sup>1</sup> <https://www.tageo.com/index-e-tz-v-00-d-m3531597.htm>

### 2.3 Offshore Wind Energy

Offshore wind energy refers to the harnessing wind energy using wind turbines placed in bodies of water, such as seas and oceans. It has gained a lot of interest as a sustainable alternative energy source due to its higher wind speeds and lower turbulence compared to onshore locations, which boost energy generation efficiency (Ahmad et al., 2022; Li et al., 2020; Shu et al., 2015). Offshore wind energy is particularly beneficial for offshore industries like oil and gas operations, aquaculture, offshore data centers, and maritime transportation because it provides localized renewable energy solutions that reduce dependency on fossil fuels and enhance sustainability (Michael et al., 2021).

As of 2024, the global offshore wind energy sector is experiencing impressive growth, with significant contributions from Europe and China. The worldwide installed offshore wind energy capacity has reached approximately 75.2 gigawatts (GW), and 10.8 GW were added in 2023 alone, reflecting a 24% year-over-year increase. The continued expansion of the sector is expected, with projections indicating an additional 234 GW of offshore wind capacity by 2030. Europe remains the dominant region in offshore wind energy, with the UK, Germany, and the Netherlands playing leading roles. The UK currently represents about 22% of the global installed capacity. However, China is rapidly scaling up its offshore wind capacity, and it is anticipated that China will contribute to nearly 60% of global renewable energy projects by 2030 (Costoya et al., 2021; Irena et al., 2021; Mazumder et al., 2019)

Despite the positive outlook, the offshore wind industry faces significant challenges. Increasing costs, project delays, and supply chain issues have hindered progress. For instance, the average cost of offshore wind projects has risen to \$230 per megawatt-hour, making them less competitive compared to onshore wind energy. These hurdles have led to the cancellation or reevaluation of several projects. To address these challenges and ensure the achievement of global wind energy

goals, experts emphasize the need for supportive policies, streamlined regulatory processes, and technological innovation. Both public and private sector investments will be key to overcoming obstacles and achieving the ambitious targets set for 2030 (Irena et al., 2021)

Offshore wind energy in Africa is an emerging sector with significant potential, though it remains in the early stages of development. Morocco is leading the continent's efforts, with plans for its first offshore wind farm. The Moroccan Agency for Sustainable Energy (MASEN), supported by the European Investment Bank, is advancing a project that could generate up to 200 GW, positioning Morocco as a key player in Africa's offshore wind energy (Allouhi et al., 2017; Benazzouz et al., 2021)

In South Africa, the technical potential for floating offshore wind technology is substantial, estimated at 589 GW. This potential is significantly indicating a promising opportunity for future development. While these developments are promising, the broader African continent has yet to fully harness its offshore wind energy (Rae & Erfort, 2020). The African Development Bank's report on offshore renewable energy highlights that Western Africa possesses favorable conditions for offshore wind energy. However, the report also notes that some technologies, such as floating offshore wind, may be more relevant for future energy production (Adedipe et al., 2018; Olaofe, 2017).

As of now, Tanzania has not developed any offshore wind energy projects, while the country has substantial offshore wind energy, with favorable wind speeds along its offshore zone, no operational offshore wind farms have been established. Studies have indicated that the coastal regions of Tanzania, particularly at a height of 100 meters, experience wind speeds ranging from 3.1 to 6.5 meters per second, which is suitable for harnessing wind energy. Despite this favorable resource, no substantial progress has been made to convert this potential into active useful energy (Michael et al., 2021).

In contrast, Tanzania’s energy development focus has primarily been on onshore renewable energy projects, such as the Miombo Hewani Wind Power Station in the Njombe Region. This project, which is expected to generate 300 MW of electricity, is one of the country’s first steps toward large-scale wind energy generation (Kibona, 2020; Marcel et al., 2021). However, the offshore wind sector is still in a nascent stage, with limited activity and no offshore wind farms under construction or in operation. Globally, offshore wind energy has seen rapid growth, with countries investing heavily in offshore projects, but Tanzania has yet to follow this trend.

## 2.4 Rayleigh Probability Distribution.

The Rayleigh distribution is easier to use and still offers a good match for a lot of wind speed data because it is a particular instance of the more general Weibull distribution. The Rayleigh distribution is accessible and accurate enough for many real-world applications, especially when wind speed data is easily accessible and a thorough analysis is not immediately required, since wind energy evaluations frequently call for preliminary, fast assessments. (Olaofe, 2017; Saeed et al., 2020).

Furthermore, because it provides a reliable first approximation without requiring the more intricate calculations associated with other distributions, like the Weibull distribution, the Rayleigh distribution is particularly useful when thinking about wind turbine site selection and preliminary energy potential evaluations. Because of its simplicity, precision, and capacity to offer significant insights into wind energy potential without requiring a great deal of data processing, the Rayleigh distribution is commonly chosen (Pallikonda & Rsr, 2020).

The Rayleigh distribution is still a competitive option because it can model wind speed data with fewer parameters, which makes it more approachable for wind energy analysis researchers and practitioners, even though the Weibull distribution might provide a better fit for capturing the variability in wind speeds across various

datasets. The Rayleigh distribution is frequently regarded as an accurate and efficient tool for estimating wind energy potential in a variety of settings, but ultimately, the choice between Rayleigh and other mathematical models depends on the particular goals of the wind energy study (Al-Noor & Assi, 2020).

According (Al-Noor & Assi, 2020) Depending on the data available, the average value for a certain time period which could be hourly, daily, monthly, or annual is one of the simplest statistical analyses of wind speed data. The mean wind speed,  $V_m$ , is obtained from equation (1) regardless of duration.

$$V_m = \frac{1}{n \sum_{i=1}^n v_i} \quad (1)$$

$V_i$  represents the site's daily wind speed measurement.

$V_m$  represents mean wind speed

Also

$$Vm = c. \Gamma(1 + \frac{1}{k}) \quad (2)$$

Take  $k = 2$  in Eq. (1), attain

$$Vm = c. \Gamma \frac{3}{2} \quad \longrightarrow \quad c = \frac{2Vm}{\sqrt{\pi}} \quad (3)$$

Where:  $f(v)$  = likelihood of measuring wind speed  $V$

$V$  = Wind speed [ $m/s$ ]

$$f(V) = \frac{\pi}{2} \frac{V}{V_m^2} e^{-\left[\frac{\pi}{4} \left(\frac{V}{V_m}\right)^2\right]} \quad (4)$$

Wind speed projections at various hub heights.

The height at which wind data is collected and the height of the wind turbine hub change. Given that wind speed at hub height is essential for precise power calculation, the existing wind speed data must be calibrated to the turbine's hub height. The power-law equation, as illustrated in different equations, is commonly used for performing this extrapolation.

$$\frac{V}{V_0} = \left(\frac{h}{h_0}\right)^\alpha \quad (5)$$

As in equation (5),  $V$  represents wind speed at hub height  $h$ ,  $V_0$  represents wind speed at original height  $h_0$ , and  $\alpha$  represents the surface roughness coefficient, which is normally considered to be 0.143 (or  $1/7$ ). The following formula can be used to get the surface's roughness coefficient, or  $\alpha$ : (Al-Noor and Assi, 2020)

$$\alpha = [0.37 - 0.088 \ln V_0] / \left[ 1 - 0.088 \ln \left( \frac{h_0}{10} \right) \right] \tag{6}$$

The projected wind speed predictions at various heights can also be obtained using the Rayleigh probability density function. The scale factor ( $c$ ) of the Rayleigh distribution will vary as a function of height due to the non-linearity of boundary layer growth and the ground's effect with regard to wind speed. The equations are as follows: (Paraschiv et al., 2019)

$$c(h) = c_0 \left( \frac{h}{h_0} \right)^n \tag{7}$$

The scaling factor ( $c_0$ ) and the shape parameter ( $k_0$ ) are defined at the measurement height ( $h_0$ ). Thus, the exponent ( $n$ ) is outlined as follows:

$$n = [0.37 - 0.088 \ln(c_0)] / \left[ 1 - 0.088 \ln \left( \frac{h}{10} \right) \right] \tag{8}$$

### 3.0 Results and Discussion:

#### 3.1 Results:

The study's results determine potentiality of offshore wind energy were initial measured at a height of 10 meters and then projected to higher heights of 50 and 70 meters using the Rayleigh distribution. The mean wind speed varied between 9 and 10 m/s, based on an investigation of monthly and annual wind speed distributions.

Tables 3.2, 3.5, and Figures 3.1, 3.2 present the monthly mean wind speed ( $V_m$ ) values for the Rayleigh parameters, while Tables 3.1 and 3.4 provide data for the Scale parameter ( $c$ ).

**Table 3.1 Rayleigh factor parameters for the annually shape  $k$  and scale  $c$  at 50 meters**

<i>k and c at 50M</i>										
Monthly	2020		2021		2022		2023		2024	
	<i>k</i>	<i>C</i>	<i>k</i>	<i>c</i>	<i>k</i>	<i>c</i>	<i>k</i>	<i>c</i>	<i>k</i>	<i>c</i>
Jan	2	9.131312214	2	15.85072456	2	10.44457572	2	9.985929	2	9.126071757
Feb	2	7.947256075	2	16.16529226	2	10.57800025	2	10.32506	2	10.4746431
Mar	2	7.140737641	2	12.05955657	2	10.4692617	2	10.66468	2	8.693173622
Apr	2	12.77507995	2	11.52955226	2	10.5803503	2	9.374787	2	8.374126842
May	2	13.01940484	2	13.16702431	2	12.66666222	2	11.299	2	9.593107494
Jun	2	11.81687766	2	13.82513511	2	13.40382689	2	10.81328	2	9.216356665
Jul	2	10.22032968	2	14.52967897	2	13.29344253	2	12.8386	2	8.902255471
Aug	2	10.82594133	2	12.25149262	2	11.68605969	2	11.99753	2	9.598248726
Sep	2	11.47836239	2	11.02043666	2	12.26774871	2	10.28143	2	9.472603417
Oct	2	11.3288178	2	10.37682667	2	13.16702431	2	9.496729	2	7.146301365
Nov	2	13.21966475	2	10.95164086	2	13.82513511	2	10.22945	2	8.636103801
Dec	2	15.54725743	2	9.98832312	2	11.568138	2	9.599019	2	8.573041177
<b>Avr. Ann</b>	<b>2</b>	<b>11.20425348</b>	<b>2</b>	<b>12.64297366</b>	<b>2</b>	<b>11.99585212</b>	<b>2</b>	<b>10.57546</b>	<b>2</b>	<b>8.98383612</b>

*k*, dimensionless Rayleigh shape parameter;  
*c*, Rayleigh scale parameter;

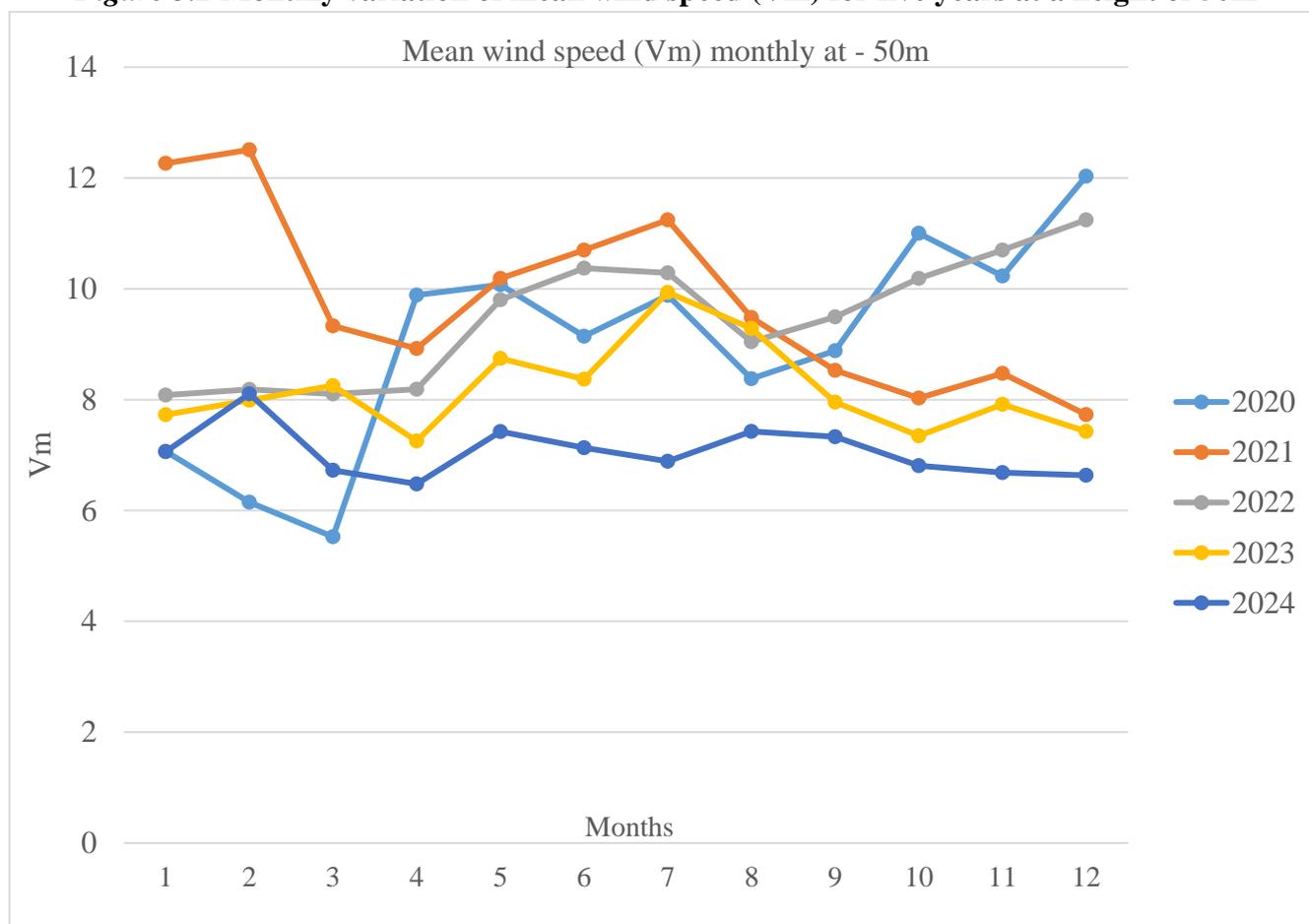
**Table 3.2 The Mean wind speed (Vm) monthly at - 50m for five years**

<i>Mean Wind Speed Monthly (Vm) at 50M</i>					
<i>Monthly</i>	<i>2020</i>	<i>2021</i>	<i>2022</i>	<i>2023</i>	<i>2024</i>
	<i>Vm(m/s)</i>	<i>Vm(m/s)</i>	<i>Vm(m/s)</i>	<i>Vm(m/s)</i>	<i>Vm(m/s)</i>
<i>Jan</i>	7.066050769	12.26570966	8.082288783	7.727375511	7.061995565
<i>Feb</i>	6.149796829	12.50913046	8.185536212	7.98980382	8.105555723
<i>Mar</i>	5.525691546	9.332003661	8.101391446	8.252610519	6.727007545
<i>Apr</i>	9.88569456	8.921872309	8.187354748	7.254458326	6.480120713
<i>May</i>	10.07475962	10.18899147	9.801798061	8.74346163	7.423400164
<i>Jun</i>	9.144212302	10.698255	10.37223556	8.367604957	7.131860414
<i>Jul</i>	9.880115804	11.24344967	10.28681723	9.934848072	6.888800607
<i>Aug</i>	8.377399572	9.480528848	9.042981899	9.284009093	7.427378585
<i>Sep</i>	8.882260241	8.527905201	9.493108239	7.956043925	7.330150924
<i>Oct</i>	11.00056951	8.02986278	10.18899147	7.348820102	6.808238633
<i>Nov</i>	10.22972604	8.474669193	10.698255	7.915820493	6.682845409
<i>Dec</i>	12.03087878	7.729228463	11.24344967	7.42797489	6.634045884
<i>Avr. Annual</i>	<i>9.020596297</i>	<i>9.783467227</i>	<i>9.473684027</i>	<i>8.183569278</i>	<i>7.058450014</i>

*Avrg. Vm, Average mean wind speed;*

**9.115329207**

**Figure 3.1 Monthly variation of mean wind speed (Vm) for five years at a height of 50m**



**Table 3.4 Rayleigh factor parameters for the annually shape k and scale c at 70 meters**

<i>k and c at - 70M</i>										
Monthly	2020		2021		2022		2023		2024	
	<i>k</i>	<i>c</i>								
Jan	2	10.18407031	2	17.3450352	2	8.693953659	2	11.10289764	2	10.17842723
Feb	2	8.906068086	2	17.67727144	2	8.801160228	2	11.46674392	2	11.62709749
Mar	2	8.031839317	2	13.32148345	2	8.713792379	2	11.83070186	2	9.711877327
Apr	2	14.08384982	2	12.75577938	2	8.803048078	2	10.44612955	2	9.367517851
May	2	14.34382842	2	14.50082401	2	10.47367284	2	12.50941545	2	10.68091383
Jun	2	13.06256707	2	15.20000608	2	11.06160627	2	11.98982986	2	10.27563312
Jul	2	11.35442633	2	15.94724854	2	10.9736406	2	14.15145594	2	9.937310033
Aug	2	12.00338003	2	13.52613437	2	9.689738124	2	13.25532843	2	10.68644054
Sep	2	12.70109462	2	12.21152589	2	10.15502684	2	11.41996058	2	10.55134522
Oct	2	12.5412918	2	11.52224746	2	10.8728665	2	10.57729033	2	8.037881393
Nov	2	14.55679322	2	12.1379163	2	11.39712039	2	11.36421134	2	9.650312155
Dec	2	17.02430745	2	11.10546816	2	11.95741045	2	10.6872689	2	9.582265803
Avr.										
Annual	2	12.39945971	2	13.93757836	2	10.13275303	2	11.73343615	2	10.0239185

*k*, dimensionless Rayleigh shape parameter;  
*c*, Rayleigh scale parameter;

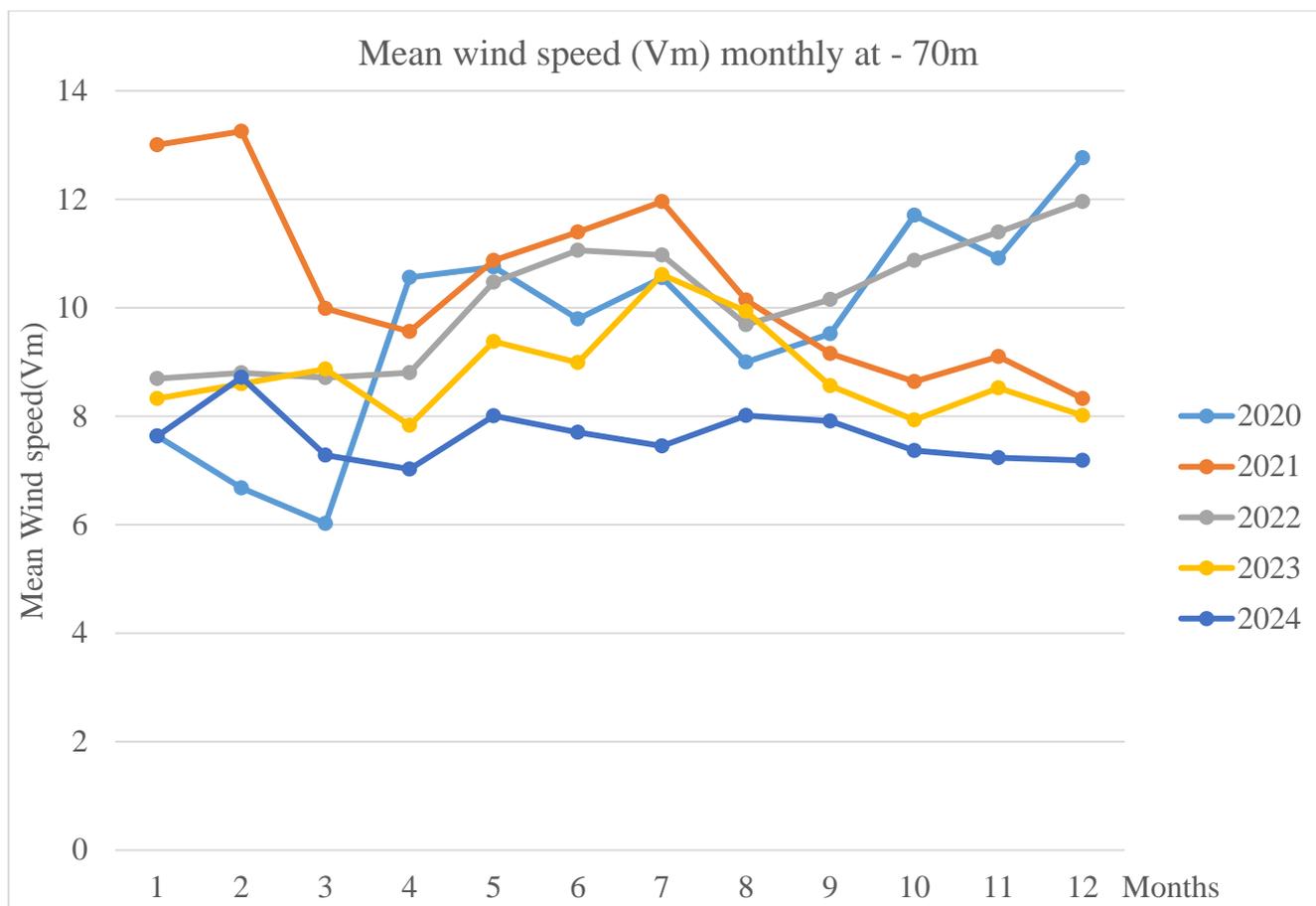
**Table 3.5 The Mean wind speed (Vm) monthly at - 70m for five years**

<i>Mean Wind Speed Monthly (Vm) at 70M</i>					
Monthly	2020	2021	2022	2023	2024
	<i>Vm(m/s)</i>	<i>Vm(m/s)</i>	<i>Vm(m/s)</i>	<i>Vm(m/s)</i>	<i>Vm(m/s)</i>
Jan	7.636120328	13.00548522	8.693953659	8.325066477	7.63188909
Feb	6.677861157	13.25459935	8.801160228	8.597882152	8.718116898
Mar	6.022355463	9.988584865	8.713792379	8.870781548	7.282065187
Apr	10.56021498	9.56441415	8.803048078	7.83261503	7.023860921
May	10.75514961	10.8728665	10.47367284	9.379687951	8.00865869
Jun	9.794446707	11.39712039	11.06160627	8.990097346	7.704775062
Jul	10.55446109	11.95741045	10.9736406	10.61090675	7.451096941
Aug	9.000257408	10.14203422	9.689738124	9.938981149	8.012802675
Sep	9.523410958	9.156327307	10.15502684	8.562803522	7.911506816
Oct	11.70792394	8.639499272	10.8728665	7.930960726	7.366947911
Nov	10.91483279	9.101134084	11.39712039	8.521002169	7.23590299
Dec	12.76500026	8.32699388	11.95741045	8.013423788	7.184881137
Avr. Annual	9.659336224	10.45053914	10.13275303	8.797850717	7.627708693

Avrg. Vm, Average mean wind speed;

9.760119778

Figure. 3.2 Monthly variation of mean wind speed (Vm) for five years at a height of 70m



#### 4.0 Conclusion and Recommendation:

##### 4.1 Conclusion:

Analysis shows that at heights of 50 and 70 meters above sea level, the monthly and annual average wind speeds range from 9 to 10 m/s. That indicates the offshore mean wind speed is sufficient for generating offshore wind energy. According to these results, greater heights can result in more efficient offshore wind energy generation.

##### 4.2 Recommendation:

Further research on the potential for offshore wind energy provides precise wind behavior at different heights on offshore zones will help to explore much on renewable energy particularly offshore energy resources in coastal areas for offshore activities. By enhancing offshore wind-turbine technology, it is feasible to increase sustainable energy generation and make it easier for renewable resources to be successfully integrated in offshore zones.

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