Social Science and Humanities Journal
Everant Journal
https://sshjournal.com/
Impact Factor: 2024: 6.576
2023: 5.731
ISSN: 2456-2653
Volume 08 Issue 09 September 2024
DOI: https://doi.org/10.18535/sshj.v8i09.1329

Different Heights Monthly and Yearly Mean Wind Speeds Investigation Using a Weibull Model: A Case of Short Ferry Route

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***Received* 22-08-2024**
***Revised* 23-08-2024**
***Accepted* 19-09-2024**
***Published* 20-09-2024**

Abstract:

This study investigates the possibility of integrating wind energy into onboard ferry power generation along Tanzania's Kivukoni-Kigamboni ferry route. Wind energy is recognized as a viable substitute as the maritime industry experiences pressure to adopt renewable energy, especially for short to medium routes. The research uses the Weibull distribution to evaluate wind speeds at 10,20,30 and 40 meters using wind speed data from 2020 to 2023. The results show that wind energy harnessing is a viable option, with mean wind speeds of 4.017482,5.06268,5.80696 and 6.40713 m/s respectively. This highlights how ferry operations could become less reliant on single-unit conventional nonrenewable energy particularly fossil fuels by incorporating wind-assisted technologies. Ferries must transition towards onboard multiple energy sources to engage in sustainable maritime operations. Wind energy may play a significant role in reducing the environmental impact of ferry operations. The study emphasizes how important it is for the maritime industry to use renewable energy. More study on the similar use of wind energy for maritime operations is recommended.

Keywords: Wind Energy Potential, Wind Assisted Technologies, Maritime Route, Onboard Power Generation

1. Introduction:

The maritime industry has relied only on a single unit energy source which are conventional and non-renewable energy sources onboard power generation based particularly on fossil fuels as its primary energy source to meet its operational needs. Due to this reliance, there is an urgent need for transition from a single conventional energy source to onboard multiple energy sources particularly renewable energy while adhering to environmental and regulatory regulations, to comply with global energy source innovation approaches(Arief & Fathalah, 2022; Ouchi et al., 2013; Pan et al., 2021).The most potential alternative to conventional energy sources among renewable sources is wind energy, due to its abundance and reliability in various maritime geographical locations(Aziz et al., 2023).

Ferries play a major role in Tanzania's maritime transportation system, connecting waterways and communities across the Indian Ocean. They can integrate renewable energy sources, such as wind energy, into their operations because they rely much on ferry boats. The port of Dar es Salaam is a major hub for trade. It is a traffic navigation channel. Its connection to the Kivukoni and Kigamboni terminal ferries emphasizes maritime transportation's importance while drawing attention to the region's heavy reliance on fossil fuels, contributing to environmental concerns(Chusi et al., 2022).

Tanzania is actively pursuing renewable energies such as hydro power plants and wind energies to reduce its dependency on single energy sources based on fossil fuels to multiple energy sources(Bishoge et al., 2018).To realize this potential, the government has started several projects, mainly land-based in wind-rich regions like Kititimo-Singida and Makambako-Njombe. An important project that could generate up to 100 MW of electricity is the Singida Wind Farm. International cooperation has been essential in advancing the development of wind energy and its infrastructure. Financial and technical help is provided by partners such as the World Bank and the African Development Bank, which facilitate change in regulations and capacity building (Michael et al., 2021).

Moreover, aligning with more extensive African initiatives that promote the use of renewable energy, Kenya and Uganda are looking into wind energy as a sustainable way to meet their energy needs (Kazimierczuk, 2019; Kibona, 2020; Yongo et al., 2016). As seen by initiatives like the Lake Turkana Wind Power Project, Kenya is dedicated to increasing its capacity for wind energy, whereas Uganda is still in the early phases of development and exploring several areas with strong wind potential as a component of a strategic plan to utilize the continent's abundant natural resources (Kazimierczuk, 2019).

Tanzania should adopt a comprehensive energy policy that incorporates wind energy projects in both land-based and marine applications particularly onboard power generation for small to medium marine vessels like ferry boats. This approach could establish Tanzania as a pioneer in regional collaboration and sustainable development by transferring knowledge from land-based initiatives to maritime applications, encouraging nearby nations like Kenya and Uganda to look into similar renewable energy options.

Africa is committed to reduce its dependency on non-renewable energy sources, as demonstrated by projects like South Africa's solar-powered ferries. Leading nations in the use of modern technologies for maritime transportation with zero emissions include Norway and Japan. While Norway uses hybrid and electric boats powered by wind and solar energy, Japan uses hydrogen fuel cells on its ferries, demonstrating sustainable ferry operations (Chou et al., 2021; Pan et al., 2021). Due to Tanzania's rich wind resources, there are also chances to incorporate wind energy into ferries, which would support international efforts to improve the efficiency and sustainability of maritime transportation.

With the advancement and integration of wind-assisted technologies such as Wind-Assisted Electrical Generation (WAEG) and Wind-Assisted Propulsion Technologies (WAPT), wind energy is experiencing significant growth in maritime applications worldwide (Ouchi et al., 2013; Pan et al., 2021). Many could think that we are returning to those days before steamships where wind was the primary energy source (Kim et al., 2016). However, since technological developments, wind energy harvesting is now more effective than before and can be adapted to a range of maritime variables, such as wind speed, vessel type, and season maritime vessels such as sailboats have traditionally powered themselves using wind energy, but modern boats combine this renewable resource with onboard traditional power systems for increased efficiency and adaptability (Rutkowski, 2017; Yiğit & Acarkan, 2018). These advancements signify a significant change in the direction of maritime transportation and emphasize the growing usage of renewable energy (Al-Falahi et al., 2019).

Wind-assisted technology is being more widely used as the maritime industry transitions to more ecologically acceptable energy strategies. Reducing reliance on single energy units particularly fossil fuels and other non-renewable energy sources is the goal of innovations like WAEG and WAPT, which are contributing to this transition. For example, WAEG systems incorporate onboard wind turbines to generate electrical power, which benefits both recently constructed and retrofitted vessels by adopting different operational requirements. By using wind energy to increase maritime operations' efficiency, these remarkable innovations signify advancement in the industry's transition to renewable alternative energy sources which are greener practices (Chou et al., 2021; Li et al., 2021; Pan et al., 2021).

Several remarkable vessels serve as examples of how wind-assisted technologies have been applied successfully. For example, Japan has the *Wind Challenger* developed by TOKYO Researcher, and *Shin Aitoku Maru* developed by JAMDA IN 1970 as a new concept sailing vessel fitted with sails (Arief & Fathalah, 2022; Ouchi et al., 2013; Pan et al., 2021; Tay & Konovessis, 2023). Also, Germany has *Beluga Sky Sail*. Both utilize the wind modern technology. With the innovation of the propulsion system of rotor sails being incorporated with two traditional propulsion systems on "E-Ship 1," fuel consumption has been lowered by as much as 30% (Rutkowski, 2017). Similar to that, the "Energy Observer" establishes a standard for self-sufficient, emission-free transportation by incorporating wind power with solar panels and hydrogen fuel cells. Additionally, under ideal circumstances, ships with Flettner rotors like the MV Afros have been shown to save up to 12% on fuel. These examples demonstrate the significant influence of wind-assisted technologies on modern marine applications (Arief & Fathalah, 2022; Tay & Konovessis, 2023).

Data on wind speed is estimated using a variety of analytical techniques, such as probability density functions such as Weibull, Rayleigh, Gamma, Beta, Gaussian, and Lognormal distributions (Michael et al., 2021). In comparison to other models, the Weibull distribution offers a more accurate knowledge of wind speed distributions because of its simplicity and precision (Akdağ & Güler, 2018; Mohammadi et al., 2016).

Determining the Weibull distribution involves determining the scale and shape parameters, which characterize the wind distribution. The scale parameter represents wind speed intensity, while the shape parameter indicates wind speed variation. Enhancing wind energy potential predictions and turbine performance over a range of geographic and climatic variables increases the economic viability of wind power plants (Soulouknga et al., 2018).

This research focuses on exploring the wind energy potential along short maritime routes, where adopting wind-assisted technology could significantly increase initiative in harnessing natural resources such as wind as energy for reducing reliance on single energy units particularly fossil fuels and other non-renewable energy sources. The Meteorological Authority, which is prominent in providing precise and comprehensive meteorological data, serves as the primary source of the research data. The research guarantees the accuracy and consistency of wind speed readings by utilizing data from a reliable source.

2. Literature Review:

This provides readers and other researchers with a thorough understanding of monthly and annual mean wind speeds at various heights as one of the wind potential aspects of the maritime environment. This also indicates a promising potential for wind energy harnessing or adopting wind energy potential into the ferry operations such as the ferry's electrical power system. It also reviews previous studies on wind energy potentials. The primary focus of this section is on the ferry route located near Tanzania's coast region, namely the Kivukoni and Kigamboni ferry route within Dar es Salaam port along the Indian Ocean.Chusi et al., (2022) tell as more on Dar es Salaam port, Between Kigamboni and Kivukoni Terminal, ferries like Magogoni, Kigamboni, and Mv Kazi operate a vital transit service by traversing a single-traffic channel that links to the port of Dar es Salaam. These ferries must use advanced and modern navigation and safety systems to enable safe and fast crossings in difficult locations with heavy traffic, supporting local economies as well as vital trade and travel.

In addition to their role in transportation, ferries have a lot of potential to integrate sustainable energy sources. They can serve as test platforms for renewable energy sources in terms of full or hybrid approaches in emerging terminologies (Gagatsi et al., 2016b). Also Pan et al., (2021)say that by using local wind resources and enhancing energy efficiency, ferries can minimize the environmental impact of conventional transportation systems and promote global sustainability goals. This innovative approach is in harmony with the desire to reduce reliance on fossil fuels, dependence on single-unit energy generation, and the rising demand for renewable energy sources. Tay & Konovessis, (2023) found that incorporating renewable energy technologies, like wind turbines, onto marine vessels may significantly decrease fuel consumption and greenhouse gas emissions, resulting in more environmentally friendly maritime operations. Optimizing ferry routes to travel through areas with significant energy potential, such as those with strong and constant wind currents, is one approach that shows promise. Ferry boats can use this to generate power, particularly electricity power to suit their electrical power demand. The study conducted by Gullbring & Pandic (2021) provides support for this approach. They found that strategically positioned wind turbines aboard ferries might efficiently harness local wind resources to produce electricity, hence decreasing dependence on diesel engines.

Additionally, the integration of wind energy systems on ferries has the potential to promote a reciprocal relationship between sustainable energy generation and transportation. According to Al-falahi et al., 2018; Anwar, Zia, et al., (2020) hybrid energy systems on ferries function as mobile power plants that, when parked, can deliver energy to neighboring communities in addition to offering a cleaner mode of transportation. This multiple purpose optimizes the use of sustainable energy resources and raises the expectations for maritime operations' sustainability. The incorporation of power generation technologies into ferry boats is a remarkable advancement in mitigating the environmental impact of the maritime industry said by Anwar, Zia, et al., (2020). Ferries may transition from conventional fossil fuel-based systems particularly single-unit power generation to more multiple sustainable energy solutions by utilizing renewable energy resources like wind, which will encourage the generation of clean energy as well as efficient transportation.

Figure 1. Mv Kazi Ferry Boat

Source: Researcher, 2024

The ferry operation area is the route that ferries travel to a specific path to connect two or more terminals and enable transportation across bodies of water. These routes require a coordinated strategy for safe and effective operations, including infrastructure, docking facilities, and navigational channels(Gagatsi et al., 2016b). Because renewable energy has significant advantages for the environment and the economy, integrating renewable energy technologies like wind power into ferry systems is becoming increasingly important.

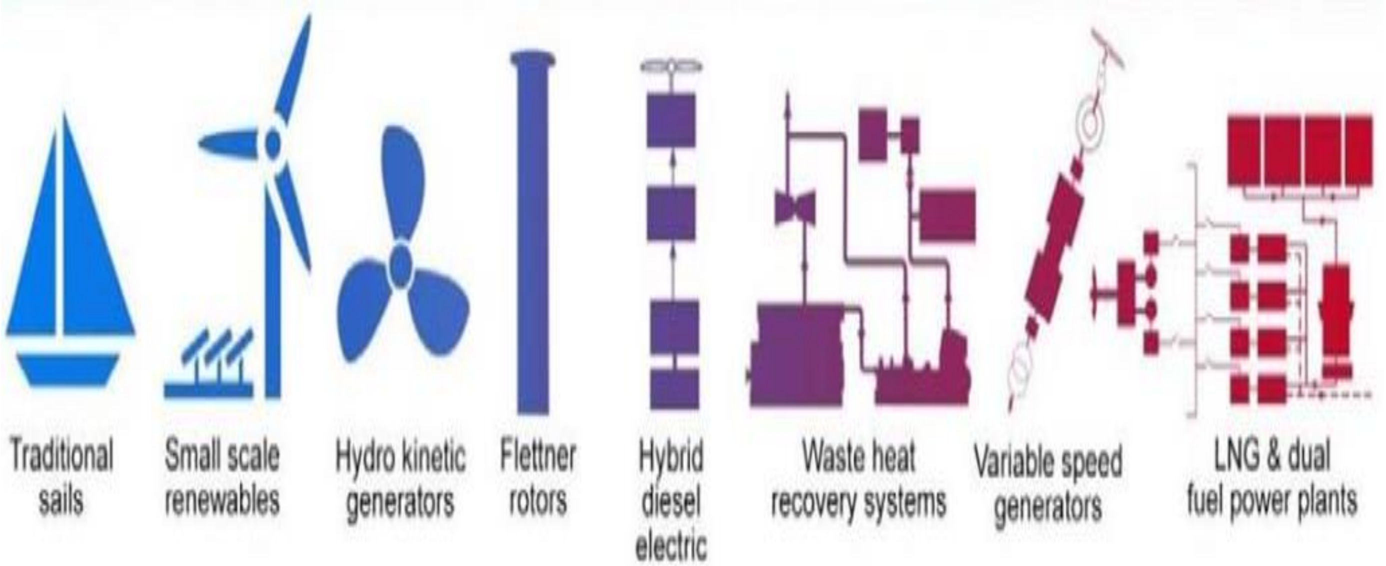
Adopting renewable energy solutions strengthens operational flexibility and reliability of power while promoting innovation and investment in green technologies, which advances the industry and is in harmony with global sustainability goals and advancements toward a low-carbon economy (Sciberras et al., 2017).

Figure 2. Ferry route crossing in the port of Dar Es Salaam

Source: Google 2024

2.1 Energy Sources

Figure. 1 Marine energy source technologies



(Rutkowski et al., 2017)

Fossil fuels, including coal, oil, and natural gas, have powered ships for more than a century, providing the necessary energy for propulsion and onboard systems (Gullbring & Pandic, 2021; Pan et al., 2021). However, these resources are limited and non-renewable, with their significant impacts on the environment. The maritime industry has historically relied on non-renewable energy sources like nuclear power and fossil fuels due to their high energy density and ease of storage and use, despite desirable effects on climate change.

Although it has high energy output, nuclear energy has concerns in terms of safety concerns and managing radioactive waste (Arief & Fathalah, 2022).The maritime industry is being forced to explore alternative renewable energy sources due to the sustainability difficulties and severe environmental concerns raised by the continuous reliance on these non-renewable energy sources (Chou et al., 2021).

Another promising way to reduce the environmental effect of marine vessels especially ferries and smaller ships is through the use of renewable energy sources. As practical solutions for incorporating renewable energy into marine operations, wind, solar, and biofuels emerged in recent years. (Pan et al., 2021) Cleaner options that may reduce emissions and reliance on fossil fuels include wind energy, which is captured by onboard wind turbines, and solar electricity, which is captured by photovoltaic cells (Tay & Konovessis, 2023).However, since natural resources are unpredictable, a vessel's energy needs may not be fully satisfied by depending just on a single renewable energy source. By compensating for the intermittent character of each source, multiple energy systems that integrate many renewable energy sources, such as solar and wind, can increase efficiency and reliability. According to Pan et al., 2021; Yuan et al., (2020) these technologies have the potential to significantly decrease greenhouse gas emissions and fuel consumption, which will help achieve global climate change targets and promote innovation in maritime technology.

To minimize the negative effects of non-renewable energy, maritime vessels are using hybrid and integrated energy systems that combine conventional systems such as diesel engines with renewable energy sources. Projects like the Ampere ferry in Norway, which achieves significant CO2 emission reductions by using shore-based renewable energy in addition to battery-powered electric propulsion, serve as examples of this change (Gagatsi et al., 2016b; Gullbring & Pandic, 2021). By incorporating modern innovations like hydrogen fuel cells, which provide zero-emission substitutes with promising efficiency, maritime transportation's sustainability is further advanced (Al-falahi et al., 2019; Rutkowski, 2017). These achievements emphasize the need for regulatory support, technological improvement, and financial investment to speed up the use of renewable energy in the maritime industry. They also represent a wide range of transitions toward sustainable maritime practices. The marine industry may greatly minimize its adverse environmental impact and offer the path to a cleaner and more sustainable future by utilizing renewable energy sources including solar, wind, hydroelectric, and geothermal energy (Gagatsi et al., 2016b; Pan et al., 2021; Yiğit & Acarkan, 2018).

The marine industry experienced significant advances in power sources due to the desire to meet the global demand for sustainable energy, enhance energy efficiency, and minimize environmental effects. Traditional marine vessels only use fossil fuels, but as environmental concerns and fossil fuel resources diminish, the industry is exploring progressively alternate energy sources (Arief & Fathalah, 2022).Together with standalone energy sources like solar and wind power, these systems also incorporate innovative hybrid and integrated energy sources. By improving energy efficiency and reducing fuel consumption, the integration of renewable energy sources with conventional systems has the potential to decrease operating costs and environmental effects (Pan et al., 2021). Developing hybrid energy systems is a major advance toward developing a marine industry that is sustainable and more efficient.

The potential of hybrid energy systems in maritime applications is significant, as they provide more sustainable and reliable energy in rigorous marine environments. These systems increase energy availability while minimizing dependency on fossil fuels by integrating conventional fuels with renewable energy sources like solar, wind, and marine energy (Yiğit & Acarkan, 2018). Energy efficiency can be raised, greenhouse gas emissions can be decreased, and major cost savings can result from the usage of hybrid energy systems. According to Nadarajan et al., (2016) By harnessing the benefits of each energy source, hybrid ships, and other boats can optimize energy efficiency. Pan et al., (2021) tell us that, incorporating various energy sources, a continuous power supply is guaranteed, and total output power is maintained, which improves the operational dependability of ships.

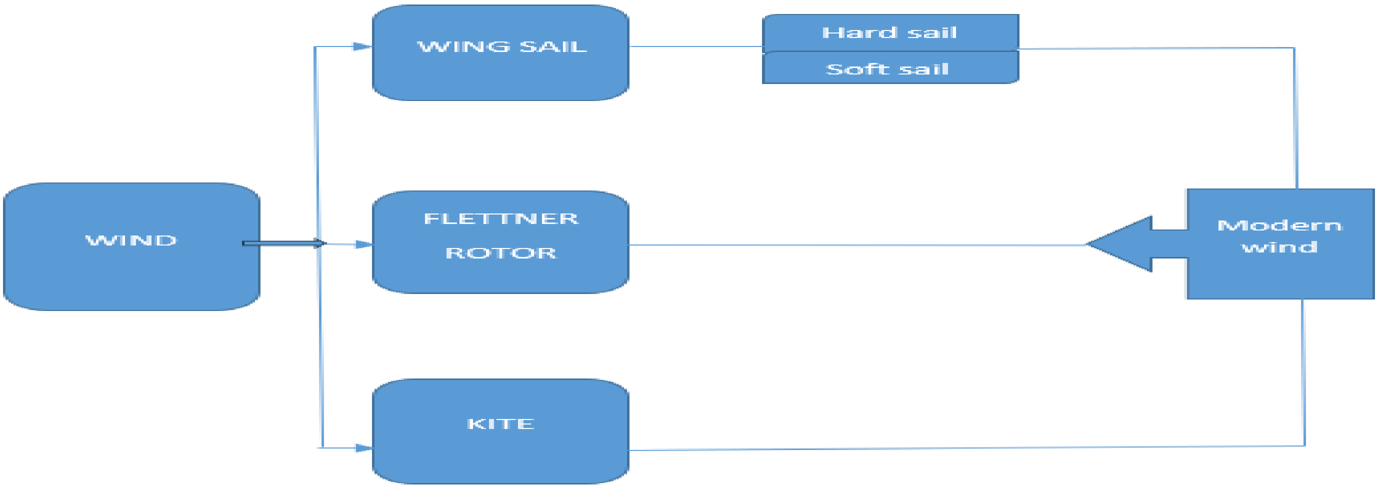
2.2 Wind Energy:

In recognition of its environmental benefits and sustainability, wind energy is becoming a popular renewable energy source. Because of changes in atmospheric pressure, wind is produced when air moves from high-pressure to low-pressure regions (Bishoge et al., 2018; Michael et al., 2021). This makes wind a possible source of energy. The main parts of wind energy systems, wind turbines, are made of rotors and blades that harness the wind's kinetic energy to produce mechanical energy This mechanical energy may be further changed into various other energy sources. Since wind is a limitless resource that offers a sustainable substitute for fossil fuels, wind energy is regarded as renewable (Ouchi et al., 2013). Furthermore, it is a clean energy source that doesn't produce any pollutants or greenhouse gases, which helps reduce air pollution and mitigate climate change. In comparison to conventional energy sources, wind energy systems are more affordable over the long run, even though their initial setup costs may be greater (Kazimierczuk, 2019b).

Although it is less common than terrestrial applications, wind technology is beginning to emerge as a viable energy source in the maritime industry(Arief & Fathalah, 2022; Ouchi et al., 2013). The significance of utilizing wind energy has been emphasized by international efforts, such as the partnership between the World Bank and the Technical University of Denmark in developing the Global Wind Atlas. To help identify possible locations for wind energy development, this tool offers essential wind statistics for terrestrial and marine areas(Tay & Konovessis, 2023).In addition to international programs, developments in analytical methods, including Weibull Distribution Methods, enable the assessment of wind energy potential through the analysis of wind speed data. These methods are particularly helpful for unique applications, including boat rooftop wind turbines. Moreover, advanced computer models and machine learning techniques improve wind pattern prediction accuracy.

Wind energy has long been used in the maritime industry, mostly for ship propulsion. Large sails were used by traditional sailing ships to capture wind energy and transform it into mechanical power for seafaring. (Gullbring & Pandic, 2021)These traditional techniques established the foundation for modern innovations while demonstrating the potential of wind as a renewable energy source. These days, wind energy is captured using both conventional and modern techniques to power ships (Arief & Fathalah, 2022; Tay & Konovessis, 2023). Even though there are fewer wind-powered ships in modern commercial shipping, continued developments in wind technology are exploring the possibility of wind power for sustainable marine operations, indicating an increasing interest in incorporating renewable energy sources into this industry(Ouchi et al., 2013; Yiğit & Acarkan, 2018).

Figure 2. The block diagram of wind in the maritime industry from those days and current usage



Source: Tay & Konovessis, 2023

The maritime industry has been exploiting wind energy to navigate the world's oceans for centuries. Traditional sailing vessels and sail designs have been used to harness this natural resource. Fabric sails are used by traditional ships, ferries, and smaller boats to harness the wind potential to propel them forward(Arief & Fathalah, 2022; Pan et al., 2021).These sails' form, angle of attack, and precise position concerning the wind all play a significant role in determining their efficiency (Ouchi et al., 2013). Numerous sail patterns have been used historically; two notable examples are the triangular sails, such as lateens, and the rectangular sails that are frequently seen on square-rigged ships. For vessels to navigate successfully in a variety of wind situations, these sails need to be strategically planned and positioned to maximize power. Today innovations in maritime energy generation have originated from a traditional sailing concept(Arief & Fathalah, 2022; Chou et al., 2021).

The utilization of wind energy for ship propulsion and onboard electrical power generation has been revolutionized by modern technologies, enabling maritime vessels to harness wind power in unique ways. Wind technologies are integrated into ships like the Walker Wing sailship, Skysail ship, and Flettner sailship to improve propulsion efficiency and reliable electrical energy (Arief & Fathalah, 2022).

The Flettner rotor is a remarkable invention. It is a vertically placed cylindrical structure on a ship's deck that uses the Magnus principle to create a pressure differential, which drives the ship forward when the wind blows over it (Li et al., 2021). The MV Afros, a bulk carrier with notable fuel savings, and E-Ship 1, a cargo ship known for its notable fuel consumption reduction, are two examples of practical applications of Flettner rotors. These innovations show how wind technology may significantly reduce the maritime industry's reliance on fossil fuels (Lu & Ringsberg, 2020).The concept of Oceanbird, which shows how wind energy may be a major factor in modern maritime transportation, signifies an important advance toward sustainability in this area. Through the use of advanced hull and sail designs, Oceanbird, the largest sailing cargo ship, seeks to reduce emissions by as much as 90%(Li et al., 2021; Tay & Konovessis, 2023).

Integrating traditional sailing principles with modern technologies, these unique vessels use wing sails that resemble airplane wings for enhanced aerodynamic efficiency. Oceanbird is an outstanding example of the future of green shipping since it merges conventional designs with modern technology to provide primary and supplemental power options that significantly reduce emissions. It paves the way for a more sustainable and environmentally friendly future for global maritime transportation by providing a model for incorporating wind energy into large-scale marine operations(Arief & Fathalah, 2022).

By integrating innovative wind technology with traditional wind energy methods, the maritime industry is progressing toward increased sustainability. Strategic advances that lower environmental impact and improve energy efficiency are being adopted by maritime vessels(Pan et al., 2021).Although wind energy can be used in broader applications, propulsion currently serves as the main application compared to other energy demands because the focus is the actual fuel savings for specific routes. According to (Sciberras et al., 2016) , for shipboard applications, energy efficiency is crucial for both economic and environmental reasons as well as for maximizing vessel operation. Because electric systems are flexible, electrifying marine equipment makes it easier to generate and store energy from a variety of sources, potentially leading to energy savings.

Mostly relies on Wind-Assisted Propulsion Technologies (WAPT) and Wind-Assisted Electrical Generation (WAEG) systems

Systems of wind-assisted electrical generation, or WAEG, offer an innovative and promising initial move toward environmentally friendly marine transportation. With the help of its unique wing sails, which harness wind energy to power the ship, the Swedish cargo ship Oceanbird is designed to reduce carbon emissions by 90%. An example of an entire approach to using renewable energy sources is the Energy Observer, a catamaran that incorporates solar panels, hydrogen fuel cells, and wind turbines. Also, the German business Enercon's E-Ship 1 uses Flettner rotors, which are vertical spinning cylinders that use the Magnus effect to harness wind power.It is demonstrated by the coal carrier Shofu Maru of Japan, which is outfitted with an automated kite system. To harvest wind energy, the hybrid cruise ship MS Roald Amundsen combines electric propulsion, big battery packs, traditional engines, and auxiliary sail power. The Tûranor PlanetSolar is a remarkable example of renewable energy generation in nautical applications because, despite being predominantly solar-powered, it incorporates wind power through its design. To power its systems, the Energy Observer integrates solar, wind, and hydrogen energy sources as a research vessel(Arief & Fathalah, 2022).

WAEG systems also provide electricity for auxiliary equipment and onboard systems, contributing to worldwide efforts to reduce climate change and minimize greenhouse gas emissions. These examples highlight how wind energy can propel maritime operations toward a more sustainable future.In the maritime transportation industry, wind-assisted Propulsion Technologies (WAPT) are becoming increasingly popular as a greener substitute for traditional fossil fuel-based systems. The use of these technologies offers additional power to propulsion which is normally known as auxiliary power. Notable examples are the cargo ship MV Afros, which combines Flettner Rotors with conventional engines for a hybrid propulsion strategy, and the MS Roald Amundsen, which relies on Flettner Rotors to provide lift using the Magnus effect. In a similar, the CMA CGM Jacques Saadé combines dual-fuel engines with wind-assisted technologies to improve efficiency and reduce pollution. These ships serve as examples of innovative ways that wind energy is being used by the maritime industry to promote sustainability.(Pan et al., 2021; Tay & Konovessis, 2023)

Other WAPT technologies, in addition to Flettner Rotors, are transforming maritime propulsion. Wing sails, like those on the EcoClipper, are primarily powered by wind energy and offer aerodynamic efficiency. Utilizing high-altitude winds in propulsion, kite sails like those on the M/V Beluga SkySails significantly reduce fuel consumption. (Arief & Fathalah, 2022)By integrating these technologies with current propulsion systems, ships can use renewable energy sources while still operating efficiently. Also, The Norwegian fishing ship MF Hydra has Norsepower rotor sails, which reduce emissions and fuel consumption and show how wind assistance can improve vessel efficiency(Tay & Konovessis, 2023)A variety of ships are paving the way in implementing WAPT to increase efficiency and reduce environmental impact. To reduce fuel consumption by up to 25%, the E-Ship 1 uses four huge rotor sails, and Vindskip uses LNG propulsion combined with a hull shaped like a symmetrical aerofoil to achieve significant fuel savings. Other examples are the French wind-powered cargo ships Neoline is building for transatlantic routes, and B9 Ships, which is developing cargo ships with biogas engines as an alternative power source in addition to wind power. Giant kites are used in Airseas' Alizés project to maximize fuel use, while Flettner rotors have been installed on ships like the Maersk Pelican and Viking Grace to increase efficiency (Lu & Ringsberg, 2020; Pan et al., 2021).

2.3 Global Research and Innovation:

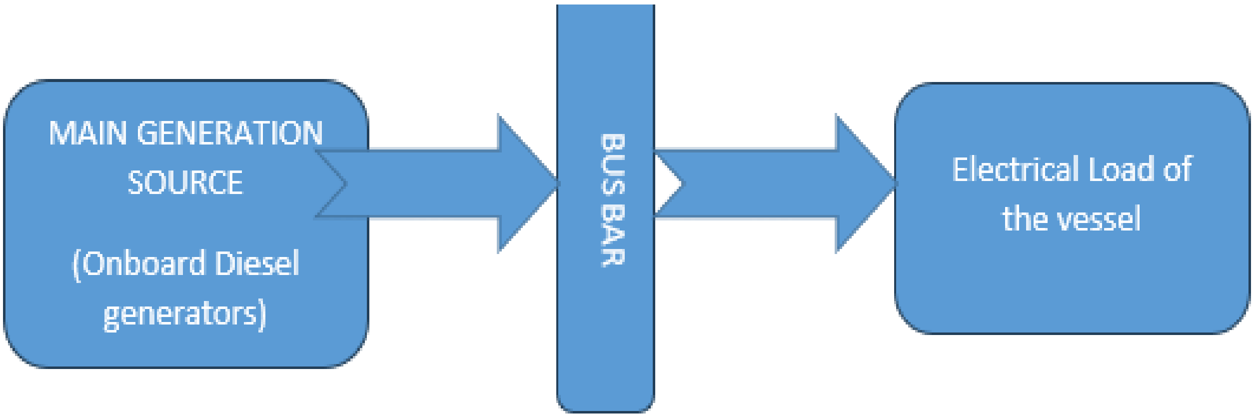
Research and innovation are advancing their application across different contexts, particularly in maritime environments. Enercon’s E-Ship 1, equipped with Flettner rotors, leverages the Magnus effect for additional thrust, resulting in significant fuel savings. In Turkey, VAWTs are integrated into coastal vessels to address Mediterranean wind conditions. Norwegian research on hybrid ferries combines VAWTs with battery storage and solar panels, optimizing turbine performance. (Gagatsi et al., 2016b)These advancements reflect the transformative impact of VAWTs on the maritime industry, driving innovation and contributing to more sustainable practices (Pan et al., 2021; Tay & Konovessis, 2023).

Figure 5. Figure Global wind innovations

Source: Pan et al., 2021

2.4. Onboard electrical system

Figure 6. Existing block of the general electrical power system



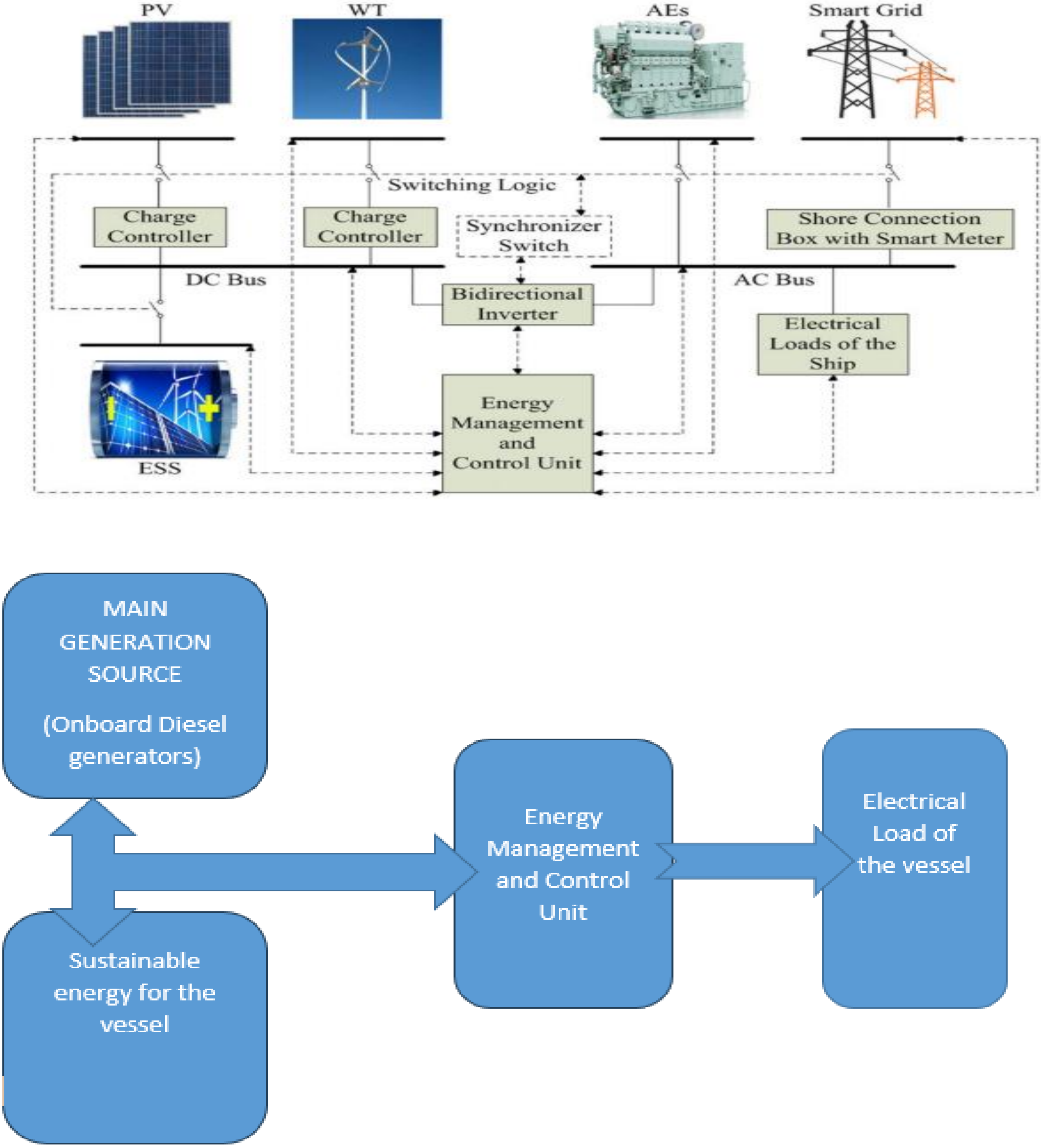
Source: Researcher, 2024

Onboard generators have played an important part in conventional marine power systems by providing continuous energy for a range of applications, including communication, navigation, and lighting. Because of their high energy output, long lifespan, and fuel efficiency, diesel generators are preferred for use in maritime applications. These generators are a reliable source of electrical energy for maritime vessels(Pan et al., 2021; Yiğit & Acarkan, 2018).

Modern marine electrical systems have advanced from conventional diesel generators to more complex designs intended to improve reliability and effectiveness. Modern large commercial vessels, such as the m/v Ince Harburg and water-go-round are equipped with different alternative energy solutions and highly efficient generators to guarantee a consistent power supply for a range of onboard needs(AIJJOU, 2020; Pan et al., 2021).

In modern maritime vessels, the power management systems (PMS) and electrical distribution panels are essential parts that provide reliable and effective distribution of electricity among different onboard systems. These innovative technologies combine diesel engines, batteries, and renewable energy sources. The incorporation of renewable energy and alternative sources, such as fuel cells, batteries, and wind technology, will improve the environmental friendliness and efficiency of marine electrical systems as maritime technology develops(Yiğit & Acarkan, 2018).

Figure 7. Onboard advanced electrical power system



Source: Yiğit & Acarkan, 2018

2.4 Weibull Model:

Given its broad range and simplicity of application, the Weibull distribution is a popular analytical technique for modeling wind speed data. (Mohammadi et al., 2016)It is a member of the same family of probability density functions as the Gaussian, gamma, Rayleigh, and lognormal distributions. However, the Weibull distribution frequently stands out due to its capacity to represent variations in wind speed(Fazelpour et al., 2019). It is very useful for evaluating wind speed patterns because of its two main parameters: the shape parameter, which indicates wind speed variation, and the scale parameter, which shows wind speed intensity. Because of its adaptability to match a wide range of wind speed datasets, the Weibull distribution is a useful tool for assessing wind resources across time. Since wind energy is more easily computed and evaluated by researchers and practitioners due to its mathematical simplicity, it is more desirable(Akdağ & Güler, 2018;Michael et al., 2021).

The Weibull distribution function is a statistical tool that models wind speed data gathered from several locations and periods that are prioritized. It provides information on the wind resource's viability, direction, and speed all of which are essential for estimating how much energy it can provide. The Weibull probability density function explains the frequency of specific wind speeds in the studied area and provides the relative likelihood that the random variable value will match a given sample. The probabilistic approach to wind speed analysis is crucial for determining the energy potential of an area. The Weibull distribution is a model of wind speed frequency that influences decisions concerning wind farm site selection and turbine design in addition to aiding in the prediction of wind energy generation(Tiam Kapen et al., 2020).The assessment of wind energy potential at different places is greatly aided by the shape of a parameter (k) that indicates the speed variation and scale parameter (c) that indicates wind speed intensity.(Aziz et al., 2023; Katinas et al., 2018) Different researchers on their Research has demonstrated the applicability of the Weibull distribution in a range of wind energy evaluation contexts as follows.

According to (Aziz et al., 2023) This study showed the Weibull distribution's ability to forecast wind resource availability and highlighted its importance for determining the two Weibull parameters K and C.

The Weibull probability distribution function f (V) is given by Eq. 2.1 (Katinas et al., 2018; Kidmo et al., 2016; Yongo et al., 2016)

$$f(v) = \left(\frac{k}{c}\right).\left(\frac{V}{c}\right)^{k-1}.\exp(-(V/c)^{k}) \qquad (2.1)$$

Where: $f(v)$ = probability of observing wind speed V

V = Wind speed $[m/s]$

C = Weibull scale parameter $[m/s]$

K = Weibull shape parameter

Where $v, k > 0$ and $c > 0$re respectively, the wind speeds (m/s) the shape factor (dimensionless). Thus, the corresponding cumulative distribution function is obtained by integrating Eq.2.1, giving the following (Akdağ & Güler, 2018; Lee et al., 2015; Michael et al., 2021; Mohammadi et al., 2016)

$$F(V) = 1 - exp(-(V/c)^{k}) \qquad (2.2)$$

$F(V)$ presents cumulative distribution function.

Weibull parameters can be estimated using various methods, including the maximum likelihood method, graphical method, power density method, energy pattern factor method, moment method, and standard deviation method.(AIJJOU et al., 2020,Aziz et al., 2023; Michael et al., 2021; Mohammadi et al., 2016)

Standard deviation method

The Standard Deviation Method is widely recognized for its accuracy in determining Weibull distribution characteristics, which is crucial for accurately estimating wind energy potential from Wind. According to (Aukitino et al., 2017; Kengne Signe et al., 2019)the standard deviation method is widely recognized for its ability to accurately measure the Weibull distribution parameters, which is necessary for accurately estimating the wind energy potential from Wind Energy Conversion Systems (WECS).

There are several advantages that researchers have discovered when estimating Weibull parameters with the Standard Deviation Method. Its ease of application all that's required are the mean wind speed ($\overline{v}$) and standard deviation (σv) among its primary benefits(Ouahabi et al., 2020). It also needs less processing effort and produces estimates that are reasonably reliable when compared to more complex techniques like Maximum Likelihood (ML), especially when working with larger datasets. Because of its harmony of ease of use, precision, and effectiveness, it has been used extensively in wind energy research and (Aziz et al., 2023) also noticed that the method has the best accuracy while measuring the spread out data value around the mean. However, it could not be as accurate as ML, especially when smaller datasets or high accuracy are required.(Aukitino et al., 2017; Mohammadi et al., 2016)

According (Yongo et al., 2016) Depending on the data available, determining the average value for a given period either hourly, daily, monthly, or annually is one of the simplest statistical studies of wind speed data. Average wind speed (v_{awg}) is given by equation (2.3) regardless of duration.

$$V_{awg} = \frac{1}{n\sum_{i=1}^{n} v_i} \qquad (2.3)$$

v_i represents the site's daily wind speed measurement.

Site Assessment: These factors are essential for assessing a site's potential for wind generation. Higher k values denote more steady winds, while higher c values represent stronger average wind speeds both of which are advantageous for the generation of energy.

K and C enable the understanding of wind patterns, accurate estimation of wind energy potential, and optimal design of wind energy systems.

Shape parameter (k)

It is the shape parameter (k) that determines the distribution's form. This has a direct impact on the wind speed distribution across time for wind speed data.

- $k < 1$: This suggests a wind speed distribution that is highly variable and has a lot of low-speed incidents; it may be unpredictable and unreliable to yield energy.
- $k \approx 2$: A normal distribution is similar to the distribution of wind speed. This is an indication of a balance between high and low wind speeds and is typical in many natural wind environments.
- $k > 3$: This implies that wind speeds are more concentrated around higher velocities, which is perfect for producing wind energy since it denotes more regular, dependable, and powerful winds.

Equation (2.3) can be used to calculate standard deviations (σ) from the average mean wind speed as per eq (2.4)

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(v_i - v_{awg})^2} \qquad (2.4)$$

(v_{awg}) represents Average wind speed

Equations (2.5) and (2.6) are used, respectively, to determine the Weibull parameters k and c from mean wind speed and standard deviations.

$$k = (\sigma / V_{awg})^{-1.086} \qquad (2.5)$$

$$c = \frac{V_{awg}}{\Gamma\left(1+\frac{1}{k}\right)} \tag{2.6}$$

Where gamma (Γ) can be obtained as in eq (2.7)

$$\Gamma(x) = \int_0^\infty t^{x-1} e^{t} dt \tag{2.7}$$

Also alternative to eq (2.6) is as in eq (2.8)

$$c = \frac{V_m}{\frac{V_m k^{2.6674}}{0.184+0.186k^{2.73855}}\left(1+\frac{1}{k}\right)} \tag{2.8}$$

4. Results and Discussion:

4.1 Results:

These study's results demonstrate the potential for incorporating wind energy into ferry routes by revealing mean wind speed variations monthly at heights of 10, 20, 30 and 40 meters. The Weibull distribution is used to determine two important parameters, k (shape) and c (size), providing a more precise model of wind behavior that can be used to assess energy potential. The Weibull parameters' monthly mean wind speed, k (shape), and c (scale) values are shown below.

Table 1. Yearly shape k and Scale c Weibull factor parameters at a height of 10m

K and C at 10M								
Monthly	**2020**		**2021**		**2022**		**2023**	
	k	c	k	c	k	c	k	c
Jan	**4.43836**	**6.07189**	**3.907198**	**7.03509**	**4.126553**	**5.674007**	**4.246699**	**5.30722**
Feb	**2.91958**	**4.574146**	**3.127118**	**5.69942**	**3.957155**	**4.317398**	**4.57754**	**5.0543**
Mar	**2.81462**	**2.797862**	**2.126721**	**5.05315**	**3.382749**	**4.592803**	**3.453283**	**5.21956**
Apr	**2.6549**	**2.958882**	**5.25074**	**4.87527**	**3.379713**	**2.969569**	**5.590959**	**3.28281**
May	**3.09596**	**3.143294**	**4.71898**	**4.54408**	**5.195633**	**3.557612**	**5.463745**	**3.7095**
Jun	**4.43839**	**6.07189**	**4.106396**	**4.76913**	**5.6909**	**4.866382**	**4.462588**	**3.71893**
Jul	**3.75514**	**4.421682**	**5.238604**	**5.92953**	**4.581101**	**3.993084**	**7.036005**	**4.92205**
Aug	**3.9495**	**4.32404**	**3.852267**	**4.40418**	**5.548396**	**3.629199**	**9.793329**	**4.76063**
Sep	**5.11744**	**4.143644**	**4.994729**	**4.66932**	**5.358573**	**3.855134**	**8.416119**	**4.4705**
Oct	**3.83627**	**3.236505**	**4.952346**	**4.32656**	**5.527524**	**4.026378**	**3.370959**	**4.14922**
Nov	**2.99532**	**3.20123**	**4.231952**	**5.0037**	**6.504572**	**4.238729**	**2.914002**	**3.10537**
Dec	**3.18144**	**5.123128**	**2.660128**	**3.2055**	**3.992113**	**4.567362**	**2.821693**	**4.37484**
Avr.Ann	**3.59974**	**4.172349**	**4.097265**	**4.95958**	**4.770415**	**4.190638**	**5.17891**	**4.33958**

k, dimensionless Weibull shape parameter;

c, Weibull scale parameter;

Table 2. Yearly shape k and Scale c Weibull factor parameters at a height of 20m

K and C at 20M								
	2020		**2021**		**2022**		**2023**	
	k	c	k	c	k	c	k	c
Jan	**4.72667**	**7.48613**	**4.16101**	**8.59613**	**4.39461**	**7.02456**	**4.52256**	**6.5973**
Feb	**3.10923**	**5.73782**	**3.33025**	**7.0541**	**4.21421**	**5.43487**	**4.87489**	**6.30164**
Mar	**2.99746**	**3.61647**	**2.26487**	**6.3003**	**3.60249**	**5.7598**	**3.67761**	**6.49493**
Apr	**2.82736**	**3.81157**	**5.59182**	**6.09182**	**3.59926**	**3.8245**	**5.95414**	**4.20214**
May	**3.29707**	**4.03422**	**5.02552**	**5.7024**	**5.53314**	**4.53162**	**5.81867**	**4.71307**
Jun	**4.7267**	**7.48613**	**4.37314**	**5.9672**	**6.06058**	**6.08139**	**4.75247**	**4.72431**
Jul	**3.99907**	**5.55805**	**5.5789**	**7.32121**	**4.87869**	**5.05062**	**7.49306**	**6.14669**
Aug	**4.20605**	**5.44273**	**4.10251**	**5.5374**	**5.90882**	**4.61719**	**10.4295**	**5.95721**
Sep	**5.44987**	**5.22923**	**5.31918**	**5.84986**	**5.70666**	**4.8866**	**8.96282**	**5.61566**
Oct	**4.08547**	**4.14646**	**5.27405**	**5.4457**	**5.88659**	**5.09015**	**3.58993**	**5.23584**
Nov	**3.18989**	**4.10401**	**4.50686**	**6.24238**	**6.9271**	**5.34183**	**3.10329**	**3.9885**
Dec	**3.3881**	**6.38219**	**2.83293**	**4.10915**	**4.25144**	**5.72983**	**3.00499**	**5.50275**
Avr.Ann.	**3.83358**	**5.25292**	**4.36342**	**6.1848**	**5.0803**	**5.28108**	**5.51533**	**5.45667**

k, dimensionless Weibull shape parameter;

c, Weibull scale parameter;

Table 3. Yearly shape k and Scale c Weibull factor parameters at a height of 30m

K and C at 30M								
Monthly	**2020**		**2021**		**2022**		**2023**	
	k	c	k	c	k	c	k	c
Jan	**4.91337**	**8.47786**	**4.32537**	**9.68389**	**4.568197**	**7.97439**	**4.701201**	**7.507241**
Feb	**3.23205**	**6.56394**	**3.4618**	**8.00665**	**4.380669**	**6.23021**	**5.06745**	**7.183309**
Mar	**3.11586**	**4.21037**	**2.35433**	**7.18184**	**3.744787**	**6.58812**	**3.82287**	**7.395144**
Apr	**2.93904**	**4.42866**	**5.8127**	**6.95307**	**3.741426**	**4.44311**	**6.18933**	**4.864393**
May	**3.4273**	**4.67726**	**5.22403**	**6.52495**	**5.751695**	**5.23077**	**6.048501**	**5.432102**
Jun	**4.91341**	**8.47786**	**4.54588**	**6.81619**	**6.299968**	**6.94162**	**4.940196**	**5.444565**
Jul	**4.15703**	**6.36599**	**5.79926**	**8.2981**	**5.071392**	**5.80587**	**7.789032**	**7.013308**
Aug	**4.37219**	**6.23886**	**4.26456**	**6.34322**	**6.142212**	**5.32576**	**10.84146**	**6.805208**
Sep	**5.66513**	**6.00326**	**5.52929**	**6.6872**	**5.932073**	**5.62438**	**9.316853**	**6.429447**
Oct	**4.24684**	**4.80237**	**5.48237**	**6.24214**	**6.119106**	**5.84958**	**3.731735**	**6.010556**
Nov	**3.31589**	**4.75506**	**4.68488**	**7.11832**	**7.200723**	**6.12757**	**3.225873**	**4.626248**
Dec	**3.52193**	**7.27162**	**2.94483**	**4.76079**	**4.419368**	**6.55515**	**3.123684**	**6.305041**
Avr.Ann.	**3.985**	**6.02276**	**4.53577**	**7.05136**	**5.280968**	**6.05804**	**5.733182**	**6.25138**

k, dimensionless Weibull shape parameter;

c, Weibull scale parameter;

Table 4. Yearly shape k and Scale c Weibull factor parameters at a height of 40m

k and c at 40M								
Monthly	**2020**		**2021**		**2022**		**2023**	
	k40	C40	k40	C40	K40	C40	k40	C40
Jan	**5.055043**	**9.26889**	**4.45008**	**10.54807**	**4.69991**	**8.733424**	**4.83675**	**8.23573**
Feb	**3.32524**	**7.22805**	**3.56161**	**8.767764**	**4.50698**	**6.870582**	**5.21356**	**7.890111**
Mar	**3.2057**	**4.69441**	**2.42222**	**7.888545**	**3.85276**	**7.253924**	**3.9331**	**8.116175**
Apr	**3.023779**	**4.9308**	**5.9803**	**7.64419**	**3.8493**	**4.946436**	**6.36779**	**5.401717**
May	**3.526121**	**5.19962**	**5.37466**	**7.186308**	**5.91754**	**5.79676**	**6.2229**	**6.013503**
Jun	**5.055078**	**9.26889**	**4.67696**	**7.497884**	**6.48162**	**7.631957**	**5.08264**	**6.026913**
Jul	**4.276896**	**7.01608**	**5.96648**	**9.077817**	**5.21762**	**6.415302**	**8.01362**	**7.708555**
Aug	**4.498258**	**6.87986**	**4.38752**	**6.991694**	**6.31931**	**5.899048**	**11.1541**	**7.486143**
Sep	**5.82848**	**6.6272**	**5.68872**	**7.359929**	**6.10312**	**6.220294**	**9.58549**	**7.08405**
Oct	**4.369292**	**5.33476**	**5.64045**	**6.883375**	**6.29554**	**6.462243**	**3.83933**	**6.635026**
Nov	**3.411497**	**5.28367**	**4.81996**	**7.820714**	**7.40834**	**6.760541**	**3.31889**	**5.144498**
Dec	**3.623483**	**7.98437**	**3.02974**	**5.28986**	**4.54679**	**7.218632**	**3.21375**	**6.950783**
Avr.Ann.	**4.099906**	**6.64305**	**4.66656**	**7.746346**	**5.43324**	**6.684095**	**5.89849**	**6.8911**

k, dimensionless Weibull shape parameter;
c, Weibull scale parameter;

Table 5. The monthly mean wind speed for the four years at a height of 10m

Mean Wind Speed Monthly (Vm) at 10M				
Monthly	**2020**	**2021**	**2022**	**2023**
	Vm(m/s)	Vm(m/s)	Vm(m/s)	Vm(m/s)
Jan	**5.529865**	**6.359304**	**5.145092**	**4.820643**
Feb	**4.076468**	**5.093824**	**3.905481**	**4.611815**
Mar	**2.490068**	**4.475038**	**4.11994**	**4.686998**
Apr	**2.628403**	**4.487192**	**2.663712**	**3.033875**
May	**2.808065**	**4.140332**	**3.272196**	**3.423052**
Jun	**5.529865**	**4.323333**	**4.502605**	**3.388069**
Jul	**3.98812**	**5.456723**	**3.643681**	**4.619461**
Aug	**3.911058**	**3.977953**	**3.352316**	**4.571392**
Sep	**3.807501**	**4.283889**	**3.552937**	**4.247711**
Oct	**2.922602**	**3.967268**	**3.718275**	**3.721383**
Nov	**2.855838**	**4.544013**	**3.957005**	**2.767292**
Dec	**4.582299**	**2.84764**	**4.133672**	**3.893913**
Avr. Annual	**3.760846**	**4.49637575**	**3.830576**	**3.982133667**

Avrg.Vm, Average mean wind speed;	**4.017482854**

Figure 8. The monthly mean wind speed for the four years at a height of 10m

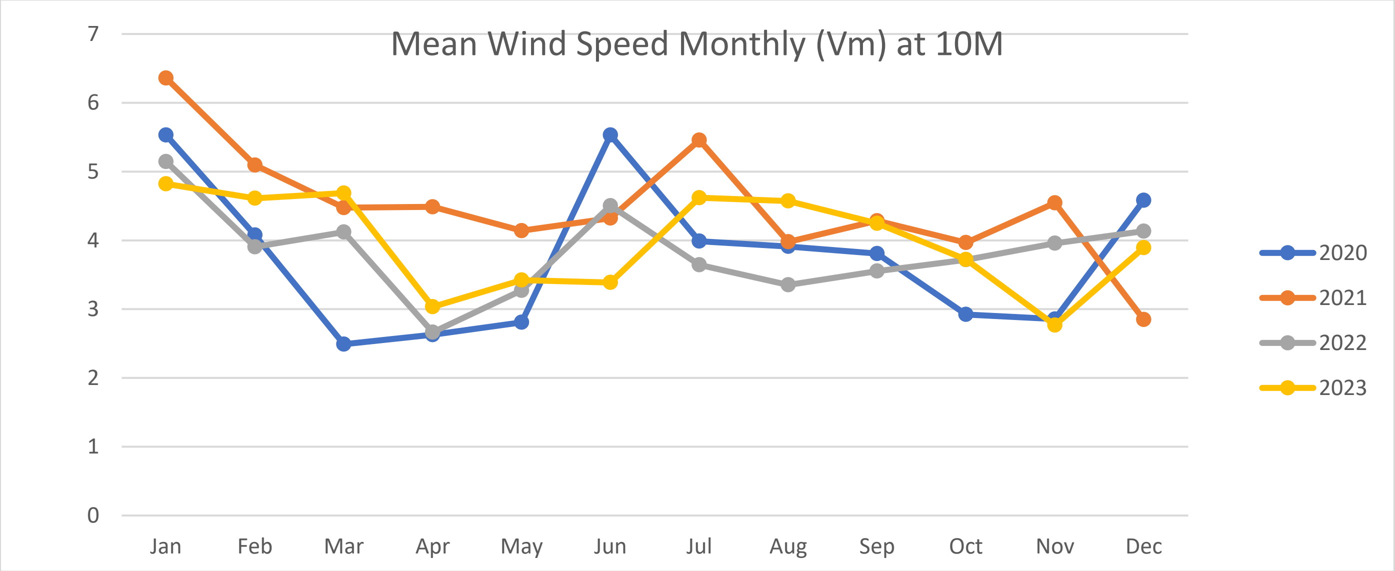


Table 5. The monthly mean wind speed for the four years at a height of 20m

Mean Wind Speed Monthly (Vm) at 20M				
Monthly	2020	2021	2022	2023
Jan	6.851174302	7.80915849	6.40161681	6.02226708
Feb	5.132075031	6.3305523	4.940922976	5.77748954
Mar	3.229316324	5.58066756	5.190379815	5.85941664
Apr	3.395288385	5.6292519	3.446240481	3.89675056
May	3.618599992	5.23730332	4.185026682	4.36494331
Jun	6.851176991	5.43648784	5.644955086	4.32496644
Jul	5.037766581	6.76440932	4.630730809	5.76989761
Aug	4.947508047	5.0263642	4.279821241	5.67736512
Sep	4.82512342	5.39031688	4.520731981	5.31683683
Oct	3.762894725	5.01545675	4.717230308	4.7173287
Nov	3.675206687	5.69713599	4.994225604	3.56711346
Dec	5.7326079	3.66064232	5.21171529	4.91420421
Avr.Annual	4.754894865	5.63147891	4.846966424	5.01738162

Avrg. Vm - Average mean wind speed **5.062680455**

Figure 9. The monthly mean wind speed for the four years at a height of 20m

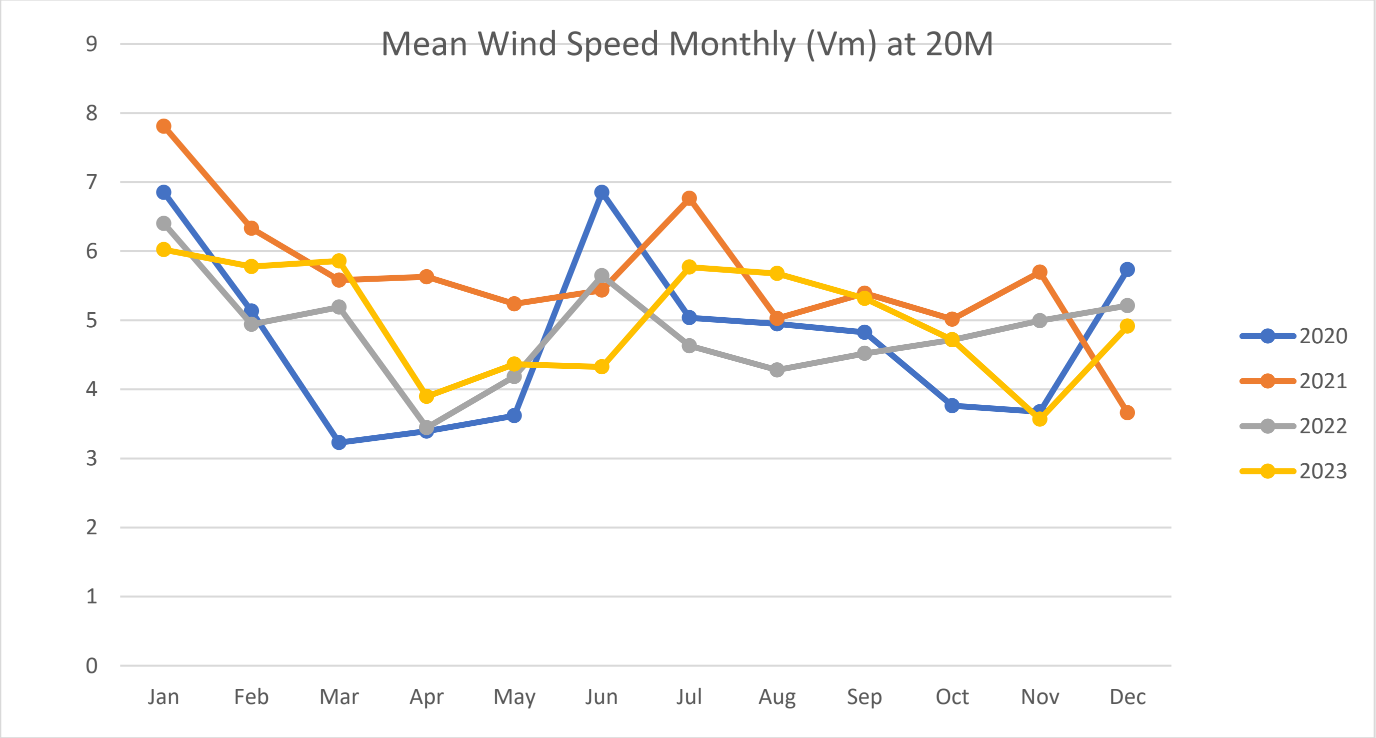


Table 6. The monthly mean wind speed for the four years at a height of 30m

Mean Wind Speed Monthly (Vm) at 30M				
	2020	**2021**	**2022**	**2023**
Monthly	Vm	Vm	Vm	Vm
Jan	**7.77623426**	**8.81700817**	**7.2835759**	**6.86833507**
Feb	**5.88187861**	**7.19979289**	**5.67666296**	**6.60059679**
Mar	**3.76624995**	**6.36449812**	**5.94942226**	**6.68587394**
Apr	**3.95119655**	**6.43912165**	**4.01215923**	**4.52051704**
May	**4.20370681**	**6.00615798**	**4.84127278**	**5.04170904**
Jun	**7.7762373**	**6.22393756**	**6.45713875**	**4.99555071**
Jul	**5.78286277**	**7.68374213**	**5.33513623**	**6.5961026**
Aug	**5.68391322**	**5.77066734**	**4.94719645**	**6.4957498**
Sep	**5.55150408**	**6.17548922**	**5.21455201**	**6.09791789**
Oct	**4.36784312**	**5.76170271**	**5.43265913**	**5.42680042**
Nov	**4.26639451**	**6.5111932**	**5.74033271**	**4.14514153**
Dec	**6.54478976**	**4.2478743**	**5.97578141**	**5.64063293**
Avr.Annual	**5.46273425**	**6.43343211**	**5.57215748**	**5.75957731**
Vm -Average mean wind speed;				**5.80697529**

Figure 10. The monthly mean wind speed for the four years at a height of 30m

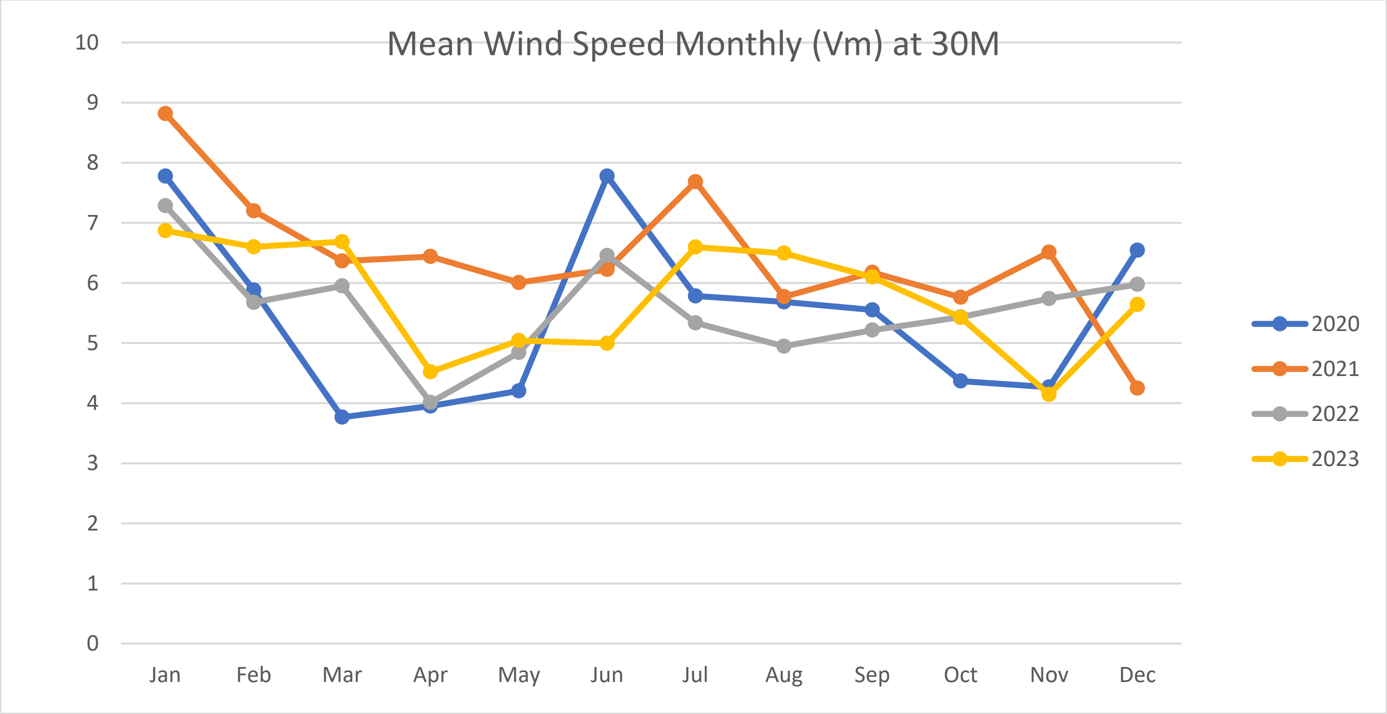
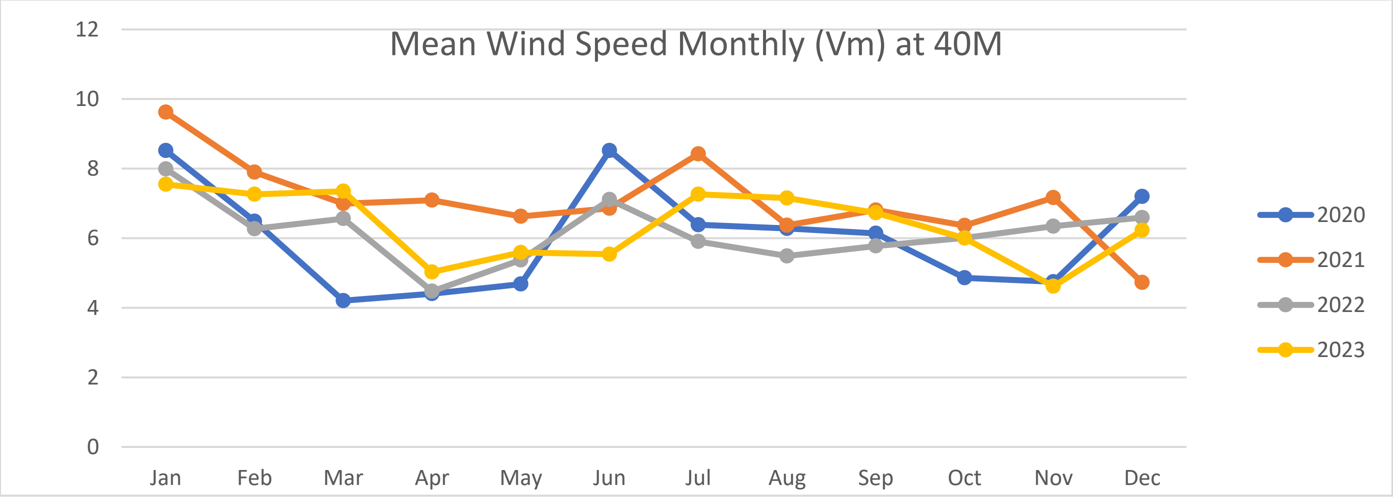


Table 7. The monthly mean wind speed for the four years at a height of 40m

Mean Wind Speed Monthly (Vm) at 40M				
Monthly	**2020**	**2021**	**2022**	**2023**
	Vm40	Vm40	Vm40	Vm40
Jan	**8.51579165**	**9.61965347**	**7.99003579**	**7.54726763**
Feb	**6.48615997**	**7.89611951**	**6.27047301**	**7.26193853**
Mar	**4.20492658**	**6.9942931**	**6.56105953**	**7.34948868**
Apr	**4.40464667**	**7.09037141**	**4.47374796**	**5.02763298**
May	**4.68019381**	**6.62570641**	**5.37363844**	**5.59004703**
Jun	**8.51579498**	**6.85771441**	**7.11021835**	**5.5389638**
Jul	**6.38385239**	**8.41905262**	**5.90481022**	**7.26007483**
Aug	**6.27823581**	**6.37107112**	**5.48824719**	**7.15379281**
Sep	**6.138273**	**6.80766971**	**5.7761165**	**6.72716825**
Oct	**4.86004236**	**6.36381838**	**6.01099076**	**6.00010197**
Nov	**4.74758697**	**7.16549923**	**6.34248259**	**4.61602053**
Dec	**7.19730089**	**4.72580542**	**6.59148865**	**6.22679153**
Avr.Annual	**6.03440042**	**7.07806457**	**6.15777575**	**6.35827405**

Avrg.Vm - Average mean wind speed; **6.4071287**

Figure 11. The monthly mean wind speed for the four years at a height of 40m



Conclusion:

This study emphasizes the benefits and possibilities of incorporating wind-assisted technologies into ferry power systems, especially for short ferry routes, such as WAPT and WAEG that are in the form of automated sails or wind turbines. Within the case study of a short ferry route as in this study, a route is Kivukoni - Kigamboni ferry route, the study highlights the significant amount of wind energy that is found in these areas with wind speeds ranging from 4.017482,5.06268,5.80696 and 6.40713 m/s at 10,20,30 and 40 meters respectively.

Reducing reliance on fossil fuels and promoting the integration of wind energy into traditional energy systems of ferries, complementing with other renewable sources are two benefits of using modern energy sources in ferry operations. This approach not only enhances energy efficiency and sustainability in ferry operations but also contributes to global efforts to reduce the carbon footprint of maritime transport.

Recommendation:

The study emphasizes the need to diversify energy sources to reduce dependency on fossil fuels and other nonrenewable resources. It suggests looking into the possibility of wind energy on various maritime routes, with a focus on those that are short to medium routes. According to the study, wind energy should be integrated into the operations of rapid passenger vessels, fishing boats, and ferries that are frequently used in these areas.

Thorough exploration of Wind Potential for Ferry Routes: This study's scope should be widened in the future by incorporating a wider variety of maritime routes with different environmental conditions and traffic densities. In addition, the different advanced modeling tools can offer a more detailed insight into wind energy potential.

Integrating Wind-Assisted Technologies: The maritime industry should engage in the development and use of wind-assisted technologies, such as automated sails or wind turbines designed specifically for maritime environments. For ferries operating within this region, such developments could have a positive influence on energy efficiency, fuel consumption, operating expenses, and global efforts to reduce the carbon footprint of the maritime industry.

The Advancement of Power Technologies: The government should prioritize the integration of renewable energy technologies as a platform for a transition from traditional, single energy source systems to multiple, renewable energy solutions especially wind energy complemented with other renewable sources, with conventional power sources.

Addressing Research Gaps

The lack of comprehensive research studies on the potential of wind energy in maritime areas, industry, and academia cooperation should be encouraged. These partnerships might focus on collecting vast amounts of wind data, including wind direction, speed, and turbine height, also should conduct long-term studies, and test wind-assisted technology in actual situations to verify its capacity and effectiveness in the maritime industry.

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