ISSN 2278-3091
Volume 9, No.1.5, 2020
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse2491.52020.pdf
https://doi.org/10.30534/ijatcse/2020/2491.52020

Wind Energy for Shipboard Electric Power Needs

Abdallah AIJJOU[1], Lhoussain BAHATTI[2], Abdelhadi RAIHANI[3]
[1,2,3] ENSET Mohammedia, Hassan II University of Casablanca, Morocco
Email:[1]Thalassa1310@yahoo.fr, [2]Lbahatti@gmail.com, [3]Abraihani@yahoo.fr

ABSTRACT

The shipping business must deal with two main constraints: new restrictions rules on pollution and CO_2 emissions and increasing of fuel oil . To this end fuel consumption shall be reduced and global ship energy efficiency shall be enhanced. Therefore, the shipping industry is constraint to find new solutions for designing and efficiently operating the ship.

In this study, an example of a practical solution is presented to enhance the energy efficiency of tanker by fitting a wind turbine for generating the electric power which is usually produced by diesel generator burning fuel oil and emitting GHG.

The sample vessel used for this study is small size tanker operating in regular between Moroccan ports.

It has been demonstrated that for the case understudy, the fuel oil consumption necessary for the shipboard electric needs may be reduced by 23%. The global ship energy efficiency will be improved accordingly, it has also proven that wind turbine will not impair the ship stability and resistance.

Key words: Wind turbine; Power generation, ship energy efficiency; CO_2 emission.

1. INTRODUCTION

The shipping sector is under considerable pressure to improve energy efficiency, while CO2 emissions are decreasing in many other activities, transport emissions are expected to increase in the future. Shipping currently accounts for about 3% of global CO2 emissions, but its share is expected to increase due to increased transportation activities, combined with challenges in implementing effective energy efficiency measures and replacing fossil fuels. [1].

In 2011, IMO adopted mandatory technical and operational energy efficiency measures which are expected to significantly reduce the amount of CO_2 emissions from international shipping [2]. All ships built after 2013 with 400 gross tonnages and above must meet the minimum standard of energy efficiency, and the ships must achieve 20% more efficient by 2020 and 30% more efficient from 2025.Therefore, ship designers and builders must innovate and develop new energy and new solutions for energy saving, in order to enable new ships to meet higher energy efficiency standards in the future.

Many papers related to the ship energy efficiency improvement can be found in the literature [3-7] and are to the study of the optimization of the machinery cooling system, loading conditions, ship's routine, waste heat recovery systems etc.

The combination of conventional generation sources and local renewable resources will increase efficiency gains and energy savings. So, a hybrid energy system will provide a more economic, environment friendly and make energy availability to end-use with affordable cost. In this way, this paper attempts to develop a hybrid diesel-Wind energy system for energy saving and greenhouse gas emissions reducing. In contrast, there are some considerations for wind turbine installing on ships like:

- Different route of ship voyage has different wind parameters. Therefore, the wind power potential also varies according to that.
- Air draft limitation: Wind turbines onboard ships will increase the air draft of the ship and may outpace the limits on air drafts of some canal or bridges, thereby restricting the ship’s operation.
- Air drag: The turbine tower and blades reference area will contribute to the drag force of the ship and increase the ship resistance.
- Ship stability: Once fitted onboard, both the height and weight of the wind turbine would affect the ship’s stability condition. As the gravity center of the ship is shifted, the overall ship stability shall be reviewed.
- Safety of and operations: Turbine motion constitutes a safety hazard on board, the turbine should not restrict the normal ship’s operations such mooring, cargo handling, maintenance and crew movements.
- Turbine structure should withstand the ship movements (rolling, pitching etc.) and should resist to the generated accelerations.
- Turbine should not disturb the ship’s radio and navigation equipment. The overshadowing influence of wind turbine on the ship’s radar performance may be a problem.

In the following sections, these constraints will be widely discussed in order to successfully set up our wind system.

2. RELATED WORKS

In order to improve the energy efficiency of ships and reduce emissions from marine activities, the use of renewable energy is considered as promising solution. In particular, wind energy has a great advantage in navigation activities as it is always available on the high seas compared to other renewable energies. [8]. In [9] fuel oil economy achieved through the application of three wind-assisted vessel propulsion technologies was discussed and Theresults show that these three solutions generate fuel savings of between 5.6% and 8.9%. In [10], the authors presented a study on the potential fuel savings achieved with a kite installed on a cargo ship.According to the study, potential fuel savings of 1% to 21% are achieved at the speed of 15 knots and 4% to 36% at 13 knots. As a result, wind aid vessel (WASP) propulsion is one of the rare solutions that offers promising fuel and emission savings and is admitted as a serious source of renewable energy for the future shipping industry.

So far wind energy is mainly studied as auxiliary power for ship propulsion and despite the performances demonstrated there's no successful prototype of its application. The wind energy for electric power generation is mainly used on small sailing boats but not in cargo ships. In this paper we will discuss the potential of fuel saving by using wind turbine for electric power generation on sample ship trading in regular line where wind potential is proven. From turbine technology for electricity generation, it is likely there are important lessons to be transferred now to the shipping sector.

3. THEORY:

3.1 Wind Turbine:

Wind turbines are the primary devices to convert the wind's momentum into rotor rotation, they can be classified into two main categories according to their axis alignment: horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs) as presented in Figures 1&2.

The mathematical model used to convert wind speed to electrical power by a wind turbine is given by equation (1).

$$P_e = \frac{1}{2} . C_p . \rho . A . v^3 \quad (1)$$

Where P_e is the electrical power [W], C_p thewind turbine power coefficient,$\rho$the air density [kg/m^3],***A*** the wind turbine rotor swept area [m^2] and v is the wind velocity at hub height [m/s];

Referred to figures 1 and 2, the wind turbine swept area is calculated as per equations (2) and (3), depending on the geometry of the rotor.

$$A = \pi . r^2 \quad (2)$$

$$A = D . H \quad (3)$$

Where:

r: the radius of the rotor expressed in meter [m];

D: the diameter of the rotor expressed in meter [m];

H: the length of the blades expressed in meter [m].

3.2 Wind energy potential assessment:

To evaluate the energy production of a wind turbine, it is not sufficient to know the average wind speed at a given site, It is also necessary that data showing, for a defined period of time, the histogram of the duration as a percentage of the different wind speed, is available. From this histogram, it is possible to draw the histogram of the statistical frequency of the occurrence of wind speed.The temporal distribution of wind speed for a given site is usually expressed using Weibull's statistical distribution function as it is close to the frequency of distribution of average wind speeds. [11].

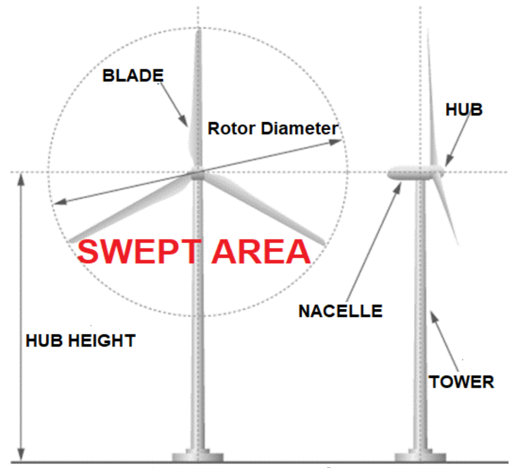

Figure 1: HAWT turbine

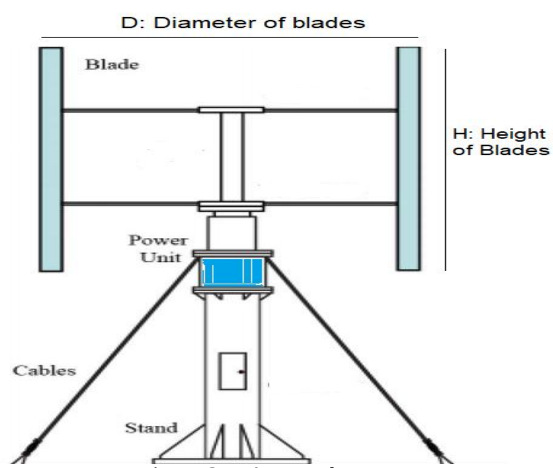

Figure 2: VAWT turbine

The annual electrical energy expressed in [kWh] can theoretically be described and calculated using Weibull's distribution taking into account the wind speed at the installation site and the curve of the electrical energy produced by the wind turbine as a function of the instantaneous wind speed.

Consequently, referring to (4), the annual producibility can be expressed as:

$$E = d. \int_0^\infty P(v) \ . f(v). dv \quad (4)$$

The Weibull distribution function (Weibull probability density function) is calculated as shown in (5).

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^k\right] \quad (5)$$

Where*:*

f (v): represents the probability of wind speed,

v: the wind velocity,

k and *c* are the shape and scale parameters.

'k' has no dimensional units whereas the 'c' parameter is expressed in (m/s).

From the integrating the Weibull probability distribution, we calculate the Weibull cumulative distribution function and it is expressed as (6):

$$F(v) = \int_0^{v_h} f(v).dv = 1 - e^{\left(\frac{v}{c}\right)^k} \quad (6)$$

Where:

v_h: is the highest wind speed under consideration.

3.3 Wind gradient:

The wind speed varies with the height above the ground due to friction against the ground structure that slows down the wind. This phenomenon is called wind gradient or wind profile.

To determine the wind speed profile based on height, the formula(7) can be used throughout a logarithmic law [12].

$$v_h = v_r.\frac{log(h)-log(h_r)}{log(h_r)-log(h_0)} \quad (7)$$

Where:

v_r: wind speed at the reference height h_r [m/s];

h_r: reference height [m];

h_0: 0.01m is the surface roughness of the sea surface.

3.4Influence of ship speed:

When moving, apparent wind is the speed and direction of wind measured on board as depicted in Figure 3. It is composed of the combined speeds and directions of the ship and wind observed by a stationary wind instrument (the true wind). A true wind coming from the bow increases the apparent wind induced by the speed of the ship, coming from the stern it decreases apparent wind.

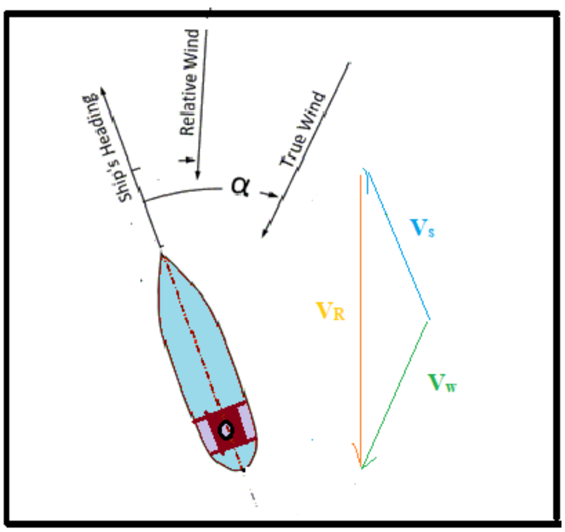

Figure 3: Ship speed vs wind speed

The apparent (Relative) wind speed V_R is given by equation(8).

$$V_R = \sqrt{V_s^2 + V_w^2 + 2V_s.V_w.cos\alpha} \quad (8)$$

Where:

V_s: Ship speed over the ground.

V_w: True wind speed

α: True pointing angle

4. METHODOLOGY

For this study, the structural integrity of any wind technology devices is assumed a given.

The adopted method intends to meet the requirements listed under chapter 1 related to shipboard wind energy barriers.

Ship routes: we consider ships that are operating in regular lines within Moroccan coasts where there's a wind energy potential, for this end we collect the wind data from specialized websites, we also reviewed the wind data recorded on ship logbook from existing vessel.

Wind turbine type: we will use the VAWT type, for the reasons stated in next chapters.

Sample ship: Many small tankers are chartered for oil products transport and distribution within Moroccan ports. A project of small size tanker, prepared by the local company "Oskar and PartnersSarl" intended for oil product transport for Moroccan market,has been chosen for this case study. The tanker ship is the most convenient for fitting VAWT due to free deck area.

Some data used in this paper are collected from records of similar shipoperating within Moroccan coasts.

A potential of energy harvesting and fuel oil save will be evaluated for this ship and influence on its energy efficiency considering the ship's route pattern.The influence on ship stability and resistance will be also assessed.

5. CASE STUDY

5.1 Ship's route:

The main disadvantage of wind power generation is that fluctuations in wind speed may prevent production of stable power. Therefore, we shall assess the wind potential in ship's route zones**.** For this study we consider a ship trading in regular voyages within Moroccan coasts (Mediterranean and Atlantic side). The Ship allocated for supplying main Moroccan regions with fuel oils (Diesel oil, Kerosene, Gasoline etc.).

According to data derived from the "Global Wind Atlas 1.0" of the Department of Wind Energy of the Technical University of Denmark (DTU Wind Energy) presented in Figure 4, the average wind speed varies from 5.7 (m/s) in the north to 10.2 in the south along more than 90% of the Moroccan coasts[13].

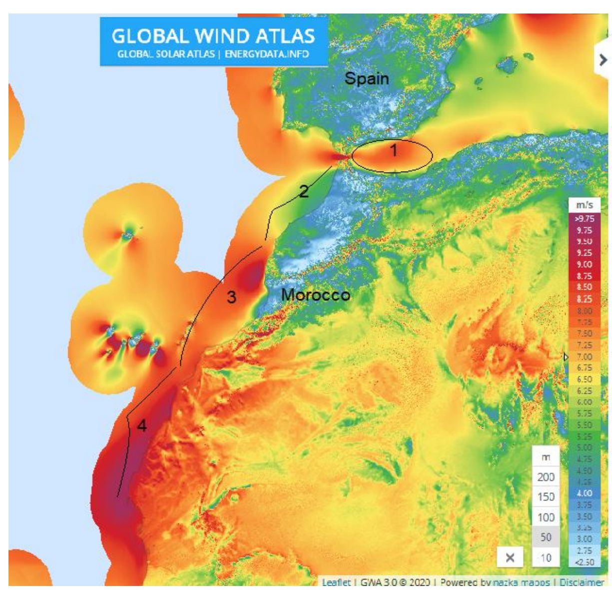

Figure 4: Mean wind speed at 50m map

We divided the Moroccan coasts to four zones based on the average wind speed: Mediterranean (1), Atlantic (2-3-4) as shown in Figure 3.
The annual average wind speed data has been provided by "VORTEX FDC" [14].
The average wind speed and dominate wind directions are presented in Table 1 while the calculated Weibull distributions parameters are summarized in Table2.

Table 1: Wind data per zone

	Dominant wind	Average wind speed (m/s)
Zone 1	E - W	6.47
Zone 2	NW	5.92
Zone 3	N. NNE	8.09
Zone 4	NNE	9.7

Table 2: Weibull distribution parameters

	k	c (m/s)
Zone 1	1.919949863	7.288621771
Zone 2	2.252292572	6.684651317
Zone 3	2.689139145	9.094107631
Zone 4	3.75948146	10.74103738

The wind speed to the height of 40m, which corresponds to the eventual shipboard turbine hub height, has been calculated as per formula (7).
Figures 3 and 4 represent respectively the wind speed distributions and the wind speed rose for different zones as extracted from [14].
Table 3 summarizes the Weibull distribution function and the Weibull cumulative distribution function for each zone at different wind speeds.

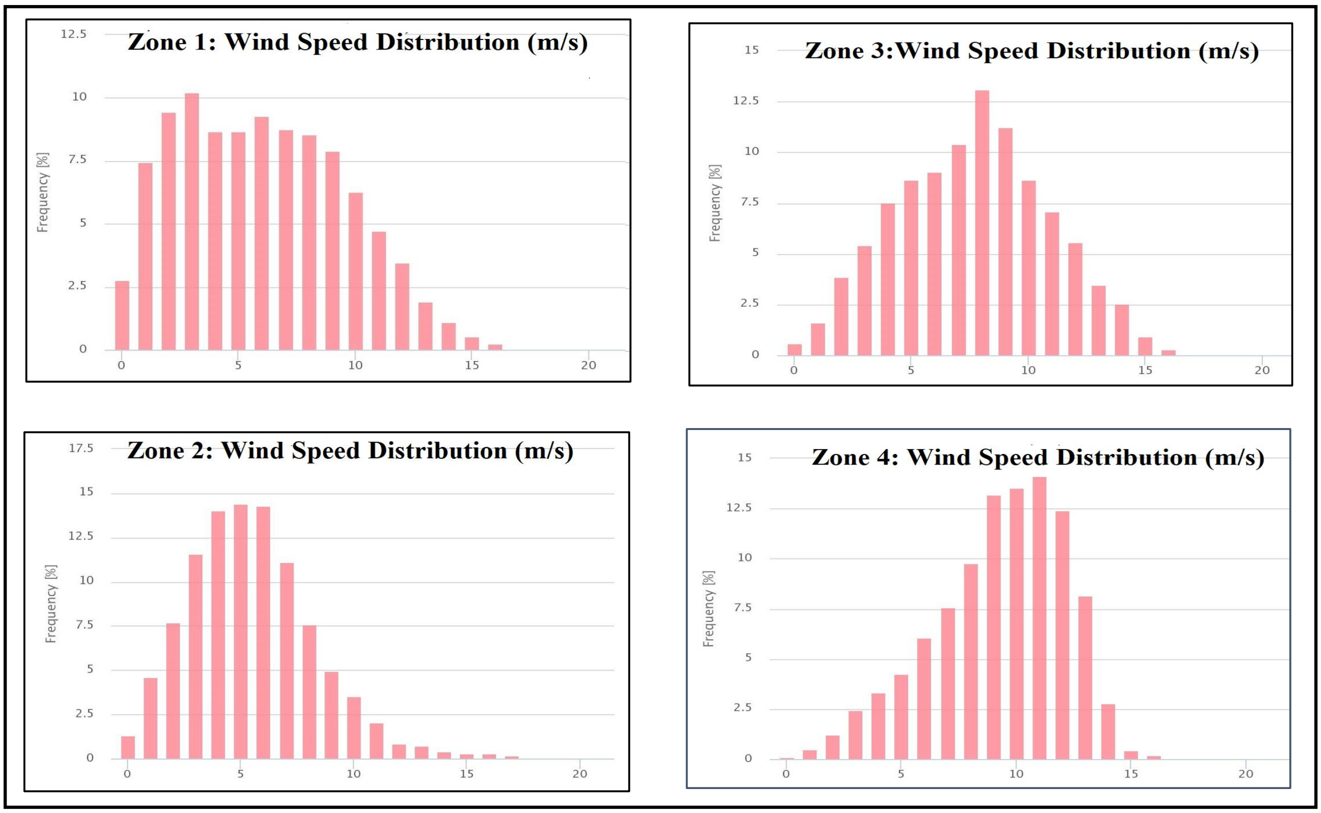

Figure 4: Wind variation curve [14]

Table 3: Weibull distribution function and cumulative function

Wind speed (m/s)		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Zone 1	*f1(v)*	3	7	9	10	9	9	9	9	9	8	6	5	3	2	1	1	0	0
	F1(v)	3	10	19	29	38	47	56	65	74	82	88	93	96	98	99	100	100	100
Zone 2	*f2(v)*	*1*	*5*	*8*	12	14	15	14	11	8	5	4	2	1	0	0	0	0	0
	F2(v)	*1*	*6*	*14*	*26*	*40*	*55*	*69*	*80*	*88*	*93*	*97*	*99*	*100*	*100*	*100*	*100*	*100*	*100*
Zone 3	*f3(v)*	*1*	*2*	*4*	5	8	9	9	11	13	11	9	7	6	3	2	0	0	0
	F3(v)	*1*	*3*	*7*	*12*	*20*	*29*	*38*	*49*	*62*	*73*	*82*	*89*	*95*	*98*	*100*	*100*	*100*	*100*
Zone 4	*f4(v)*	*0*	*0*	*1*	2.5	3	4	6	8	10	13	14	15	12	8	3	0.5	0	0
	F4(v)	*0*	*0*	*1*	*3.5*	*6.5*	*10.5*	*16.5*	*24.5*	*34.5*	*47.5*	*61.5*	*76.5*	*88.5*	*96.5*	*99.5*	*100*	*100*	*100*

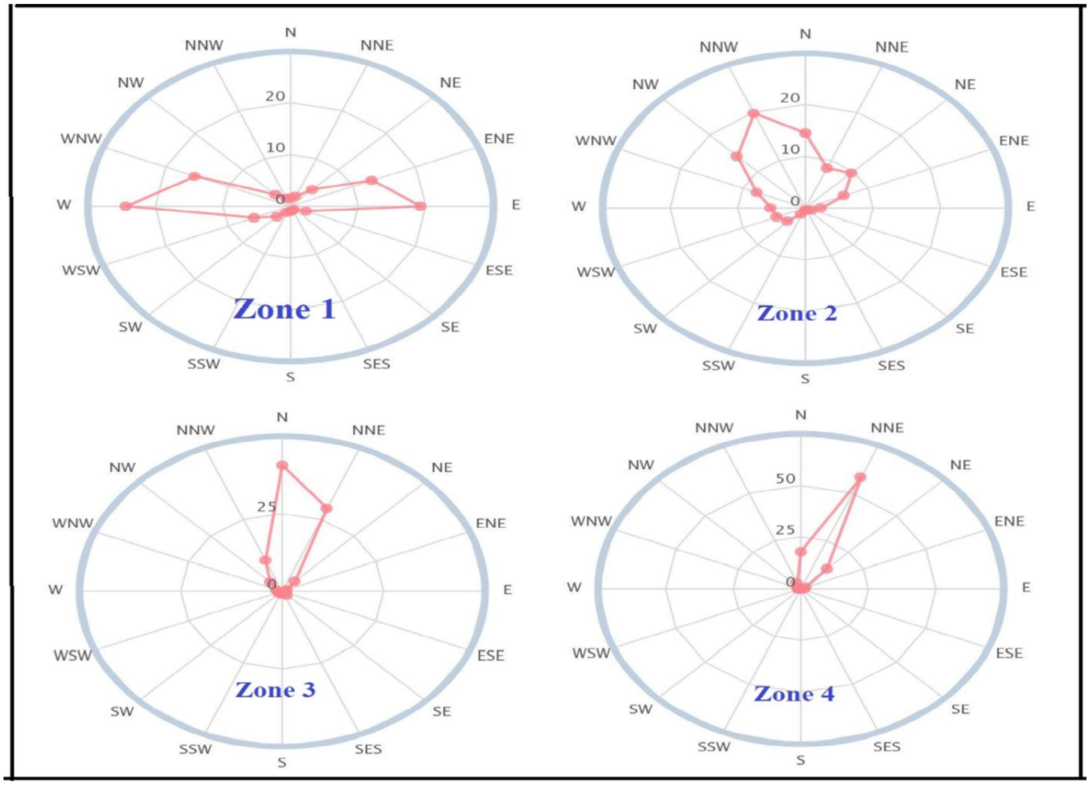

Figure 5: Wind speed rose for different zones[14]

5.2 HAWT or VAWT?

In general, the performance of the horizontal axis wind turbine (HAWT) exceeds that of the equivalent class of vertical axis wind turbines (VAWT) [15]. HAWTs are more popular in large scale because of its economy while VAWTs are popular in small and medium power range. In figure 6, the power curves of two wind turbines of 200KW are presented (HAWT:
Hummer 25 200 KW and VAWT: New-M1 200KW and) [16-17]. VAWT, however, has some favorable features compared to HAWT, especially in maritime application:

-Lower center of gravity this will prevent increasing heeling moments of the ship.

-Less complex as it doesn't require to be aligned to wind direction (no need of Pitch and Yaw control).

-Lower operating costs: lower complexity, gear box and generator are placed near the deck.

-Low noise levels compared to HAWT.

Because of these favourable features, the vertical axis wind turbine was found more convenient for shipboard use and for this case study we opted for the a medium-size vertical axis wind turbine, rated at 200 kilowatts by Anew Institute - VAWT Manufacturers (Figure 7). The main data of the turbine is presented in Table 4.

Table 4: VAWT New-M1 200kW Data sheet

Rated power:	200 KW	Number of blades:	3
Cut-in / off wind speed:	3.2 / 12 m/s	Hub Height	40m
Rated wind speed:	12 m/s	Blade height	15
Diameter:	24 m	Estimated weight:	25000 Kg
Swept area:	360 m^2	Tower diameter	2.5 m

Figure 6: Example of VAWT and HAWT power curves

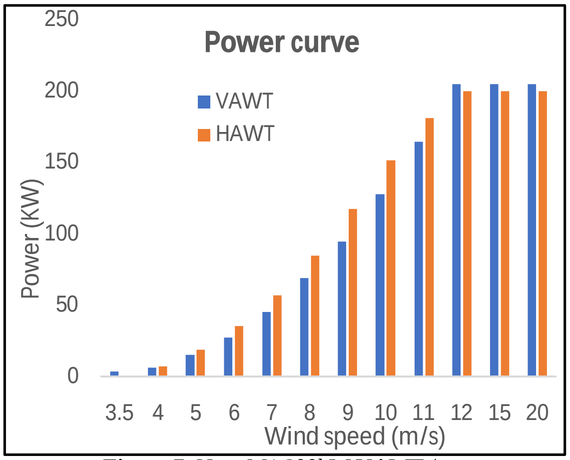

Figure 7: New-M1 200kW VAWT (source https://www.google.com/)

5.3 Sampleship.

Due to limited free space on the ship's deck and cargo handling constraints the VAWT is found not fit for ships having hatch covers (Containers ships, Bulk carriers etc.). Tankers are more convenient for VAWT fitting.

For this study we project to install the VAWT mentioned above on board a small coastal tanker. Its main are presented in Table 5. The ship is fitted with diesel generators of 500KW each, one generator is sufficient to supply the ship consumers in normal conditions.

Figure 8 illustrates the shipboard turbine installation.

The ship is intended for regular line alternating round trips from loading ports (Mohammedia or Tanger Med) to distributions ports (Nador, Casablanca, JorfLasfar, Agadir, Laayoune and Dakhla),

Table 5: Ship under-study main particulars

Item	Amount
Length x Breadth x Draught (m)	120 x20x7
Air Draught (m)	36
Gross tonnage	7400
Propulsion engine power (KW)	2800
Diesel generator set (number x KW)	2 x 500
Average Dieselgenerator Fuel oil consumption (ton / day)	0.9

As per the records taken from ship operating in the same ship voyages, the ship average speed is within range of 10-12 Knots 5-6m/s.

The course of the ship when heading the north of Morocco is generally 30-33deg and 210-220 for the trip back this correspond to the head and follow winds in the Atlantic side.

Same in the Mediterranean zone, the ship may alternate head wind and follow winds as the predominant wind direction are east and west.

To simplify the estimation of energy that can be harvested we made the calculation for the extreme cases: head and follow winds.

Equation (10) $\alpha = (0; \pi)$. Results are shown inTable 4 and 5.

6. RESULTS AND DISCUSSIONS

6.1 Energy potential calculation:

For the wind parameters, the statistical distribution function of occurrence frequency has been derived from data provided by 'VORTEXFDC'as shown in Figure 4.

The power curve has been acquired by the manufacturer website [17], this curve has been used to extrapolate the power data [kW] relating to dominant speed values ranging from 3 to 14 m/s. In general, the coastal vessel spends 260 days yearly at sea (sea passage and anchorage), totaling 6240 hours.

Considering the cut in cut off speed of the turbine, the equation (4) may be written as (9), where (E_Z)is the estimated of yearly energy production by ship wind turbine at each zone within 260 days.

$$E_Z = 6240.\int_{3.5}^{14} P(v)\ .f(v).dv \quad (9)$$

Considering the number of trips carried out yearly by the vessel cited in paragraph 4, we can assume that she was operating roughly 40% of time in zone 1&2 and 60% in zones 3&4.

Therefore, the yearly energy production can be estimated using the equation (10)

$$E = 0.2\,(E_{Z1} + E_{Z2}) + 0.3(E_{Z3} + E_{Z4}) \quad (10)$$

Results are summarized in Tables 6&7 respectively for head and follow winds.

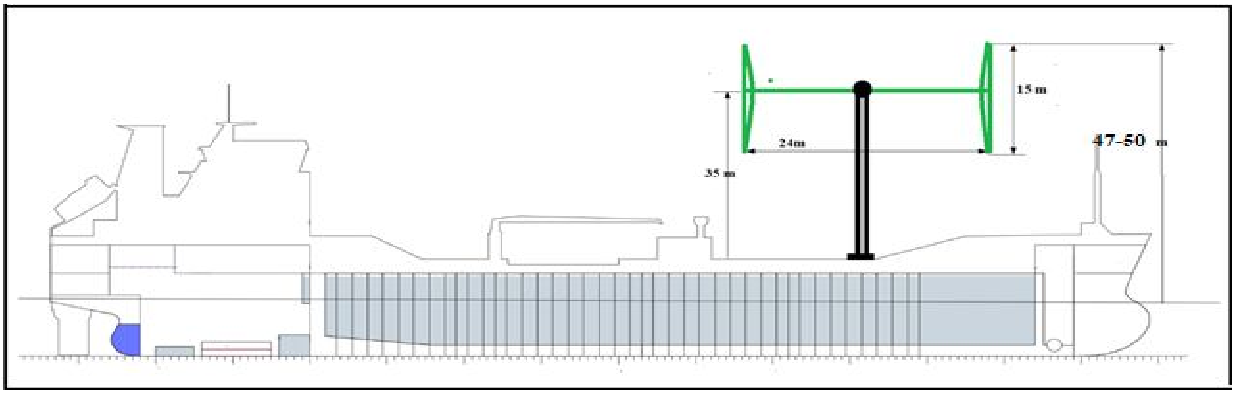

Figure 8: Shipboard wind turbine arrangement.

Table 6: Head winds.

True wind speed V_W(m/s)		3	4	5	6	7	8	9	10	11	12	13	14	E_{Zi} (KWh)
Relative wind speed V_R(m/s)		9	10	11	12	13	14	15	16	17	18	19	20	
Turbine output *P* (KW)		94.8	127.9	164.5	200	200	200	200	200	200	200	200	200	
Zone 1	*f(v)*	10	9	9	9.5	9	9	8	6	5	3	2	1	
	*P(v) * f(v)*	9.48	11.51	14.8	19	18	18	1.6	12	10	6	4	2	394355
Zone 2	*f(v)*	12.5	14	14.5	14	11.5	8	5	4	2	1	0.5	0.2	
	*P(v) * f(v)*	11.85	17.91	23.85	28	23	16	1	8	4	2	1	0.4	427466
Zone 3	*f(v)*	5.5	8	9	9	11	13	11	9	7	6	3	2.5	
	*P(v) * f(v)*	5.21	10.23	14.8	18	22	26	2.2	18	14	12	6	5	478767
Zone 4	*f(v)*	2.5	3	4	6	8	10	13	14	14.5	12	8	3	
	*P(v) * f(v)*	2.37	3.84	6.58	12	16	20	2.6	28	29	24	16	6	519127

Table 7: Follow winds

True wind speed V_W(m/s)		3	4	5	6	7	8	9	10	11	12	13	14	E_{Zi} (KWh)
Relative wind speed V_R(m/s)		3	2	1	0	1	2	3	4	5	6	7	8	
Turbine output *P* (KW)		3.8	0	0	0	0	0	3.8	6.5	15	27.2	45.4	69	
Zone 1	*f(v)*	10	9	9	9.5	9	9	8	6	5	3	2	1	13222
	*P(v) * f(v)*	0.38	0	0	0	0	0	0.30	0.39	0.75	0.82	0.91	0.69	
Zone 2	*f(v)*	12.5	14	14.5	14	11.5	8	5	4	2	1	0.5	0.2	5809
	*P(v) * f(v)*	0.475	0	0	0	0	0	0.19	0.26	0.3	0.27	0.23	0.14	
Zone 3	*f(v)*	5.5	8	9	9	11	13	11	9	7	6	3	2.5	21781
	*P(v) * f(v)*	0.21	0	0	0	0	0	0.42	0.58	1.05	1.63	1.36	1.72	
Zone 4	*f(v)*	2.5	3	4	6	8	10	13	14	14.5	12	8	3	
	*P(v) * f(v)*	0.09	0	0	0	0	0	0.49	0.9	2.17	3.26	3.63	2.1	39437

The total energy production E can also be used to calculate the wind turbine capacity factor CF [18]. Indeed, the CF of a wind turbine at a given site is defined as the ratio of the wind turbine energy produced to the produced energy when the turbine ran at its rated power, P_R, over the 6240 hours:

$$CF = \frac{E}{E_R} \qquad (11)$$

Where $E_R = 6240.P_R$

According to Table 6 and Table 7 data, the CF of our wind turbine can exceed 30% what is suitable for our application.

6.2 Benefits: Reduction of Fuel Oil Consumption and CO_2 Emission

Fitting the 200KW VAWT wind turbine on the tanker understudy may generate up to 353135 KWh yearly. As the electric power is produced on board by diesel generator having a specific fuel oil consumption of 200-210 g/KWh. This could save up to 74 tons of fuel oil yearly.

CO_2 emissions factor for marine fuel oil is 3,2 grams CO_2per gram of fuel oil [19].

Hence saving 74 tons fuel oil is equivalent to 237 tons of CO_2 emissions preventions.

The average fuel oil consumption of the electric diesel generator installed on ship cited in this article 0.9 ton per day. 74 tons of fuel oil represents 23% of the total fuel oil consumed for electric power generation on board.

6.3 Ship Stability Assessment

The vessel's stability is characterized by its ability to return to an upright position after being subjected to an external force caused by wind or waves.The design of a vessel must meet all the stability requirements applicable to its size and type in order to operate safely at sea.

The ship stability is characterized by the metacentric height (GM) which is a measurement of the initial static stability of a floating body. It is calculated as the distance between the center of gravity of a ship and its metacenter. Simulation was done using the shipboard stability program "Delta Load" to assess the influence of deck wind turbine on the ship stability at ballast and loaded conditions. As example, the Figure 9 represents the simulation of the stability parameters for sample ship fitted with wind turbine in loaded conditions.

Results for different cases are summarized in Table 8, as we can see the turbine weight is negligible compared to the ship displacement and has minor influence on ship's draft and trim. The obtained GM values for ship with turbine are slightly different from the originals but remains largely above the minimum required, in all cases the stability criteria found to be fulfilled.

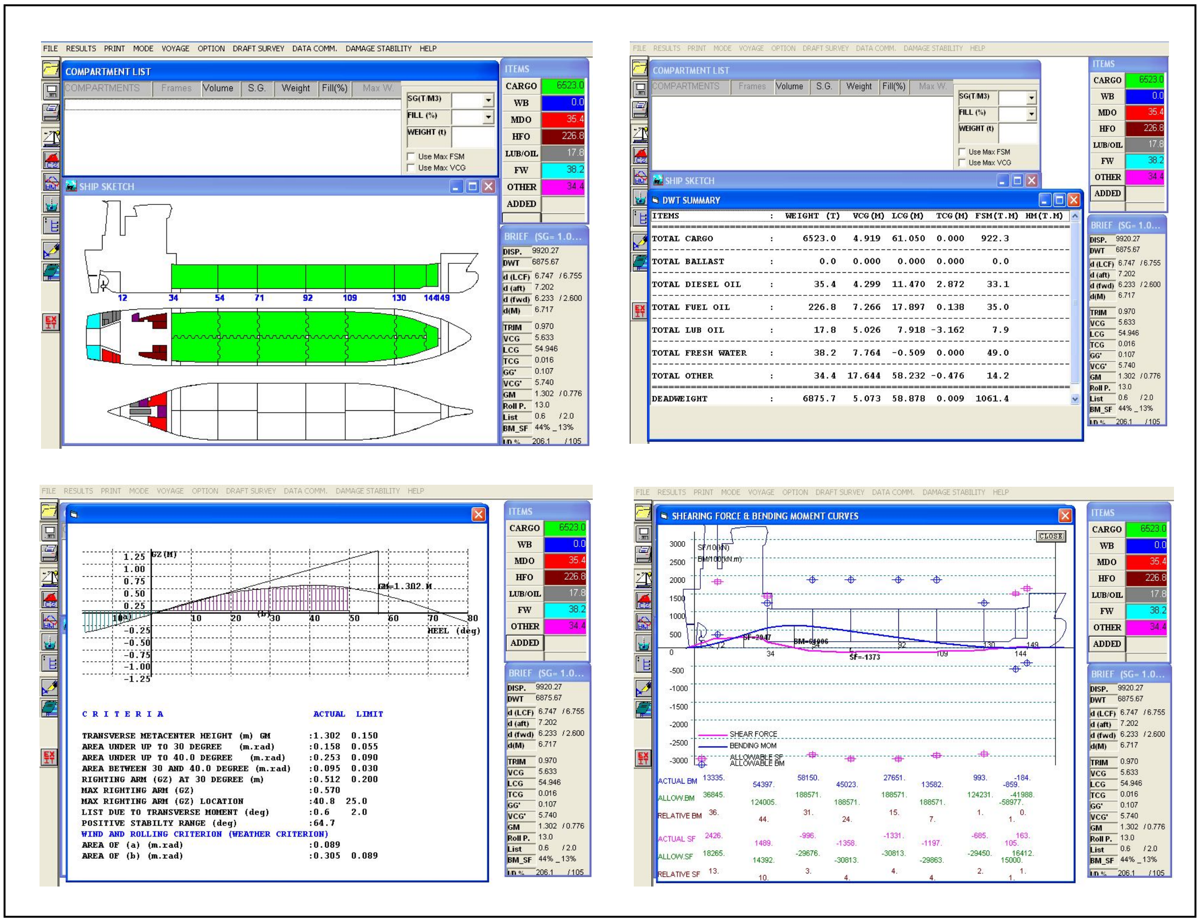

Figure 9: Stability assessment: case of loaded condition with turbine fitted.

Table 8: Ship stability

Item	Laden		Ballast	
Cargo (T)	6523			
Ballast (T)			2717	
Others (T)	327			
Turbine (T)		25		25
Displacement	9895	9920	6089	6114
Draught (m)	6.70	6.72	6.70	6.72
Trim (m)	1.015	0.97	1.015	0.97
GM (m)	1.34	1.302	1.34	1.302

6.4 Air Resistance.

Air resistance generated by the movement of air over the exposed ship structure, is affected by the shape above the waterline, the area of the structure exposed to the air, and the ship's speed through the water. According to [20], this resistance represents 2% of the total ship resistance in still waters.
Fitting wind turbine on the deck tends to increase the ship air resistance mainly during head wind.
The equation (12) is used for estimating the drag force.

$$R_A = \frac{1}{2} C_d \ . \rho \ . S \ . v^2 \quad (12)$$

Where:
R_A: the wind force in Newtons
ρ: the air density in kg/m^3
v: the wind speed in m/s
C_d: the wind resistance coefficient respect to the wind direction.
S: the windage area exposed to the wind in m^2.

When the turbine rotates the ship air resistance drag force is caused only by the turbine tower reference area, but it will be increased by the blades once the turbine stops (Cut in – Cut off).
Considering that the turbine tower reference area is estimated to 65 m2and the blades reference area is given as 3 x 20m2, the total reference area of the turbine is approximatively125 m2.
The ship initial windage area as per ship's specification is given 420m2.The air resistance of the ship represents approx. 2% of the total ship resistance.
During turbine rotation the total air resistance will be increased by 0.3% and 0.6% when stopped. Therefore, the effect of the wind turbine on ship resistance is negligible.

6.5 Air draught:

The initial ship air draught is given as 36 m. By fitting on board, the wind turbine, this draught is increased by 8-10 meters. This shall not limit the ship operations in Moroccan ports and remain below the limits of the main international sea passages, bridges and channels.

6.6 Radar Shadowing:

The performance of any radar depends highly on the correct location of its antenna. Interferences that may be caused in the path of radar beam either by reflecting constructions and structures or other transmitters, may heavily affect the radar capability by producing shadow sectors on the radar display or creation of false echoes.
Calculation from turbine width and its bearing from the center of the radar antenna indicates possible presence of blind sectors on a radar display as shown in Figure 10. However, the actual position (width and bearing)of any blind sectors should be defined during sea trials. Plan views showing these sectors should be posted near the radars concerned.
The effect of wind turbine structure on radar performance is similar to the effects of the shipboard cranes.

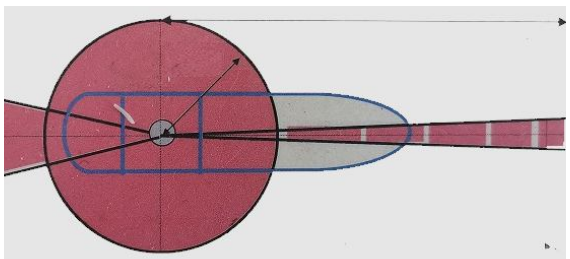

Figure 10: Example of radar blind sector caused by shipboard crane

6.7 Turbine noise:

Wind turbines generate noise from multiple mechanical and aerodynamic sources. Vertical axis wind turbines have a low noise level (below 95 dB).
The legal limit for working place of an eight hours daily is 87dB. In general, the crew members are occupied on the deck for less than 8 hours per day in addition they use the ear protection.
In any case a risk assessment shall be conducted to define the risk level and measures to mitigate it. For comparison during sailing the noise level in the ship engine room is in range of 110-120 dB
The issues related to wind turbine noise have been addressed by many literatures [21].
Noise levels can be evaluated and measured, but, as other environmental issues, the public's perception of its impact and consequences is in part a subjective determination.

7. CONCLUSION

The wind turbine mainly the vertical axis type may be one of the practical solutions for reduction of greenhouse gas emissions by vessels and improving the global energy efficiency of ships. In this study it was demonstrated that by fitting the wind turbine on board a coastal tanker operating between Moroccan port, the reduction of fuel oil consumption and CO_2 emission by 23% for electrical generation. The fitting of wind turbine on ship has minor influence on ship stability and resistance.

However, the capability of the shipboard wind power system depends mainly on the prevailing wind condition (speed and direction) along the ship routes.

Recommendation: Is to carry out a test project with wind turbine mounted on model tanker and conduct a measurements campaign at sea. This would complete the technical analysis identified in this study, the risk assessment and technology verification. Eventually this would also complete the techno-economic study.

ACKNOWLEDGEMENT

This work was completed using wind data provided by Vortex FDC (Spain) which is acknowledged for its support.
This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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

REFERENCES

1. **Third IMO Green House Emission Study**. Executive Summary and Final Report. Published in 2015 by the international maritime organization. 4 albert embankment, London Se1 7Sr www.imo.orgwww.imo.org.
2. IMO, Resolution MEPC.203(62): Amendments to the annex of the protocol of 1997 to amend the international convention for the prevention of pollution from ships, 2011. Available online: http://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Marine-Environment-Protection-Committee-(MEPC)/Documents/MEPC.203(62).pdf
3. G. Theotokatos, K. Sfakianakis and D. Vassalos. **Investigation of ship cooling system operation for improving energy efficiency**. *Journal of Marine Science and Technology* 22, 38–50 (2017). https://doi.org/10.1007/s00773-016-0395-9
4. E. G. Pariotis, T. C. Zannis and J. S. Katsanis. **An Integrated Approach for the Assessment of Central Cooling Retrofit Using Variable Speed Drive Pump in Marine Applications**. J*ournal of Marine Science and Engineering.* 2019; 7(8):253. https://www.mdpi.com/2077-1312/7/8/253
5. M.E.Mondejara, J.G.Andreasena, L.Pierobona, U.Larsenc, M.Thernb, F.Haglinda.**A review of the use of organic Rankine cycle power systems for maritime applications**. *Renewable and Sustainable Energy Reviews*Volume 91, August 2018, Pages 126-151. https://doi.org/10.1016/j.rser.2018.03.074
6. R. Zaccone, E. Ottaviani, M. Figari and M. Altosole. (2018). **Ship voyage optimization for safe and energy-efficient navigation: A dynamic programming approach**. *Ocean Engineering. 153. 0.1016*/j.oceaneng.2018.01.100.
7. K. Wang, X. Yan, Y.Yupeng and F. Li. (2016). **Real-time optimization of ship energy efficiency based on the prediction technology of**

working condition. *Transportation Research Part D. Transport and Environment*. 46. 81-93. 10.1016/j.trd.2016.03.014.

8. L. Talluri, D.Nalianda, K.Kyprianidis, T.Nikolaidis, and P. Pilidis .(2016). **Techno economic and environmental assessment of wind assisted marine propulsion systems.** *Ocean Engineering*. 121. 301-311. 10.1016/j.oceaneng.2016.05. 047.
9. R. Lu and J. W. Ringsberg (2020) **Ship energy performance study of three wind-assisted ship propulsion technologies including a parametric study of the Flettner rotor technology**, *Ships and Offshore Structures, 15:3, 249-258*, DOI: 10.1080/17445302.2019.1612544.
10. M. Schlaak, R. Kreutzer and R. Elsner. (2009). **Simulating Possible Savings of the Skysails-System on International Merchant Ship Fleets.***International Journal of Maritime Engineering* - INT J MARIT ENG. 151. 10.3940/rina.ijme. 2009.a4.161.
11. *ABB. (2011*). **Technical application papers no.13—Wind power plants**. Retrieved from https://library.e.abb.com/public/92faf0c1913f5651c1257937002f88e8/1SDC007112G0201.pdf
12. M.L. Kubik, P.J. Coker and C. Hunt (2011) **Using meteorological wind data to estimate turbine generation output: a sensitivity analysis**. *In: World Renewable Energy Congress 2011*, Linkoping, Sweden, 8–13 May 2011, pp.4074–4081
13. Global Wind Atlas 1. 0.. Retrieved from https://globalwindatlas.info/.
14. Vortex FDC. https://vortexfdc.com/(consulted on 2020-05).
15. J. Fadil, Soedibyo and M. Ashari, **Performance comparison of vertical axis and horizontal axis wind turbines to get optimum power output**, (2017)*15th International Conference on Quality in Research (QiR) : International Symposium on Electrical and Computer Engineering,* Nusa Dua, 2017, pp. 429-433, doi: 10.1109/QIR.2017.8168524.
16. Hummer H25.0-200KW. Data sheet and Power curve. Retrieved from https://en.wind-turbine-models.com/turbines/1681-hummer-h25.0-200kw
17. A New-M1 200kW Medium VAWT Data sheet. Retrieved from https://www.anew-institute.com/anew-m1-vawt.html.
18. A. Allouhia, O. Zamzoum, M.R. Islam, R. Saidur, T. Kousksou, A. Jamil, A. Derouich. **Evaluation of wind energy potential in Morocco's coastal regions**. Renewable and Sustainable Energy Reviews 72 (2017) 311–324
19. H.O. Kirstenen (2015). **Energy Demand and Exhaust Emissions of Marine Engines.** *Technical University of Denmark: Lyngby, Denmark, 2015.*
20. A. F. Molland, S. Turnock and D. Hudson, (2011). **Ship Resistance and Propulsion: Practical Estimation of Ship Propulsive Power**. Cambridge: Cambridge University Press. doi:10.1017/9781316494196.
21. E. Möllerström,F. Ottermo, J. Hylander and H. Bernhoff. **Noise Emission of a 200 kW Vertical Axis Wind Turbine**. *Energies* 2016, *9*, 19.