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Research Articles

A Hybrid Green Energy Propulsion Technology for Navigation of Inland Watercrafts

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ship-propulsion
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wind-mill
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ABSTRACT

In view of the hazardous effects of emissions from fossil-fuel-propelled boats and their contributions to global warming, this study investigated the operability potentials of inland watercraft powered by a hybrid of solar, wind, and electric-drive green energy technologies. The objectives were to estimate the rate-of-change coefficients in rpm for solar- and wind-propelled boats under varying energy outputs, evaluate the resulting changes in boat speed and distance traveled, and compare the performance of the two motive-power sources for inland navigation. An experimental research design was adopted. Solar panels, wind turbines, electrical capacitors, DC motors, and batteries were integrated to generate hybrid green propulsion for a small laboratory watercraft constructed with lightweight aluminum and fitted with dual mini-propellers. Primary data on operability were obtained by sailing the craft in a laboratory towing tank and in the Otamiri freshwater. Analytical methods included rate-of-change analysis, log-linear regression, and descriptive and inferential statistics. Findings show that solar - and wind-powered propulsion systems perform disproportionately in rpm, speed, and distance traveled. Solar energy demonstrated superior performance, yielding higher rpm, speed, and travel distance. A unit increase in the solar-powered DC motor rpm produced an additional 0.004 m in distance traveled; while the rate-of-change coefficient for speed relative to solar power output was 0.015 m/s. Solar power also increased DC motor rpm by 312 rpm per unit rise in output, compared to 402 rpm for wind power. The average rate-of-change coefficient for distance traveled relative to rpm variation in freshwater was 0.0023 m. The study discusses the implications of these results and draws conclusions aligned with the research objectives.

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1. Introduction

The adverse environmental effects of emission of gaseous pollutants, high energy cost and inefficiencies associated with the use of fossil fuel types particularly marine diesel, has led to serious research and innovation for alternative energy sources for marine use. The use of fossil fuels particularly diesel oil and other high sulfur rich hydrocarbon types in maritime operations and shipping show significant adverse impacts on the environment and health. As a result, regulations have emerged in the global shipping sector and regional economies to regulate and curtail the negative impacts of emissions from shipping operations; particularly greenhouse gases (GHG), Sox, Nox and Co_2 emissions. This underscores the need for the development and use of alternative green energy types, that could significantly limit emissions and the associated environmental and health risks [1,2].

The regulations and restrictions of fossil fuel use for marine propulsion has equally led to extra cost of propelling ships powered by fossil fuels. For example, various maritime jurisdictions place heavy tax on vessels operating on HFO while ship-owners are subjected to modify the propulsion system of their fleet to install scrubbers, at extra costs. These identified challenges form the drivers of the search for better environmental friendly alternative energy technologies for use in ships and marine operations globally. The International Maritime Organization for example advocates for the massive development of green shipping technology in view of the very high level of carbon pollution associated with use of diesel energy and other fossil fuel types [3].

The concept of green shipping technology for marine propulsion according to [2] connotes the use of non-greenhouse gas (GHG), Sox, Nox and Co_2 emissions energy types, including the use of renewable energy and other viable alternatives that do not emit greenhouse gases. As a result green shipping technologies do not result to the danger of environmental pollution and the associated adverse effects. Typical green energy options that have been explored for purposes of marine navigation include: wind power, solar power, Hydrogen gas, Methanol, Advanced biodiesel, hydro-treated vegetable oil (HVO), Electricity (in batteries) cum photovoltaic energy (solar/electrical energy hybrid) [4].

In the West African maritime region where Nigeria dominates maritime affairs, the implementation of the IMO regulations on emission prevention and control seems to be concentrated only on seagoing vessels, mostly by the use of tax-based policies, where non-compliant vessels are taxed for breach of emission prevention requirements. Boats involved in Coastal and Inland navigation still operate on fossil fuels unregulated. This portends danger of environmental and health hazards.

The implication is that coastal and inland water crafts contribute to the emission of greenhouse gases in the region which cannot be completely overlooked in the drive towards limiting the impacts of ship emissions and the associated adverse effects. It is important to state that, the drive towards combating hazardous emissions from coastal and inland vessels in Nigeria can be approached through the development and use of alternative green shipping technology, rather than a tax-based approach. The innovation and development of alternative green energy types of hybrid of green energy types for propelling coastal and inland watercrafts can be achieved through a mix of other locally available energy sources such as solar and wind energy [2].

Thus, this study was carried out to develop and determine the operability of a hybrid alternative green shipping technology for navigating small boats and watercrafts in Nigeria coastal and inland waters through a mix of electric drive system, solar energy and wind energy. Nigeria is a tropical Country with high degree of sunshine and with potentials for development and use wind energy. The interest of the study in harnessing the solar and wind energy potentials predominantly available in the Country, for marine navigation, through an electric battery system that stores energy and subsequently feed it to the propulsion systems of the boat/watercraft involved in inland water navigation. The study aim to investigate to what extent a mix or hybrid energy, starting with solar energy stored as electrical charges in energy storage devices such as batteries and capacitors; and wind energy, can be hybridized and integrated to electric motors for purposes of propelling small inland watercrafts.

The integration of solar energy stored in batteries and capacitors with wind energy which is subsequently integrated with electric drives connected to the propellers of the watercraft creates motion that is transmitted to propellers driven by rotary motors. Thus, green energy from `the sun and wind are harnessed and stored in storage devices, for example a battery, and used to achieve the motion of the boats in inland water navigation. The configuration is confirmed to have capacity to enable the propulsion system to run continuously without end, except at the end of life of the battery or if it develops fault. At that point it can be replaced with a new battery or storage system. Though solar energy and wind energy form the original sources of energy for the propulsion, the system is governed by the principle of electricity and electronics since batteries, capacitors and electric motors are required to store charges and drive the propellers.

Hence, the innovation employs the use of electric motors and motor controllers powered through solar and wind energy sources for propulsion, rather than the use of the internal combustion engines (ICEs) which are dependent on fossil fuels. The study is therefore cast to investigate the operability of a hybrid green shipping propulsion system developed from solar, wind energy and electric drive system. The specific objectives of the study are as shown below.

1.1 Objectives of Study

1) To determine the rate (extent) of change coefficient of rpm of solar and wind propelled boats relative to variations in solar power fed into the system.
2) To estimate the rate of change of distanced sailed by solar and wind propelled boats relative to variations in motive power output.
3) To determine the coefficient of rate of change of speed of the watercraft associated with changes in solar and wind motive power outputs.
4) To compare the performances of the solar and wind alternative energy sources for ship propulsion.

1.2 Research Questions

1) What is the rate (extent) of change in rpm of solar and wind propelled boats relative to variations in solar power fed into the system?
2) What is the rate of change of distanced sailed by solar and wind propelled boats relative to variations in motive power output?

3) What is the coefficient of rate of change of speed of the watercraft associated with changes in solar and wind motive power outputs?
4) Is there a significant difference in the performances of the solar and wind alternative energy sources for ship propulsion?

2. Literature Review

Studies by references [5,6] note the importance of green shipping technology in the propulsion system of watercrafts and the benefits of the use of renewable energies and other viable alternatives that do not harm the planet in propelling water vehicles. Reference [7] note that this can be achieved by storing charges in energy storage devices, such as batteries, capacitors etc. and using electric motors in which motion is created by propellers driven by rotary motors. It is observed that energies from the sun and wind are harnessed and stored in storage device; while propeller and shaft are connected to the electric motor to supply the motion to the shafting system [8]. Though information about the scalability potential of these hybrid green energy options in the shipping industry is West Africa is still obscure, empirical literature support the propulsion of ships with hybrid green energy alternatives that limits emissions and the associated environmental hazards [9,10].

Reference [10] note the dominance of use of Electric propelled water vehicles is the inland navigation in developed countries, as alternative to fossil fuel-powered boats while noting that electric drives have capacity to receive their power from a wide range of sources, including fossil fuels, nuclear power, and renewable sources such as tidal power, solar power, and wind power or any combination of those. The study notes that the energy generated; is first transmitted to the vehicle through use of overhead lines, wireless energy transfer such as inductive charging, or a direct connection through an electric cable. The electricity may then be stored onboard the vehicle using as battery, flywheel, super capacitor, or fuel cell [10-12]. This corroborates the findings of [13] that operability of a hybrid multi-scheme energy system for maritime operations. Research for the advancing the performance and use of such hybrid alternative propulsion system for marine transportation purposes is what seems to be stampeded and lacking currently, particularly in Nigeria and West African inland water transport subsector.

Vehicles making use of engines working on the principle of combustion can usually only derive their energy from a single or a few sources, usually non-renewable fossil fuels. However, the objective in a hybrid propulsion system is to operate the primary power source at the optimum points as much as possible with basic aims of limiting operational cost and achieving environmental standards through the limitation of emissions which are harmful to society [14,10].

Although electric or hybrid electric watercrafts are known to have a key advantage of capacity to recover braking energy as electricity to be restored to the on-board battery or sent back to the grid, its ability to achieve high speed and acceleration in comparison to diesel propelled ships is in question. For this reason, operators have continued to favour the use of diesel propelled boats in coastal and inland water navigations, to the detriment of the environment [15,16]. Therefore, research studies are necessary to provide evidences of the relationship between rpm cum speed generation capacity of hybrid green energy types for shipping operations. This is because the concern is increasing over the environmental impact of the petroleum-based transportation infrastructure, along with the spectra of peak oil. There is thus renewed interest in the advancement and use of electric transportation infrastructure and hybrid green energy sources for marine purposes [17].

Reference [18] evaluated the design requirements and performance of hybrid green energy shipping technology based on solar power, wind power and electric motors integrated to the propulsion system of a vessel. A hybrid power ship propulsion system includes more than one type of energy storage system (ESS) and power plant for meeting the needs of a power consumption. The basic technologies for such a hybrid green energy system for ship propulsion consisting of a mix of solar power, wind energy and electrical energy system are presented to include solar panels, wind mill or wind turbine, electrical battery system, a DC motor and ship propeller shafting system [18]. See figure-1 below:

The Central building block and smallest element of a solar panel is the photovoltaic (PV) cell. The photovoltaic effect occurs within the cell, initiating the power for the rest of the system. The PV effect results from the electricity potential that develops between two dissimilar materials within the cell, separates by a common junction which is illuminated with radiation of photons [18]. When in series, the current is constant and the current is added. The most appropriate configuration is determined by the amount of power needed and the space one has to work.

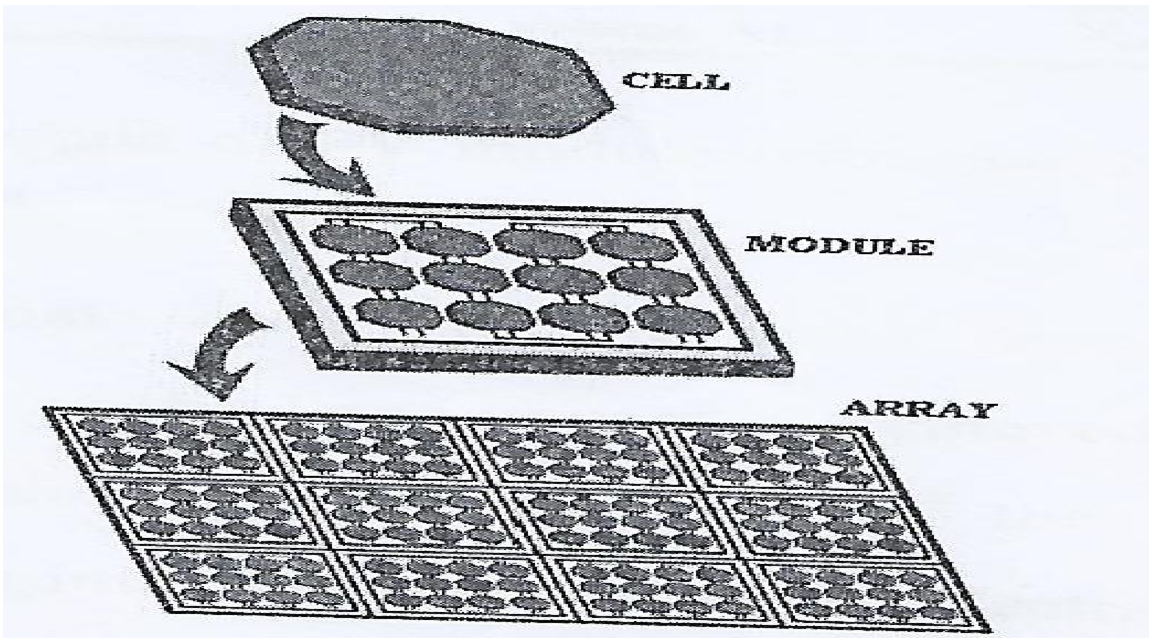

Figure 1. Solar panel. Source: Reference [18].

In general the electrical characteristics of the PV cell are illustrated by the current versus voltage (i-v) curve [18]. Maximum power is found at the voltage corresponding to the knee of the curve. An example of i-v curve is shown in Figure 2, where ISC is the short circuit current is the open circuit voltage. These are two main parameters when determining the electrical performance of the cell. The photo conversion efficiency of the cell is simply given by:

$$\eta = \frac{\textit{electricity power output}}{\textit{Solar power impinging the cell}}$$

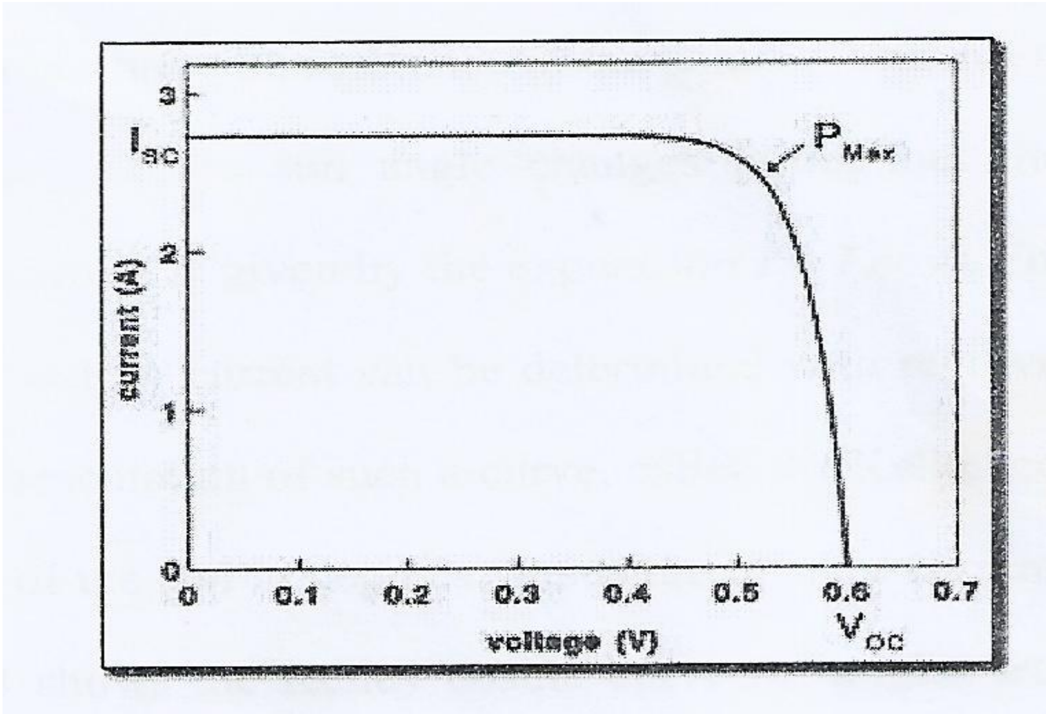

Figure 2. characteristic if PV module with maximum power at the knee of curve. Source: [18].

The wind energy is a renewable source of energy. Wind turbines are used as the turbine converts the mechanical power into the electric power. The energy production by wind turbines depends on the wind velocity acting on the turbine. It is used to run a windmill which in turn derives a wind generator or wind turbine to produce electricity.

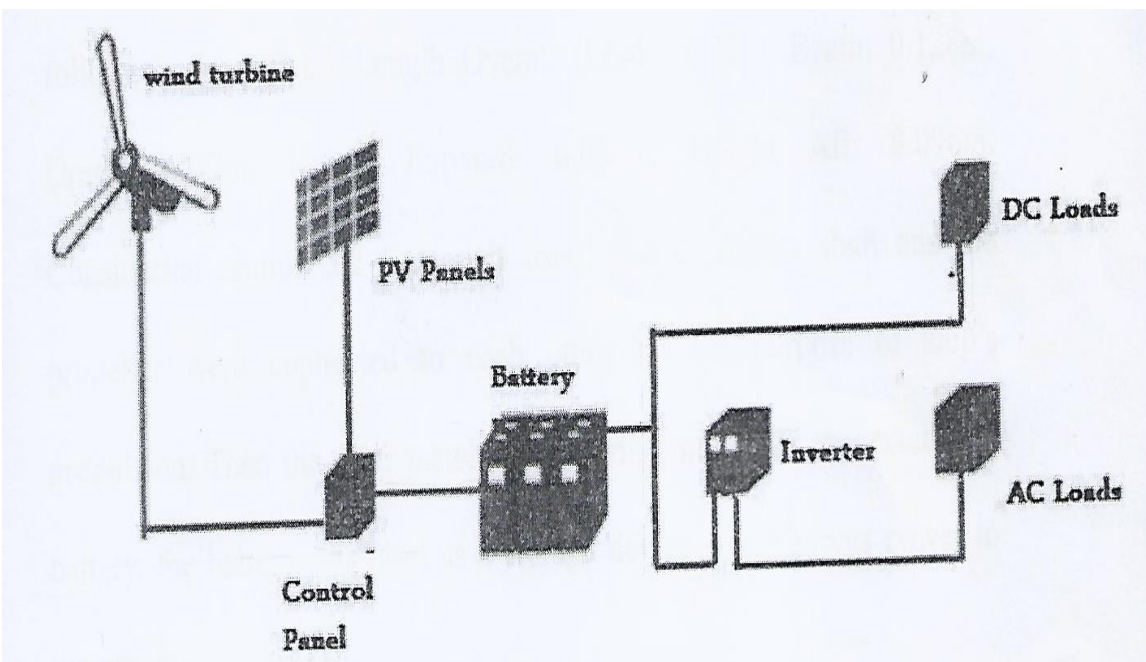

Figure 3. Windmill/wind turbine. Source: (18)

The other components such as the electric batteries, electric motors and capacitors as already aforementioned are used to convert mechanical energy from the wind turbine into electric energy which is used to drive the propeller shafts [14-16].

Studies by references [19, 18] opine that the sizes of the components depends of the size and type of ship, the kind of trade in which the ship is involved, GRT and NRT of the vessels as well as other parameters that influence the speed of sail, ship strength and structural integrity. The naval architect and the marine engineer have a duty to determine the sizes and capacities of the components in line with prevailing industry regulations [19].

Though available empirical studies have emphasized the operability of the hybrid green energy sources for ship propulsion in the maritime industry; such studies did not however provide empirical information on how the power capacity, the rpm of the electric drive can be scaled-up to improve on or achieve the desired speed performance of such watercrafts propelled with hybrid green energy sources. This is key knowledge gap which this study is determined to bridge.

3. Materials and Methods

The study used experimental research design method in which solar energy panels, winder turbines, electrical motors, capacitors, DC motors and electrical batteries were hybridized to produce a hybrid green energy source of power for propulsion of small laboratory watercraft designed with aluminum hull and double mini propellers system used for experimental purposes. The purpose was to determine to what extent varying the capacity of the solar power and wind power outputs would energize the DC motors with inbuilt 2000rpm capacity to maximum rpm and thus be extended to the design of watercraft that uses a hybrid of solar and wind energy to generate electrical energy, which is fed to the propellers, to generate motion for inland water navigation.

As aforementioned, for the purpose of the experiment, four mono-crystalline solar panels with varied capacities of 3watts, 3.5watts, 4watts and 4.5watts were used while wind mill (wind turbine of the same power output of 1.3watts, 3.5watts, 4watts and 4.5watts were used. A Li-polymer battery of 500mAh capacity, two DC motors of 4volts each with maximum rpm of 2000rpm with each connected to the wind turbine and the solar panel respectively. Each of the propellers (recall it used a double propeller ship) were connected to each DC motor to transmit the rpm rotary motion of the DC drives to propulsion motion by the propeller. The hull was designed with Ceases friendship software and it has the following dimensions:

1) Length Overall (LOA): 0.32m
2) Beam: 0.128m, Draft: 0.032m
3) Height Forward: 0.064m
4) Height Aft: 0.096m
5) Draft: 0.032m
6) Beam 0.128m
7) Weight of propeller 0.009grams

The Dc motor, shaft and the propeller were connected to each other for the purpose of ship's hybrid propulsion system consisting of solar and wind turbine energy sources. Then the solar panel and the wind mill were connected to a battery, the battery was used as a storage device which power to the motor. The ship was subsequently subjected to motion in towing tank (towing tank experiment) in the laboratory while the solar system was on to energize the DC motors to produce the motion of the ship. Readings of the rpm of the drives and the speed of the ship was taken for various solar power capacities of 3watts, 3.5watts, 4watts and 4.5watts. Similarly, the ship was subjected to motion in windy riverside of the otammiri waterfront while setting the windmills to energize the dc motors to produce the required energy for propelling the ships. The rpm of the dc motors and the speed of the ship for various changes in windmill power (at 3watts, 3.5watts 4watts and 4.5watts) was also taken. A laser tachometer was used to measure the rpm of the motors while the speed achieved by the ship is calculated by timing the motion of the ship over distance covered. The ratio of the distance travelled to time taken to cover it gave the speed of the ship in m/s. the rate of change of rpm to variations in solar power and variation in wind power output were determine plotting the respective graphs and rate of change analysis.

4. Results and Discussion

Table 4.1. Result of the Performance of Solar DC Drive in propelling the small watercraft.

					Mean
Solar panel power output capacity (watts)	3.00	3.50	4.00	4.50	3.75
DC motor rpm	1500	1710	1800	1990	1750
Distance traveled by watercraft (meters)	6.00	6.90	7.50	8.00	7.1
Time taken (seconds)	15.00	17.10	18.00	19.10	17.3
Speed (M/S) = distance/time	0.400	0.403	0.416	0.420	0.410

Source: Experimental result

Table 4.1. above shows the result of study on the power output of solar powered DC drive in generating the power for the propelling of the small watercraft used for the experiment. The result indicates that the mean power produced by the solar panel is a average of 3.75 watts while the average rpm achieved by the DC motor following that solar power output is 1750rpm. The watercraft travelled an average of 7.1 meters in the simulation tank (water tank) within an average time period of 17.3 seconds. This gives an average speed of the watercraft in the simulation tank as 0.410m/s. The dataset on table-4.1 form the primary data which was further analyzed to determine the rate of change of rpm and speed of the solar powered watercraft relative to variations in power output of the solar energy source.

Table 4.2. Result of the Performance of Wind Mill/Turbine (wind power and DC Motors in propelling the small watercraft.

					Mean
Wind mill/wind turbine power output capacity (watts)	3.00	3.50	4.00	4.50	3.75
DC motor rpm	1350	1530	1740	1950	1642.5
Distance traveled by watercraft (meters)	5.00	6.00	6.70	7.50	6.30
Time taken (seconds)	14.00	16.00	17.00	19.50	16.63
Speed (M/S) = distance/time	0.357	0.375	0.39	0.41	0.383

Source: Experimental result

Table 4.2. above shows the result of study on the power output of the wind turbine in driving the DC motors to provide motion to the propellers of the small watercraft used for the experiment. The result indicates that the average power produced by the wind mill/turbine to DC drive for the propulsion of the watercraft is 3.75 watts while the average rpm achieved by the DC motor connected to the windmill following that wind turbine power output is 1642.5rpm. The watercraft travelled an average of 6.30 meters in the open otamiri River within an average time period of 16.63 seconds. This gives an average speed of the watercraft in the Otamiri River as 0.383m/s. The dataset on table-4.2 form the primary data which was further analyzed in subsequent sections to determine the rate of change of rpm and speed of the wind powered watercraft relative to variations in power output of the wind turbine energy source.

Table 4.3. Coefficients of rate of change of ship speed, DC drive rpm and distance travelled by the watercraft to variations in solar power output and capacity.

Relationship Modeled	R	R Square	F score	B_0 (Constant)	B_1= Reg. Coef. = rate of change	t score	p-value
Rate of change of distance travelled by watercraft relative to variations in rpm of DC drive	0.988 [a]	0.977	84.665	-0.213	0.004	9.201	0.012
Relationship between speed achieved by watercraft and solar power output	R	R Square	F score	(Constant)	B_1= Reg. Coef. = rate of change	t score	p-value
	0.967 [a]	0.936	29.120	0.355	0.015	5.396	0.033 [b]
Rate of change of rpm of DC drive relative to variation in solar power output	R	R Square	F score	(Constant)	B_1= Reg. Coef. = rate of change	t score	p-value
	.990 [a]	.980	96.571	580.000	312.000	9.827	0.010

Source: Authors calculation

The result of the study on Table 4.3 above indicates the average rate change coefficient of distance the distance travelled by the watercraft in water, following changes in rpm of the DC motor and propeller shaft is 0.004. This implies that a unit change (increase) in rpm of the DC motor integrated to the solar power increases the distance sailed by the watercraft by 0.004 units. This implies that, to design a bigger tonnage/capacity solar energy powered inland water boat with that can produce higher rpm and motion to the shafting system, enough to sail longer distances in water, it should be design such that for every 1 unit increase in rpm of the propulsion system, the boat can achieve an addition 0.004 meters of distances covered. The coefficient of correlation between distance travelled by the watercraft in the water and the rpm of the solar power propulsion system is 0.99%; indicating about 99% positive correlation between the distances travelled in water and the rpm DC motor as a part of the propulsion system. The f-score of 84.67 and p-value of 0.012 shows that, there is a significant relationship exists between the rpm of the DC motor and the distance traveled in water by the watercraft. The result has implications for the advancement in the design of solar energy power watercrafts for inland water navigation in Nigeria, such that the projection of the extent or distance of travel and the relative rpm of the DC motor (rpm requirement) can be based on the rate of change coefficient of o.004 meters for every 1 unit increase in rpm.

The result also shows that the coefficient of rate of change of speed of the watercraft relative to change in solar power output of the propulsion system is 0.015m/s. This implies that for each unit increase in solar power output of the propulsion system, the speed of travel of the watercraft increased by 0.015m/s. The coefficient of correlation of the relationship between the speed of travel of the watercraft in water and the solar power output of the propulsion system is 0.967; indicating the existence of about 97% positive relationship (correlation) between the travel speed and solar power output of the propulsion energy. The study reveals f-score of 29.12 and p-value of 0.033. This indicates that there exists a significant relationship between the speed of travel of the watercraft and the motive energy source. This relationship have implications for extrapolating the effects of solar power energy sources on the speed of travel of inland watercrafts, for purposes of advancing the construction and use of solar powered boats for inland water operations in Nigeria.

Similarly, the result of the study shows that the rate of change of rpm of the DC motor relative to the variations in solar power output of the motive power units 312.00 rpm. This indicates that for each unit increase in power output of the solar energy motive power source, the rpm of the DC drive increased by 312.00 rpm. The coefficient of correlation between the rpm of the DC motor and the solar motive power source is 0.99. This also implies the existence of about 99% positive correlation between the rpm of the DC motor and the motive power source. The f-score is 96.57 and the p-value is 0.010. This indicates that, there is significant relationship between the rpm of the DC motor and the solar motive power source of the watercraft. This has implications in the advancement of the design of bigger capacity solar powered boats for inland navigation in Nigeria waterways.

Table 4.4. Coefficients of rate of change of ship speed, DC drive rpm and distance travelled by the watercraft to variations in wind turbine power output and capacity.

Relationship Modeled	R	R Square	F score	B_0 (Constant)	B_1= Reg. Coef. = rate of change	t score	p-value
Rate of change of distance travelled by watercraft relative to variations in rpm of DC drive	0.978[a]	0.957	73.312	0.172	0.0023	7.015	0.030
Relationship between speed achieved by watercraft relative to power output of the wind-turbine	R	R Square	F score	(Constant)	B_1= Reg. Coef. = rate of change	t score	p-value
	0.967[a]	0.936	29.120	0.355	0.015	5.396	0.033[b]
Rate of change of rpm of DC drive relative to variation in power output of the wind-mill	R	R Square	F score	(Constant)	B_1= Reg. Coef. = rate of change	t score	p-value
	0.999[a]	0.999	1496.333	135.000	402.000	38.682	0.001[b]

Source: Authors calculation

Table 4.4. above shows the result of the study indicating the coefficient of rate change of distance travelled by the watercraft in water relative to the variations in rpm of the DC motor when powered by the wind turbine; the coefficients of rate of change of speed of the watercraft in water relative to the variations in power output of the wind turbine as alternative energy source. The result shows that the average rate of change coefficient of the distance travelled by the watercraft in the fresh water, following changes in rpm of the DC motor is 0.0023. This implies that a unit change (increase) in rpm of the DC motor when powered by the wind mill increases the distance sailed by the watercraft by 0.0023 meters. This implies that, to design a bigger tonnage/capacity wind energy powered inland water boat that can produce higher rpm and motion to the shafting system, enough to sail longer distances in water, it should be designed such that for every 1 unit increase in rpm of the wind powered propulsion system, the boat can achieve an addition 0.0023 meters of distances. The coefficient of correlation between distance travelled by the watercraft in the water and the rpm of the wind mill motive power system is 0.978%; indicating about 98% positive correlation between the distance travelled in water and the rpm of the DC motor component of the propulsion system. The f-score of 73.312 and p-value of 0.030 shows that, there is a significant relationship between the rpm of the DC motor and the distance traveled in water by the watercraft when powered by wind-mill. The result has implications for the advancing the design of wind energy powered watercrafts for inland water navigation in Nigeria, such that the projection of the extent or distance of travel relative to the rpm of the DC motor (rpm requirement) can be based on the rate of change coefficient of o.0023 meters for every 1 unit increase in rpm.

The result also shows that the coefficient of rate of change of speed of the watercraft relative to change in power output of the wind turbine is 0.015m/s. This implies that for each unit increase in wind power output of the propulsion system, the speed of travel of the watercraft increased by 0.015m/s. The coefficient of correlation of the relationship between the speed of travel of the watercraft in water and the wind power output of the propulsion system is 0.967; indicating the existence of about 97% positive relationship (correlation) between the travel speed and wind-mill power output of the propulsion system. The study reveals f-score of 29.12 and p-value of 0.033. This indicates that there exists a significant relationship between the speed of travel of the watercraft and the motive energy source. This relationship have implications for extrapolating the effects of wind energy sources on the speed of travel of inland watercrafts, for purposes of advancing the construction and use of wind powered boats for inland water operations in Nigeria.

Similarly, the result of the study shows that the rate of change of rpm relative to the variations in power output of the wind turbine 402.00 rpm. This indicates that for each 1 watt increase in power output of the wind turbine motive power source, the rpm of the DC drive increased by 402.00 rpm. The coefficient of correlation between the rpm of the DC motor and the wind-mill motive power source is 0.99. This also implies the existence of about 99% positive correlation between the rpm of the DC motor and the wind motive power source. The f-score is 135.00 and the p-value is 0.0010. This indicates that, there is significant relationship between the rpm of the DC drive and the power output of the wind turbine. This has implications in the advancing the design of bigger capacity wind powered boats for inland navigation in Nigeria waterways.

Table 4.5. Significances in Differences in Performance of the solar and wind power propulsions systems of the watercraft.

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SRPM	1750.0000	4	203.46990	101.73495
	WRPM	1642.5000	4	259.66324	129.83162
Pair 2	SDIST	7.1000	4	.86023	.43012
	WDIST	6.3000	4	1.06145	.53072
Pair 3	STIME	17.3000	4	1.73781	.86891
	WTIME	16.6250	4	2.28674	1.14337
Pair 4	SSPEED	.4098	4	.00974	.00487
	WSPEED	.3830	4	.02249	.01125

Paired Samples Test

		Paired Differences			
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference
					Lower
Pair 1	SRPM - WRPM	107.50000	68.00735	34.00368	-.71487
Pair 2	SDIST - WDIST	.80000	.21602	.10801	.45626
Pair 3	STIME - WTIME	.67500	.71822	.35911	-.46784
Pair 4	SSPEED - WSPEED	.02675	.01350	.00675	.00527

Paired Samples Test

		Paired Differences	t	df	Sig. (2-tailed)
		95% Confidence Interval of the Difference			
		Upper			
Pair 1	SRPM - WRPM	215.71487	3.161	3	.051
Pair 2	SDIST - WDIST	1.14374	7.407	3	.005
Pair 3	STIME - WTIME	1.81784	1.880	3	.157
Pair 4	SSPEED - WSPEED	.04823	3.963	3	.029

The result of the study on table-4.5 shows the comparison of the performances of the solar energy and wind energy motive power sources in terms of the rpm, speed and distance travelled by the watercraft in water when powered by each energy type. The result reveals a mean difference of 107.500 watts between the power output of the solar and wind turbine motive power sources. The positive coefficient of the difference of means indicate that the solar energy system produced higher power than the wind-turbine by an amount equivalent to 107.500 watts. The t-score value of 3.161 and p-value of 0.051 indicates that the solar energy produces significantly higher energy than the wind-turbine.

Similarly, the difference of means between the distances travelled in water by the watercraft when powered respectively by solar motive power source and wind power is 0.800. The positive coefficient of the difference of means score imply that the watercraft travelled a a distance of 0.800 meters higher, when powered by solar energy than with wind energy. The t-score of 7.407 and p-value of 0.005 also indicates the difference in the distance travelled by the watercraft when powered by solar energy is significantly higher than that achieved by the watercraft when powered by the wind-mill (wind energy).

The result also shows that when powered by solar energy source, the watercraft achieved higher speed of sail than when powered by wind alternative energy source. The watercraft achieved a higher speed when powered by solar motive power source than the wind turbine by 0.02675m/s. a t-score of 3.963 and p-value of 0.029 indicates that there is a significant difference in the speed of the watercraft in water when powered by solar and wind energy sources. The result further shows that there is no significant difference in the travel time of the boat when powered by solar and wind alternative energy sources.

5. Conclusion

The study concludes in line with the findings of the study that the operability of a watercraft that operates on a hybrid of solar energy, wind-energy and electric drive established. However, solar and wind powered ship propulsion systems perform disproportionately in terms of rpm, speed, and distance of travel under a given time period. Solar energy source shows to perform significantly better in terms of rpm, speed and distance of sail, particularly in Nigeria inland waters used in the study. For each unit change (increase) in rpm of the DC motor integrated to the solar power, the boat travels and extra distance of 0.004 meters. The coefficient of rate of change of speed of the watercraft relative to change in solar power output of the propulsion system is 0.015m/s. For each unit increase in power output of the solar energy motive power source, the rpm of the DC drive increased by 312.00 rpm. The rate of change of rpm relative to the variations in power output of the wind turbine 402.00 rpm. The coefficient of rate of change of speed of the watercraft relative to change in power output of the wind turbine is 0.015m/s. The average rate of change coefficient of the distance travelled by the watercraft in the fresh water, following changes in rpm of the DC motor is 0.0023 meters.

Furthermore, there is a significant influence of both solar and wind energy motive power sources on the rpm, speed and extent of sail (distance) of small boats for inland water navigation in Nigeria.

Authorship Contributions

Concept design: Theophilus. C. Nwokedi, John Eru, Data Collection or Processing: Osondu-Okoro Chukwuebuka, John Folayan Ojutalayo, Analysis or Interpretation: Ofurumazi Righteousness, T. C. Nwokedi, , Literature Review: Paulinus Ononuju Nwokedi, Writing, Reviewing and Editing: T. C. Nwokedi, John Eru.

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Conflict of Interest

There is no conflicting interest known to the researchers non are they envisaging any conflicting interest in the future. There is no conflict of interest in this study.

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