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INVESTIGATING WIND POWER POTENTIAL AT MAAP: AN ENERGY RESOURCE ASSESSMENT

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Abstract. The transition to sustainable energy resources in maritime operations has become a critical priority under the framework of the International Maritime Organization GreenVoyage2050 initiative. This study explores the potential use of wind as an additional energy resource, aligned with the efficient operation of educational institutions in accordance with ISO 21001 as adopted by the Maritime Academy of Asia and the Pacific.

The study focused on gathering wind speed over nine months at a selected location of the MAAP IMMAJ campus, purposely to be converted into useful energy. The computed useful energy was analyzed to determine whether it would become helpful in adding energy to the Campus.

The quantitative method of research was employed in this study. A digital anemometer was used by the researcher to measure the wind speed at the rooftop of the Mock Bridge on the IMMAJ campus. This location was chosen for preliminary data collection due to its elevated observation point, free from obstructions, its accessibility, and the presence of observable wind activity, as evidenced by the existing wind vane installed on-site. Wind speed was recorded and analyzed to determine its possibility for the school's power requirements. The presence of the wind was surveyed, measured, and monitored using the handheld anemometer. The data were compared using the historical data from the website "https://www.worldweatheronline.com/mariveles-weather-history/bataan/ph.aspx." A 3 m/s wind speed average was computed based on the actual measurement. From the website's historical data, a higher average wind speed yield of 4.86 m/s was obtained.

An analysis of the actual wind speed measurements, which showed an average of 3 m/s, led to the selection of a horizontal wind turbine model with the following specifications: a rotating diameter of 2.058 meters, a start-up wind speed of 1 meter per second, a cut-in wind speed of 1.0 to 1.5 meters per second, and a survival wind speed of 60 meters per second. The turbine begins generating energy at a minimum wind speed of 1 m/s, while it requires a wind speed between 1.0 and 1.5 m/s to produce usable electricity. Furthermore, it is engineered to withstand extreme wind conditions, surviving speeds of up to 60 m/s.

The wind speed data collected throughout the nine months ranged from 0.8 to 7 m/s, aligning well with the chosen wind turbine model's operational requirements. Based on the average wind speed of 3 m/s, the available wind power was calculated to be 55 Watts, with a power output of around 20 Watts.

The survey provides critical value by validating the compatibility of the selected wind turbine with local wind conditions, ensuring optimal energy production and long-term durability. It delivers essential data for informed decision-making, enhances project feasibility, and establishes a basis for improving renewable energy solutions. The economic value is influenced by factors such as energy cost savings, environmental benefits, and scalability potential.
If the wind energy is harnessed for 10 hours, 200 WH of energy will be obtained. This energy output will be helpful for energizing low-power loads like pathway lights, office lights, USB chargers, Battery Charging Equipment, and Backup Power Providers during emergencies.

Keywords: Alternative Energy; Green Energy; Sustainable Operation; Renewable Energy; Wind Power.

1. INTRODUCTION

1.1. Background of the Study

The energy consumption in Maritime Academy of Asia and the Pacific (MAAP) is rising due to technological improvement and office expansion. The constant progress and advancement of the school's facilities and equipment equate to an upturn in energy demand.

MAAP utilizes solar energy to power campus street lights as a sustainable alternative. Additionally, a solar farm has been established within MAAP's premises under a Power Purchase Agreement, enabling the institution to procure electricity at a rate of Php6.30 per kWh. Further sustainable energy sources can add to the existing renewable power infrastructure. Given the constant presence of wind in the school's surroundings, assessing wind resources would be a valuable step in determining whether wind energy can further enhance the campus' sustainability efforts.

MAAP is affected by the cost of energy consumption, which consumes a large portion of the school's overall budget. One way to help reduce power costs is to find alternative ways of sourcing free energy.

This study aims to collect wind speed data on the MAAP campus to assess its potential as a viable power source.

1.2. Review of Related Literature

1.2.1. Wind Resource Evaluation

Evaluating the wind resource is one step in deciding a wind energy project's future. A problematic endeavor, wind resource evaluation calls for improved wind flow modeling techniques, more precise instruments, and more recent measuring techniques. A group of skilled and knowledgeable meteorologists and engineers is needed to complete an accurate assessment. (Asian Development Bank (ADB), 2014)

The anticipated wind speeds at a planned wind turbine location must be stated as a frequency distribution to convert wind speeds into annual energy production (AEP), which is necessary for Wind Resource Assessments (WRAs). A vertical extrapolation is necessary if the anticipated wind turbine hub height and the height for which the wind speeds are available differ. Because the wind flow at complicated sites varies with direction, each wind sector's frequency distribution must be determined. (Barber, et al., July 2022)

1.2.2. Causes of Uncertainty in Wind Evaluation

Ramps, or abrupt, significant variations in wind speed, cause uncertainty in wind evaluation. Ramps were found to be most common in March and April and least frequent in November and December in a wind farm in Eastern Germany. Various wind velocity forecast outputs, such as measurement data and the numerical weather prediction (NWP) model, are supplied into the wind power prediction tool for analysis. (Lochman, et. Al, April 2023)

1.2.3. Variables in Predicting Monthly Wind Energy Output

The wind profile across the rotor impacts wind energy generation, but synoptic-scale weather patterns are a major factor in wind speed at turbine hub height. The Eolos Wind Research Station in Minnesota, USA, used a six-year hourly profile measurement record. It was discovered that wind speed, turbulence severity, and wind speed shear over the rotor were the most significant variables for predicting monthly wind energy output from the Eolos turbine at monthly time scales using a straightforward linear regression model. (Coburn & Klink, 2023)

1.2.4. Locations That Are Good Candidates for Wind Energy Integration

Wind energy is most effective in landscapes and is used for various purposes, such as agriculture. Distant or rural locations with abundant high-quality wind resources, like farms, ranches, coastal towns, and island communities, are good candidates for wind energy integration. (Energy.gov offices, 2024)

1.2.5. Effect of Wind Turbine in the Environment

Turbines produce noise. Even though wind farms have different environmental effects than conventional power plants, noise pollution from the turbine blades and their potential visual impact on the surrounding landscape is a concern.

Wind plants may influence the surrounding wildlife. Even though wind farms do not affect wild animals as much as other energy projects, research is still needed to lessen wind interactions with animals. By carefully planning wind farms, conducting ongoing environmental research, and developing new technologies, the impact of wind turbines on wildlife can be mitigated. (Energy.gov offices, 2024)

1.2.6. Wind Resource Considerations

Different wind resources can exist on the same piece of land. Considering existing obstructions like sheds, houses, and trees is necessary. Future obstacles must also be planned for, such as newly constructed structures or trees that have yet to grow to their full height. The turbine must be positioned 30 feet above anything within 300 feet and upwind any structures or trees. (Energy.gov offices, 2024)

1.2.7. Wind Turbine System Considerations

Selecting small wind turbines that meet national performance and safety standards through testing and certification is strongly advised. Ensure that there is enough space when choosing a location for the tower to be raised and lowered for maintenance. If the tower is guyed, it is necessary to make space for the guy wires. Consider also the distance of the wire run between the turbine and the load (house, batteries, water pumps, etc.), regardless of whether the system is grid-connected or standalone. The wire resistance can result in significant electricity loss. The longer the wire runs, the more electricity loss occurs. The installation costs will also go up if more or larger wire is used. Wire run losses are higher when utilizing direct current (D.C.) rather than alternating current (A.C.). It is advisable to invert D.C. to A.C., if there is a lengthy wire run. (Energy.gov offices, 2024)

1.2.8. Quantity of Electricity to Produce

Small wind turbines used for residential purposes usually range in size from 400 watts to 20 kilowatts, depending on the quantity of electricity to produce. The average household consumes 10,649 kilowatt-hours of electricity annually, or roughly 877 kilowatt-hours monthly. A wind turbine rated between 5 and 15 kilowatts would be needed to meet this demand significantly, depending on the average wind speed in the area. If a home needs 300 kilowatt-hours per month and the average annual wind speed in the area is 14 miles per hour (6.26 meters per second), a 1.5-kilowatt wind turbine can provide that energy. (Energy.gov offices, 2024)

1.2.9. Wind Turbine's Siting to Avoid Unwanted Turbulence

Placing a turbine high above and far away from barriers like trees and buildings results in less turbulence, higher turbine productivity, and a longer turbine lifetime. (U.S. Department of Energy, 2010)

1.2.10. Grid Connection

Nearly every small wind energy system in use has the potential to be securely linked to the giant power grid. A grid connection may be necessary if the system cannot supply all the necessary electricity. It is also possible to sell extra energy to the grid. (U.S. Department of Energy, 2010)

1.2.11. Factors to consider in building a small wind energy system

There are factors to consider when preparing to build a modest wind energy system. The minimum specifications are as follows: there must be no local zoning laws, building codes, or other covenants that restrict structures like turbine towers, which can range in height from 30 to 140 feet; trees and other structures that are lower in height than the turbine; and an annual average wind speed of 10 MPH (4.5 m/s) in the area. (Ayaji, Ojo and Vasel, 2019)

1.2.12. Wind Speed and Power

Studies conducted in New Zealand using modest residential turbines have shown that the increase is usually more linear; that is, when wind speed doubles, so does the produced energy. Improvements in wind speed cause noticeably more significant improvements in energy output from large turbines; the energy produced can rise to eight times for every doubling of wind speed.

Wind speeds generally range from 8 kph (2 m/s) to 12.6 kph (3.5 m/s), which is the typical cut-in speed at which a small turbine starts generating power; 36–54 kph (10–15 m/s) is the maximum generation power; and 90 kph (25 m/s) is the maximum speed at which the turbine is stopped or braked (cut-out speed). (https://www.level.org.nz, 2024)

1.2.13. Factors Affecting Generation Capacity

The generation capacity of the wind turbine will decrease when the locations are as follows: lower to the ground (with a minimum of 10 meters; wind speed increases with height above the ground), within the turbulent airspace downwind of an obstacle (for example, trees, hills, buildings, structures), downwind turbulence will extend to twice the obstacle height for a distance around 20 times the obstacle height, a distance from an upwind obstacle of more than ten times an obstacles height.

The wind power at a site can be obtained by a measurement device mounted on a pole at the height of the future wind generator. Collecting data for a whole year is not generally viable, so a couple of months of data can be taken and compared with data from a local weather station and then extra-polated for the year. Devices include an anemometer – giving average daily wind speed, and a wind totalizer – giving instantaneous wind speed and total wind over an extended period. (https://www.level.org.nz, 2024)

1.2.14. Wind Energy and Power Calculations

The Formula below must be used to compute the wind turbine power.

Procedure in computing the Wind Power:

1. Sweep area of the turbine

For HAWT (Horizontal axis wind turbine) : $A = \pi L^2$

For VAWT (Vertical axis wind turbine): $A = DH$

where:

- L is the blade length – the radius of the horizontal-axis turbine
- D is the diameter
- H is the turbine height

2. Efficiency of the turbine, µ

Total Efficiency:

$$\mu = (1 - k_m) \cdot (1 - k_e) \cdot (1 - k_{e,t}) \cdot (1 - k_t) \cdot (1 - k_w) \cdot C_p$$

where:

- C_p is the turbine efficiency. It must be lower than the Betz limit (59.3%) and is typically between 30-40%
- k_w is the wake losses due to neighboring turbines and the terrain topography, typically 3-10%
- k_m are the mechanical losses of the blades and gearbox, typically 0-0.3%
- k_e are the electrical losses of the turbine, typically 1-1.5%
- $k_{e,t}$ is the electrical losses of transmission to the grid, typically 3-10%
- k_t is the percentage of time out of order due to failure or maintenance, typically 2-3%
- μ is the actual efficiency

3. Calculate the available wind power, P_{wind}

$$P_{wind} = 0.5 \cdot \rho \cdot v^3 \cdot A$$

where:

- A is the swept area
- ρ is the air density, assumed to be 1.225 kg/m^3 by default
- v is the wind speed – the typical usable range is approximately 3-25 m/s
- P_{wind} is the available wind power

4. Calculating the output power, P_{output}

$$P_{output} = \mu \cdot P_{wind}$$

(https://windcycle.energy, 2024)

1.2.15. Common Types of Wind Turbines

Horizontal Axis Wind Turbine (HAWT). The most common type of wind turbine is the 'Horizontal Axis

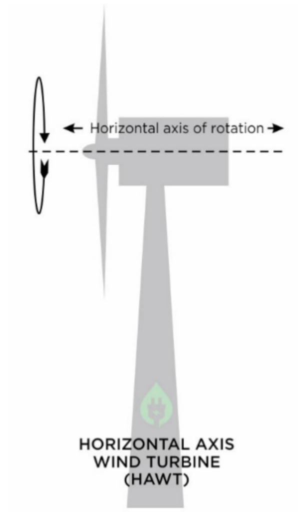

Figure 1A. Horizontal Axis Wind Turbine showing the axis of rotation (https://energyfollower.com/types-of-wind-turbines, 2021)

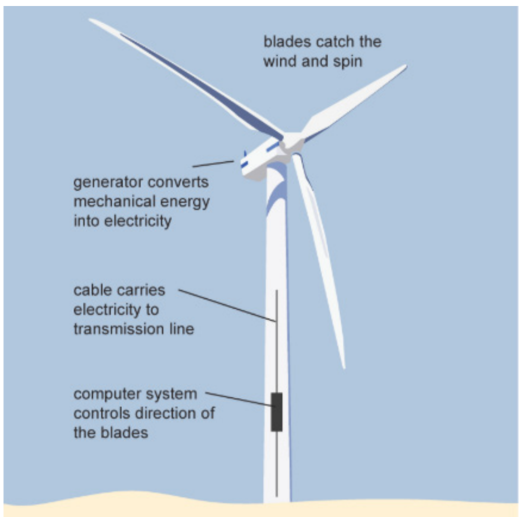

Figure 1B. Parts of Horizontal Axis Wind Turbine (Adapted from National Energy Education Development Project) (Clayton, 2021)

Wind Turbine' (HAWT). It is called a horizontal axis, as the rotating axis lies horizontally.

A HAWT must point directly into the wind to operate at maximum efficiency, and the whole head is designed to turn to face the wind. As the wind changes direction, the head must turn (or 'yaw') to stay pointing into the wind. (Clayton, 2021)

Vertical Axis Wind Turbine (VAWT) have blades attached to the top and bottom of a vertical rotor. They look like giant, two-bladed eggbeaters and are the most common type of vertical-axis turbine. Some versions are 100 feet tall and 50 feet wide. The rotating axis is referred to as vertical as it is aligned vertically upwards (see diagram below). (Lysippos, 2008, Clayton, 2021)

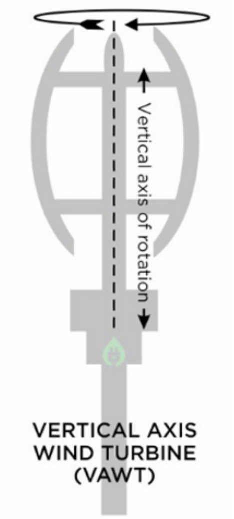

Figure 2A. Vertical Axis Wind Turbine showing the axis of rotation (Source: https://energyfollower.com/types-of-wind-turbines, 2021)

Darrieus vertical-axis wind turbine in Martigny, Switzerland

Figure 2B. Vertical Axis Wind Turbine (Source: Lysippos, Wikimedia Commons author (GNU free documentation license) (public domain)

1.2.16. Sample Models of HAWTs and VAWTs with Corresponding Rated Power and Wind Speed

Table 1. Sample Models of Horizontal Axis Wind Turbines (HAWT)

Model	AWI-E300T	AWI-E500T	AWI-E1000T
Start-up Wind Speed	1 m/s	1 m/s	1 m/s
Cut-in Wind Speed	1.0 – 1.5 m/s	1.0 – 1.5 m/s	1.0 – 1.5 m/s
Charging Wind Speed	1.5 – 2.5 m/s	1.5 – 2.5 m/s	2.0 – 2.5 m/s
Rated Power	300W at 12.5 m/s	500W at 14 m/s	1000W at 12.5 m/s
Survival Wind Speed	60 m/s	60 m/s	60 m/s

Source: A-Wing International Product Guide http://www.awing-i.com/english/wind_turbine_models.html

Table 2. Sample Model of Vertical Axis Wind turbines (VAWT)

Model	ETV-2.0	ETV-6.0	ETV-0.3kW	ETV-0.5kW	ETV-1kW	ETV-2kW	ETV-3kW	ETV-5kW
Rated Power (W)	200	500	300	500	1000	2000	3000	5000
Max Power (W)	250	650	400	650	1500	2500	4000	6000
Start-up Wind Speed (m/s)	1	1	1	1	2.8	2.8	2.8	2.8
Rated Wind Speed (m/s)	10	10	10	10	11	11	12	11
Working Wind Speed (m/s)	1-25	1-25	1-25	1-25	3-25	3-25	3-25	3-25
Survive Wind Speed (m/s)	50	50	50	50	50	50	50	50
Blades Length (m)	1.28	1.8	1.3	1.5	2.65	3.65	3.65	5.2
Blades Rotor Diameter (m)	0,78	1	1.4	1.5	1.4	2.3	2.6	4
Blades Material	FRP	FRP	FRP	FRP	FRP	FRP	FRP	FRP
Mill Weight (kg)	30	60	50	64	175	285	355	665
Swept Area (m²)	0.9	1.5	1.82	2.25	3.71	8.395	9.490	20.8
Tower Eeight (m)	6	6	6	6	6	6	8	10
Generator Type	PM Axial Flux	PM Axial Flux	PM Axial Flux	PM Axial Flux	PM Axial Flux	PM Axial Flux	PM Axial Flux	PM Axial Flux
Rate Speed (rpm)	200	200	200	200	150	160	160	100
Start Torque (Nm)	<0,1	<0.1	<0.1	<0.1	<0.3	<0.3	<1	<1
Optimal Output Voltage (VDC)	12-24	12-24	12-24	12-24	24-220	24-380	48-380	48-500
Protection Method	Brake + PWM	Brake + PWM	Brake + PWM	Brake + PWM	Brake + PWM	Brake + PWM	Brake + PWM	Brake + PWM
Protection Grade	IP54	IP54	IP54	IP54	IP54	IP54	IP54	IP54
Working Temperature (°C)	-40 +50	-40 +50	-40 +50	-40 +50	-40 +50	-40 +50	-40 +50	-40 +50
Life Time (Years)	20	20	20	20	20	20	20	20

Source: https://www.energtrade.com/vertical-axis-wind-turbine/, 2024

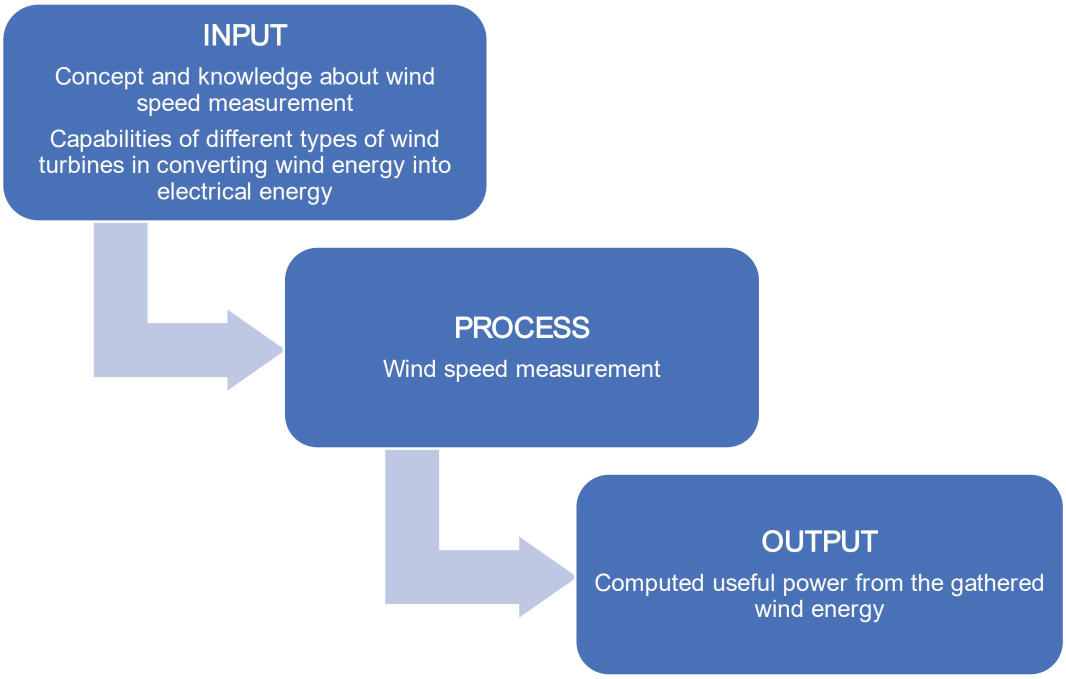

Figure 3. IPO Model of the Study

1.3. Conceptual Framework

The study was divided into input, process, and output sections. Figure 3 illustrates the input-process-output (IPO) model of the study.

For the input section, concepts and knowledge about wind speed measurement and the capabilities of different wind turbines in converting wind energy into electrical energy were gathered through reviewing related articles, discussions, and literature.

In the process stage, the wind speed was measured using a portable digital anemometer with the following features: Wind speed range of 0-30 m/s and Wind temperature range of 10–45 degrees Celsius. The data was gathered from July 2023 to March 2024.

The outcome of the input and the process stage is the computation of the produced power. The wind speed was matched with the appropriate wind turbine design to make it a useful wind speed.

1.4. Significance of the Study

Wind energy can be used as an alternative source of fossil fuel. It will be beneficial to the following units:

1. School Administration

   The decision to explore wind energy as an alternative energy source can be made based on data acquired.

2. Energy Sectors

   The widespread use of renewable energy will help energy sectors achieve sustainability. The study will serve as additional information to solve the problem of diminishing energy from fossil fuels.

3. Researcher

   This study will provide a set of results that can be useful for other researchers.

2. OBJECTIVE

General Objective: This study aims to evaluate the potential of wind energy on the MAAP campus.

Specific Objectives:

Specifically, the study intends to achieve the following:

1. To survey the following parameters: availability of wind at the rooftop of the Mock Bridge on the IMMAJ campus and speed at any given point in time.
2. To monitor and measure the wind speed in MAAP using an anemometer.
3. To compute how much power can be converted based on the gathered wind speed data.

3. METHODS

This section presents the steps and procedures used in the study. It discusses the research design, data gathering, instruments, and techniques.

3.1. Process Flowchart

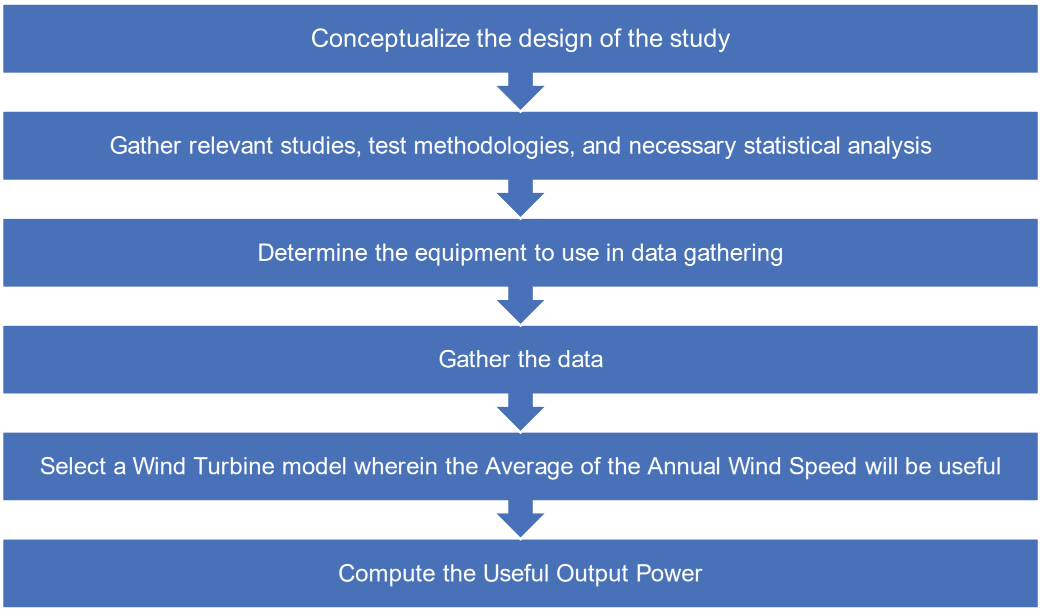

Figure 4. Process Flowchart

3.2. Research Design

This study employed a quantitative research approach. Quantitative research is a systematic investigation method focused on collecting and analyzing numerical data to identify patterns, relationships, and trends.

A digital anemometer was used to measure wind speed on the rooftop of the Mock Bridge at the IMMAJ campus. The recorded wind speed was then analyzed to assess its potential for contributing to the school's power requirements. The data were gathered from July 2023 to March 2024.

4. RESULTS

4.1. Monthly Wind Speed from Actual Measurement

Table 3 presents the recorded wind speeds from July 2023 to March 2024. Each month, data was collected four times a day, at 1000H, 1200H, 1400H, and 1600H over the course of four weeks. Data collection was conducted at these specific times as they were the periods which the researcher was available to measure wind presence at the rooftop of the MAAP Campus.

The table also displays the average wind speed recorded per month, along with the overall average for the nine-month period. The minimum observed wind speed was 0.83 m/s, while the maximum reached 7.00 m/s.

The variability in wind speed during July, August, October, and November of year 2023 was relatively low, with variance values ranging from 0.10 to 0.33. Since variance measures how spread out the data is from the average, lower values suggest that wind speeds remained stable within those months, without drastic fluctuations.

During September 2023, December 2023, January 2024, February 2024, and March 2024, the wind speed variability was notably higher, with variance values ranging from 0.5 to 2.61. A higher variance suggests that wind speeds fluctuated more significantly during these months. This means there were greater inconsistencies in wind strength, with periods of both stronger and weaker winds rather than a stable, predictable pattern.

The nine-month standard deviation of 1.31 indicates the typical amount by which wind speeds deviated from the average over the observed period. Since standard deviation measures variability, a value of 1.31 suggests moderate fluctuations in wind speed across the nine months. This means wind speeds were not completely stable, but the variations were not extreme either.

Table 3. Monthly Wind Speed in m/s (July 2023 – March 2024)

	2023 Jul	2023 Aug	2023 Sep	2023 Oct	2023 Nov	2023 Dec	2024 Jan	2024 Feb	2024 Mar
Wind Speed (m/s)	2.00	2.50	2.50	3.00	3.00	5.00	3.50	4.00	5.00
	1.45	2.10	6.12	2.00	3.00	5.00	4.00	4.20	5.00
	3.05	2.40	3.61	2.00	2.50	5.00	3.50	4.00	6.00
	2.45	2.10	1.67	1.00	2.50	3.00	3.00	5.10	7.00
	2.01	2.01	1.00	3.00	3.00	5.00	4.00	4.20	5.00
	2.05	2.05	1.95	3.00	3.00	5.00	4.00	4.50	5.00
	1.50	1.50	3.50	2.00	3.00	6.00	4.00	4.50	6.67
	2.00	2.00	3.60	2.00	3.00	4.00	4.00	5.00	4.00
	2.05	2.50	0.83	3.00	4.00	3.00	3.50	4.50	2.00
	2.00	2.10	1.67	2.50	4.00	3.00	4.00	4.20	2.00
	3.00	2.40	3.00	1.00	4.00	3.00	4.50	4.00	2.00
	2.10	2.10	3.50	1.50	4.00	3.00	3.50	3.70	1.00
	2.10	2.50	2.50	2.00	3.00	3.00	5.00	4.00	2.50
	1.50	2.10	2.10	2.00	3.00	2.00	6.00	5.00	3.00
	2.10	2.40	2.40	2.00	2.50	2.00	7.00	4.50	4.50
	2.20	2.10	2.10	2.00	2.50	2.00	4.00	4.00	4.50
	2.01	2.01	1.00	2.00	3.20	4.00	5.00	4.00	4.00
	2.05	2.05	1.00	2.10	3.00	5.00	5.00	3.50	4.00
	1.20	1.20	3.00	2.10	2.60	5.00	6.00	3.00	5.00
	2.00	2.00	3.00	2.10	2.50	5.00	4.00	2.00	4.00
Monthly Average	**2.04**	**2.11**	**2.50**	**2.12**	**3.07**	**3.90**	**4.38**	**4.10**	**4.11**
Monthly Variance	**0.20**	**0.10**	**1.57**	**0.33**	**0.28**	**1.57**	**1.02**	**0.50**	**2.61**
Monthly Standard Deviation	**0.45**	**0.32**	**1.25**	**0.57**	**0.53**	**1.25**	**1.01**	**0.71**	**1.62**

9 Months Average	**3.15**
9 Months Standard Deviation	**1.31**

Minimum Wind Speed	**0.83**
Maximum Wind Speed	**7.00**

4.2. Monthly Wind Speed from "https://www.worldweatheronline.com/mariveles-weather-history/bataan/ph.aspx"

Table 4. Monthly Wind Speed in m/s (July 2023 – March 2024). Source: www.worldweatheronline.com.

	2023 Jul	2023 Aug	2023 Sep	2023 Oct	2023 Nov	2023 Dec	2024 Jan	2024 Feb	2024 Mar
Wind Speed (m/s)	1.67	6.95	1.39	3.61	4.17	10.29	4.17	5.00	7.23
	1.67	7.51	0.56	2.78	4.17	9.73	4.17	4.73	6.95
	1.95	7.23	1.11	3.61	4.17	9.73	4.73	5.00	6.95
	3.06	7.23	2.50	4.17	4.17	8.90	4.17	5.28	8.34
	4.73	7.51	6.12	3.89	3.89	8.34	3.89	5.00	9.73
	4.45	7.23	3.61	1.67	3.06	8.62	3.34	6.12	8.34
	4.73	5.28	1.67	1.39	3.34	7.51	0.83	6.39	6.95
	3.61	5.00	2.78	2.22	3.89	7.51	3.89	5.56	6.67
	3.34	6.67	1.95	3.89	3.89	6.67	3.89	5.28	6.39
	5.28	6.67	2.50	3.89	4.17	6.39	4.45	5.00	6.67
	6.95	4.73	0.56	3.61	4.73	6.39	4.45	5.28	6.95
	8.34	5.84	1.67	4.17	4.73	6.67	5.28	5.84	6.67
	8.34	5.84	3.06	4.17	4.45	7.51	4.73	5.28	4.73
	8.62	6.95	5.00	3.34	4.73	8.06	5.28	6.39	4.73
	8.34	6.12	4.17	2.78	8.62	6.67	5.84	6.12	5.28
	6.67	4.17	4.73	2.50	5.56	6.12	5.84	5.00	3.89
	3.34	3.61	2.50	3.34	5.00	5.28	4.17	5.00	3.61
	2.78	3.89	1.39	3.34	4.45	5.56	4.45	4.17	3.89
	2.50	3.34	0.83	4.17	4.45	5.84	4.73	5.28	3.89
	2.78	4.17	1.95	3.34	4.73	5.84	5.00	5.56	3.61
	4.17	6.12	3.61	3.34	5.28	5.56	4.45	4.45	1.95
	5.56	6.39	3.89	1.67	6.12	5.84	4.17	5.00	2.22
	5.00	4.17	3.61	2.50	5.84	5.00	5.00	5.56	3.34
	1.95	3.61	3.34	2.22	6.12	4.17	6.12	6.12	2.22
		3.06	1.67	3.06		5.84	5.00	5.84	4.73
		3.06	1.39	2.50		6.67	6.12	4.17	4.73
		1.95	0.83	3.06		6.95	7.51	4.73	5.00
		3.34	0.83	3.34		8.62	8.06	5.28	6.39
		5.84	3.34	2.22		10.29	7.78	5.28	6.95
		6.12	4.17	2.22		10.56	7.78	4.17	7.51
		3.89	3.61	2.22		10.84	7.23	4.73	7.51
		3.06	3.06	3.61		10.56	7.23	5.56	6.95
Monthly Average Wind Speed (m/s)	**4.58**	**5.20**	**2.61**	**3.06**	**4.74**	**7.45**	**5.12**	**5.26**	**5.66**
Monthly Variance	**5.15**	**2.64**	**2.02**	**0.64**	**1.30**	**3.52**	**2.37**	**0.37**	**3.84**
Monthly Standard Deviation	**2.27**	**1.62**	**1.42**	**0.80**	**1.14**	**1.88**	**1.54**	**0.60**	**1.96**

Nine Months Average	**4.86**
Nine Months Standard Deviation	**2.05**

Minimum Wind Speed	**0.56**
Maximum Wind Speed	**10.84**

Table 5. HAWT Computed Output Power for a specific Wind Speed

Air Density	Wind Speed	Sweep Area	Available Wind Power	Assumed Turbine Efficiency	Output Power
ρ	V	A	P_{WIND}	μ	$P_{OUTPUT} = \mu \cdot (P_{WIND})$
kg/m³	m/s	m²	Watts		Watts
1.225	1.000	3.326	**2.037**	0.350	**0.713**
1.225	2.000	3.326	**16.299**	0.350	**5.705**
1.225	3.000	3.326	**55.009**	0.350	**19.253**
1.225	4.000	3.326	**130.393**	0.350	**45.638**
1.225	5.000	3.326	**254.674**	0.350	**89.136**
1.225	6.000	3.326	**440.076**	0.350	**154.027**
1.225	7.000	3.326	**698.824**	0.350	**244.589**

4.3. Output Power Computation for Horizontal Axis and Vertical Axis Wind Turbines

The formula below is used to compute the power from a wind turbine.

$$P = C_p\, 1/2\, \rho A V^3$$

where:

– P = Power output, watts

– C_p = Maximum power coefficient, ranging from 0.25 to 0.45, dimension less (theoretical maximum = 0.59)

– ρ = Air density, kg/m^3

– A = Rotor swept area, m^2 or $\pi D^2 / 4$ (D is the rotor diameter in m, π = 3,1416)

– V = Wind speed, meter per second (m/s)

There are two general categories of wind turbines: horizontal-axis wind turbines (HAWT) and Vertical-axis wind turbines (VAWT). Only one Formula is applied to both types to compute the power output.

The researcher selected different types and models of wind turbines to match the gathered yearly average wind speed to their specifications. The purpose of selecting the models and types was to verify whether there would be a yield of helpful power.

4.3.1. Output Power (Usable Power) of Horizontal Axis Wind Turbine (HAWT)

An A-Wing Wind Turbine model with a maximum output of 1000 Watts and maximum wind speed of 14 meters per second specification was chosen among the products manufactured by "A Wing International Co. Ltd." (http://www.awing-i.com). This model fits the gathered available wind speed. This model was engineered for small wind energy solution having a start-up wind speed from 1 m/s.

Table 5 illustrates the computed output power corresponding to wind speeds from 1 m/s to 7 m/s. The row for a wind speed of 3 m/s is highlighted, as it represents the average wind speed measured over a nine-month period, resulting in an output power of 19.253 Watts.

4.3.2. Output Power (Usable Power) of Vertical Axis Wind Turbine (VAWT) ETV 2.0

Based on Table 2, the ETV 2.0 VAWT, which has a rated power of 200 Watts, a start-up wind speed of 1 m/s, a sweep area of 0.9 square meter, and a rated wind speed of 10 m/s, was chosen from the selection of products offered by "EnergTrade" (https://www.energtrade.com/vertical-axis-wind-turbine/). This model

Table 6. ETV2.0 VAWT Computed Output Power for a specific Wind Speed

Air Density	Wind Speed	Sweep Area	Available Wind Power	Assumed Turbine Efficiency	Output Power
ρ	V	A	P_{WIND}	μ	$P_{OUTPUT} = \mu \cdot (P_{WIND})$
kg/m³	m/s	m²	Watts		Watts
1.225	1.000	0.900	**0.551**	0.350	**0.193**
1.225	2.000	0.900	**4.410**	0.350	**1.544**
1.225	3.000	0.900	**14.884**	0.350	**5.209**
1.225	4.000	0.900	**35.280**	0.350	**12.348**
1.225	5.000	0.900	**68.906**	0.350	**24.117**
1.225	6.000	0.900	**119.070**	0.350	**41.675**
1.225	7.000	0.900	**189.079**	0.350	**66.178**

Table 7. ETV6.0 VAWT Computed Output Power for a specific Wind Speed

Air Density	Wind Speed	Sweep Area	Available Wind Power	Total Turbine Efficiency	Output Power
ρ	V	A	P_{WIND}	μ	$P_{OUTPUT} = \mu \cdot (P_{WIND})$
kg/m³	m/s	m²	Watts		Watts
1.225	1.000	1.500	**0.919**	0.350	**0.322**
1.225	2.000	1.500	**7.350**	0.350	**2.573**
1.225	3.000	1.500	**24.806**	0.350	**8.682**
1.225	4.000	1.500	**58.800**	0.350	**20.580**
1.225	5.000	1.500	**114.844**	0.350	**40.195**
1.225	6.000	1.500	**198.450**	0.350	**69.458**
1.225	7.000	1.500	**315.131**	0.350	**110.296**

is well-suited to the gathered wind speed data as well.

Table 6 depicts the computed output power corresponding to wind speeds ranging from 1 to 7 m/s. The row denoting a wind speed of 3 m/s is highlighted, as this value represents the mean wind speed recorded over a nine-month period, yielding an output power of 5.209 Watts.

4.3.3. Output Power (Usable Power) of Vertical Axis Wind Turbine (VAWT) ETV 6.0

The ETV 6.0 model, a vertical-axis wind turbine (VAWT) with a rated power of 500 Watts, a start-up wind speed of 1 m/s, a sweep area of 1.5 square meters, and a rated wind speed of 10 m/s, was selected from Table 2. This model, offered by EnergTrade (https://www.energtrade.com/vertical-axis-wind-turbine/), is well-suited to the recorded wind speed data also.

Table 7 shows the computed output power for wind speeds ranging from 1 to 7 m/s. The row corresponding to a wind speed of 3 m/s is highlighted, because this value represents the average wind speed recorded over a nine-month period, producing an output power of 8.682 Watts.

4.4. Result Summary

Tables 5, 6, and 7 present the output power data based on wind speed of 3 m/s for different wind turbine configurations. Specifically, Table 5 displays the output power for the horizontal axis wind turbine (HAWT), while Tables 6 and 7 detail the output power for vertical axis wind turbines (VAWTs). Based on the computed values, the HAWT yields the highest power output.

20 Watts (Rounded Off value from 19 Watts**) Power Output Useful Application in MAAP:**

1. Pathway Lights
2. Office Lights
3. USB Chargers
4. Battery Charging
5. Backup power

When the 20 Watts power is harvested for 10 hours in a day, it will become 200 Watts (collected in 10 hours). The accumulated power must be stored in a battery of 24 Volts and 8.33 AH features.

The computation below shows how the values mentioned in the above paragraph were attained.

At three meter per second wind speed, Power output = approx. 20 Watts

Table 8. Output Power Summary

Model	AWI-E100T	ETV2.0	ETV6.0
Wind Turbine Type	HAWT	VAWT	VAWT
Rotor Diameter (meter)	2.058	0.78	1.00
Sweep Area (square meter)	3.326	0.9	1.5
Nine Months Average Wind Speed (meter per sec)	3	3	3
Available Wind Power (Watts)	55	15	25
Output Power (Watts)	19	5	9

Assumptions:

- Energy is harvested for 10 hrs. in a day for 3 m/s wind speed
- Power will be utilized 10 hrs./day
- Battery storage = 24 V

Using the Power Formula and Ohm's Law:

Power = Voltage X Current

Current = 20 Watts / 24 V

= 0.83 Amperes (A)

Capacity of the battery if used for 10 hrs.:

Battery Capacity = Current × No. of hours

= (0.83 A) × 10 hours

= 8.3 Ampere Hour

= 8.3 AH

Power Output of the Wind Turbine for 10 hours:

(20 Watts) × (10 hours) = 200 WH

5. CONCLUSION

Based on the results of the study, the following conclusions were drawn:

1. The presence of the wind at the rooftop of the Mock Bridge on the IMMAJ campus was surveyed using a handheld anemometer. The wind speed was measured and monitored using this equipment. The data gathered were compared using the historical data from "https://www.worldweatheronline.com/mariveles-weather-history/bataan/ph.aspx" website. A 3 m/s wind speed average was computed based on the actual measurement. The website's historical data obtained a higher yield of an annual average wind speed of 4.86 m/s.
2. Based on the actual measurement of wind speed, which is 3 m/s average wind speed in nine months, available wind power of 55 Watts and power output of almost 20 Watts were obtained using a horizontal axis wind turbine with a Rotor diameter of 2,058 m and a Sweep Area of 3,326 m^2.
3. If the wind energy is harnessed for 10 hours, 200 WH of energy will be obtained. This energy output will be useful to energize low-power loads like pathway lights, office lights, USB chargers, Battery Charging equipment, Backup Power Providers during emergencies and many more.

6. RECOMMENDATIONS

The following are recommended for future enhancement and complete application of the study:

1. It is recommended to perform the Siting on the IMMAJ campus. Project siting encompasses all the activities that precede construction, such as Environmental Impact Assessment (EIA), obstruction to aviation airspace analysis, interference with radar and telecommunications analysis, visual impact assessment, site planning and engineering, logistics planning, grid interconnection, and permitting and licensing. (Guidelines for Wind Resource Energy, Asian Dev. Bank, May 2014)
2. In relation to recommendation no. 1, it is needed to reevaluate the wind speed on the selected site.
3. The road lights from the main Campus going to IMMAJ campus are powered by Solar energy stored in a battery. Solar energy is present only in the daytime; therefore, harnessing free energy in this case is not happening. A small wind turbine can be connected to the road light post and add energy to the battery. This makes a hybrid of solar and wind energy.
4. The useful power output is computed only using one (1) horizontal wind turbine. To multiply the power output, add more wind turbines and consider studying and utilizing other types of turbines, such as Vertical Axis and bladeless turbines.

Conflict of interest: The author declares that no financial or personal interests have influenced the findings of this study. This research was conducted independently, without external funding or institutional affiliations that could introduce bias in assessing wind power potential at MAAP. All methodologies, data collection, and conclusions have been developed with objectivity, ensuring the integrity and reliability of this study.

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