Electric Ferry Ecosystem for Sustainable Inter-Island Transport in Philippines

A Pilot Study

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Abstract—**An electric boat system as a pilot study for the electric ferry was designed and field-tested in Samal Island, Philippines, to verify sustainability for inter-island transport. This pilot study uses 4.5m monohull with a displacement weight of 343kg. During the experiment, two cases were compared: in the first case the boat was powered solely with batteries and in the other case with the aid of photovoltaic (PV) modules. For the first case, 24V electric propulsion was driven by two 12V, 100Ah batteries, which resulted to a navigational range of around 18, 16 and 15 trips with energy consumption of 111.64Wh, 117.19Wh and 123.92Wh respectively. In the second case, the photovoltaic modules were attached on the boat to supplement the PV used while on sail. Results in the second case showed that PV module supplemented energy was about to 13.4%, 26.8% and 38.7% using three different speeds like 3.18, 3.32 and 3.84knots and the navigational range extended to 4km, 1km, and 14.4km respectively. Therefore, the electric boat with the aid of PV module answers the problem in the energy management system that deals with the sustainability of the system in the inter-island transport in Philippines.**

Keywords-batteries; electric propulsion; electric boat; photovoltaic module

I. INTRODUCTION

Energy security, sustainability, pollution, and climate change are some major challenges the world is experiencing today. The conversion of the present transport system is one of the difficult aspects of the renewable transition. Studies show that a 100% renewable transport system will consume 18% less energy. In the transition, the road transport sector will have an expected reduction of 69% of energy but in the shipping sector the consumption would increase by 163% [1]. The 11% of the petroleum used globally is consumed by the maritime sector, so a 100% renewable energy source will be beneficial [3]. Authors in [4] showed that using electric vehicles powered by batteries or by hydrogen and fuel cell resulted in 80% reduction of greenhouse emissions, decreased oil dependency and reduced air pollution. Reinforcing and implementing electric transportation, especially in maritime sector, is not impossible in the face of low specific energy, state of the art, batteries compared to fossil fuels [3].

Mobility electrification is becoming reality, and batteries can be a sustainable solution not only in household and commercial sectors but also in transportation. In the case of islands and isolated communities in Europe, the implementation of electric boats was materialized because of the challenges in the price increase of energy and the demand of renewable energy-efficient sources, which steered a new trend towards ferry electrification. The first fully electric ferry using Li-ion batteries can be found in Europe and became the "ship of the year" in 2014. Another one was built and operated in Sweden, it uses Nickel-Metal-Hydride (Ni-MH) batteries and its operation is expected to reduce CO_2 and NOx emissions by 130 and 1.5tons per year respectively [2]. Another solar powered ferry boat for the rural area of Bangladesh has been retrofitted with a 48V, 500W motor, and 1kW solar panel with 9600VAH battery. The boat is capable of covering 60km distance in one full charge [5]. An eco-friendly electric propulsion boat was developed for public transport in Lake Trasimeno. The development aimed to have zero emissions, the boat is powered by Li-ion batteries that can be charged at any harbor [6].

Moving towards green energy sources in the maritime transportation sector is the solution to the high price of fossil fuels and can reduce water pollution. The use of electric propulsion powered by batteries and renewable energy are efficient and effective solutions to the problem [7]. This study aims to implement an electric ferry ecosystem for inter-island transport in Philippines. Specifically, it aims to verify the suitability of the electric motor. Also to observe the performance of the outboard applied in the existing boat in a real situation, and finally to evaluate the sustainability of the system using the battery source alone and the system with the aid of PV module charging the battery while on voyage.

II. SAMAL ISLAND

A. Geology, Climate, and Hydrology

The island garden city of Samal, is a group of islands in the heart of Davao Gulf and unattached to the mainland of Mindanao Philippines. It is 900m east of Davao City, it stretches over 116km of continuous coastline and covers a total land area of 30,130 hectares. The island is endowed with extensive mountain range at the eastern coast. The city enjoys a mild pleasant climate with no dry or wet season and it is typhoon-free [11]. Samal island is one of the 7,000 tropical islands in Philippines with a large number of soft white coral sand beaches with rustling coconut palms and gently lapping turquoise water [11].

B. Transportation to Samal Island

There are 205 registered sea transportations in Philippines that operate in the area [12]. Routes allowing the communication of the two islands and Davao can be seen in Table I, which shows the perspective route with the distance and the speed of the ferry from Davao to potential destinations for electric ferries [13]. To showcase the feasibility of electric mobility in the area, this study conducted an experiment using a fishing motorboat (banca) with a capacity of four persons. The motorboat was converted with an electric motor without altering the design as shown in Figures 1 and 2.

Fig. 1. Existing boat

Fig. 2. Solar electric boat

TABLE I. POTENTIAL DESTINATIONS

Routes	Distance (m)	Speed (knots)
Davao – Babak	2300	6
Davao – Paradise Beach Resort	900	4.5
Davao – Costa Marina	900	4.5
Davao – Chemas	1000	4.5
Davao – Blue waters	1000	4.5
Davao – Pearl Farm	15000	5
Sta Ana Davao – Talikud	18800	8

III. EXPERIMENTS

A. The Study Area

The converted to electric boat was field tested in Samal Island, particularly in the Rocky beach resort. The electric boat navigated 1.3km from Rocky beach as shown in Figure 3 to verify the sustainability and functionality of the system. During the field-testing, data like the energy used of the electric propeller with the different speed of the motor was gathered. The charge and discharge of the energy source were also monitored to test the sustainability during navigation.

Fig. 3. The navigational range of the electric boat

B. The Existing Boat

The boat used for this study is monohulled and made of marine plywood as shown in Figure 1. The existing boat is driven by a diesel motor, it has a capacity of 4 persons and it is used for fishing. The boat dimensions are shown in Table II.

TABLE II. BOAT DIMENSIONS

Dimension	Length (m)	Weight (kg)	Number
Length overall (LOA)	4.5	-	-
Load waterline (LWL)	3.5	-	-
Empty weight	-	30	-
Displacement weight	--	343	-
No. of persons	-	-	4

The boat dimensions are needed for determining the basic requirements in converting the diesel engine into electric propulsion. Table III shows the estimated electric propulsion needed for navigation and the requirements for inter-island transportation sustainability. Green mobility is very important for reducing the dependency on fossil fuels and carbon gas emissions. Figure 2 shows the converted pilot electric propulsion motorboat that that will traverse 1.3km in the island of Samal. The outboard motor is 11182W and was installed without the design alterations. Two 100Ah batteries and four 100W solar panels were attached to supplement the energy used during navigation.

C. Power Management System

A power management system is used to manage the energy onboard and monitor the exact power through an innovative measuring procedure based on the complete discharge and charge of the battery [6]. The monohulled house contains a battery bank with a battery management system and the outboard motor as shown in Figure 4. The battery is connected in series, so it can cater the 24V outboard motor. The energy of the photovoltaic module is connected to the 50A maximum power point tracking (MPPT) controller to charge the batteries while on voyage. PMS helps monitor the status of the battery in terms of charging and discharging rate while in use as well as it measures the current and the voltage of the system, so it can figure out the energy usage of different navigational speeds.

TABLE III. BOAT, SOLAR PANEL AND BATTERY SPECIFICATIONS

Boat specification		
Water line length	3.5	m
Boat displacement	343	kg
Speed	4.54	knots
Equivalent engine	1.500	Hp
Equivalent engine	1118.2	W
Energy	367.32	Wh
Battery Bank Capacity		
Nominal Voltage	24	V
Days of autonomy	1	Day
Ampere-hour	77.67	Ah
No. of batteries	2	pcs
Solar Panel		
Average daily exposure	4.5	hr
Solar panel	100	W
Wattage per panel	450	Wh
No. of solar panels	3.11	pcs
Daily electricity usage	1397.7	W

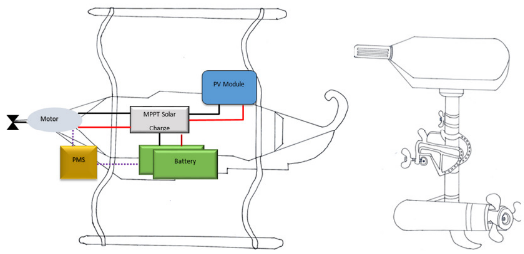

Fig. 4. Electric system and outboard motor diagram

IV. ELECTRIC SYSTEM ENDURANCE

A. PV

PVs systems are commonly known as solar panels, a PV is an interconnected cell that provides electricity for commercial or residential applications and it is extended to the transportation sector. Different cell types have different power efficiency. Monocrystalline cells are made up of monocrystalline silicon and have a single continuous lattice structure with almost no impurities [14]. Furthermore, the main advantage of the monocrystalline cell PVs is their high efficiency, which increased from around 15% [14] to 16%-22% [15]. Polycrystalline panels have efficiency of about 13%-15% [16, 17]. Polycrystalline has a low-concentration photovoltaic system [18]. Moreover, the amorphous silicon solar cell has a 1.1eV-1.3eV bandgap, it has low energy efficiency [19], and gallium arsenide which is modeled as a thin film device with band gap of 1.45eV which shows energy efficiency of 44% [20]. Polycrystalline panels were utilized in this study thought monocrystalline has higher efficiency value, because polycrystalline is much cheaper. Four polycrystalline photovoltaic modules of 100W each are attached to the boat based on the system requirements. Table IV presents the specifications of the solar panels used in this study. Philippines have a large potential in solar energy. But there are days that the solar radiance is not available as shown in Figure 5 [21]. About 5.11 days per month are no-sunny (No-Sun) days, which means that in that case, a utility grid must be used to charge the battery.

TABLE IV. SPECIFICATIONS OF POLYCRYSTALLINE PV

Parameter	Specification
Maximum power	100W
Tolerance	±5%
Maximum operating voltage	17.5V
Maximum operating current	5.71A
Open circuit voltage	21.5V
Short circuit current	6.46A
Irradiance (STC)	1000W/m^2
Weight	3.5kg
Dimensions (L×W)	1000mm×510mm

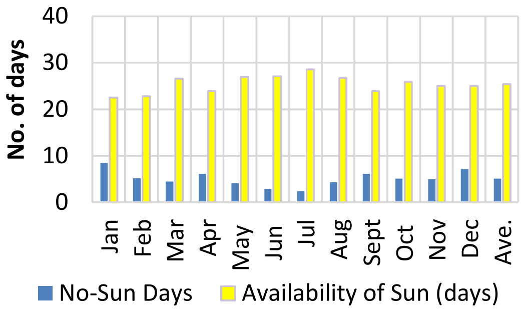

Fig. 5. Solar radiation and No-Sun days

B. MPPT

Maximum power point tracker (MPPT) is a power electronic system that extracts maximum power from the PV system. MPPT varies the electrical operating point of the PV modules and enables them to deliver maximum available power [22]. The PV panels are connected to a MPPT charge controller to improve the charge efficiency of supplying the desired power required by the load [23]. A charge controller protects the battery from overcharging preventing battery power from flowing back into the solar module. The MPPT charge controller used in this study is a 50A charge controller with 12/24V system automatic recognition.

C. Electric Propulsion

Equation (1) shows the formula in sizing electric motor [24]. As a result of our relevant investigation, the system uses an outboard motor with an input voltage of 24V, 48A, with maximum power input of 1152W and weight thrust of 37.2kg as shown in Figure 4. Furthermore, it has a speed controller, five levels of forwarding speed and three level of reverse speed. The outboard motor is mounted at one end of the boat through the metal holder. Energy requirements were taken into consideration. Figure 6 illustrates propulsion power vs speed. The desired power to operate the system is equal to 1118.2W, with a maximum hull speed of 4.54 knots.

$$Hp=\frac{\text{Displacement weight}}{\left({}^{10.665}/_{\text{SL Max}}\right)^3} \quad (1)$$

D. Battery

Two 12V solar deep cycle lead acid batteries were used in this study. The batteries were connected in series to supply the power requirements of the outboard motor. The system needs were 24V and 48A that resulted in 1152W power consumption. The two batteries had a capacity of 100Ah and a total voltage of 24V, so the system could navigate continuously for up to 1.5 hours considering a 75% discharging rate. The battery plays a very important role for the sustainability of the operation. Equations (2) and (3) size up the battery bank needed for the operation [25]:

$$\text{Energy demand=load, kW}\times\text{time, hr} \tag{2}$$

$$\text{Battery capacity} = \frac{\text{Energy demand}}{\text{voltage x 0.7 x0.8}} \text{ x 2} \tag{3}$$

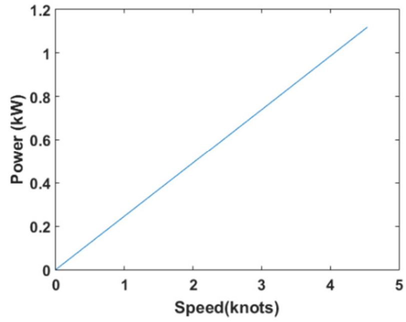

Fig. 6. Speed vs propulsion power

E. Results and discussion

1) Case 1: Electric Boat Powered Solely by a Battery

In this study, the diesel boat was converted by an electric boat powered by two 12V batteries connected in series to supply 24V volts electric propulsion, with a displacement weight of 343kg and with a target navigational range of 1.3km. The experiment evaluates energy used, speed, total navigational range, and battery discharge. In terms of speed evaluation, both time and distance were taken into consideration. Figure 7 shows the energy consumption over the speed of the electric boat. For speed 1 (3.18 knots), the energy consumed was 111.64Wh, while speed 2 (3.32 knots), consumed 117.19Wh of the energy and speed 3 (3.84 knots) consumed 123.92Wh.

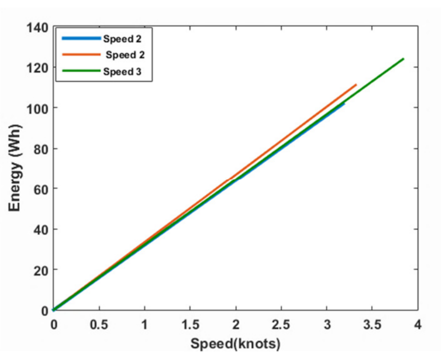

Fig. 7. Energy consumption vs speed

Figure 8 shows the range covered and the equivalent energy needed to reach the desired distance of 1.3km. For speed equal to 3.18 knots, the boat covers 18 trips with a total range of 23.4km and with an equivalent total energy consumption of 1.83kWh. For 3.32 knots, it can cover 16 trips with a total range of 28.8km with an equivalent energy consumption of 1.77kWh and with speed of 3.84 knots it covers 15 trips with 1.85kWh total energy consumption. Figure 9 illustrates the battery capacity discharged over the equivalent number of navigational range or boat trips considering a 1.3km distance. Figure 9 shows that the system can navigate safely, and it is sustainable.

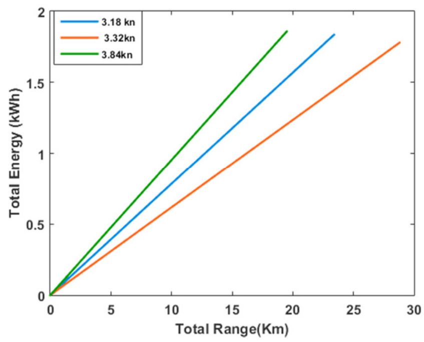

Fig. 8. Energy vs range

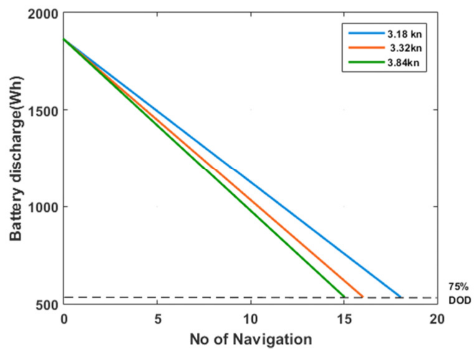

Fig. 9. Battery discharging rate vs number of trips

2) Case 2: Electric Boat Supplemented with Solar Panels

In this case, the existing boat was converted into an electric boat powered by a battery with an energy capacity of 1862.4Wh. Considering a 75% depth of charge it is supplemented with four 100W solar panels. The solar module charges the battery with the MPPT controller during the navigational trips. During the experiment of travelling 1.3km distance, 343kg displacement weight and time traveled were taken into consideration in measuring the supplemented power coming from the photovoltaic module. Figure 10 displays the supplemented energy coming from the PV module while on sail. Results show that 13.4%, 26.8%, and 38.7% decrease is the equivalent energy supplemented by the PV module into the battery while on sail with speed of 3.18, 3.32 and 3.84 knots respectively. The result shows that PV module helps the sustainability of the system for inter-island transportation. This study investigates the range of the electric boat under the presence of PV modules. Figure 11 shows the results of consumed energy with the equivalent navigational range. Figure 12 shows the comparison of the navigational range of the electric boat with a battery source of energy over a battery source with the aid of PV module. The result shows that with the aid of the PV module, the navigation range extended to 4km, 1km and 14.4km using speed of 3.18, 3.32 and 3.84 knots respectively.

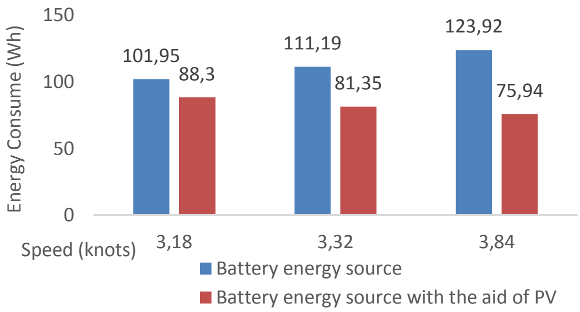

Fig. 10. Comparison of the energy consume supplied solely with battery and with the PV module

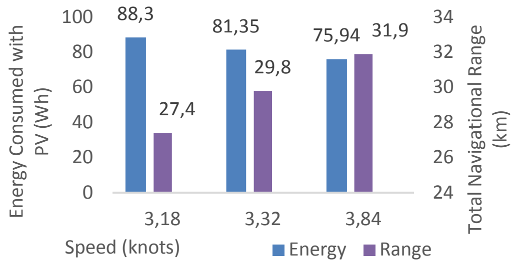

Fig. 11. Energy vs. navigational range with the aid of the PV module

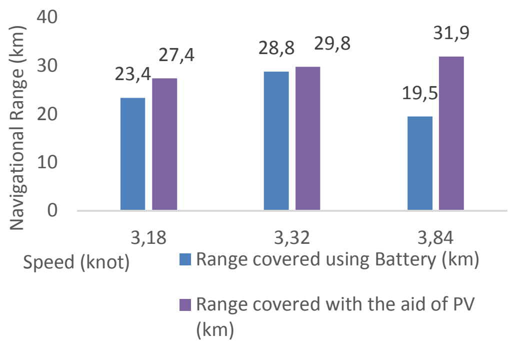

Fig. 12. Comparison of the navigational range with the use of battery alone and with the aid of the PV module.

V. CONCLUSIONS

In this study, two cases were compared for the use of the same boat with a displacement weight of 343kg. During the experiment a 24V outboard motor was used, driven by two 12V, 100Ah batteries which were connected in series. The electric boat would traverse for about 1.3km distance. In the first case, with total energy capacity of the battery equal to 1.8624kWh considering 75% depth of charge, the electric boat could navigate around 18, 16 and 15 trips with an energy consumption of 111.64Wh, 117.19Wh and 123.92Wh respectively using the three different test speeds. In the second case, with the aid of the PV modules, the navigational range extended to 4km, 1km, and 14.4km respectively. The PV module attached to the boat helped replenish the energy consumed by the electric boat for about 13.4%, 26.8% and 38.7% using the three different test speeds of 3.18, 3.32 and 3.84 knots respectively. The electric boat with the aid of PV module answers the problem in the energy management system that deals with the sustainability and safety for inter-island transport in Philippines

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