E-mobility for fishermen on Lake Victoria

Part 1: introduction to the project and preliminary testing

Written by: Federico Aleotti, ENGIE Equatorial

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Introduction

In January 2022, ENGIE Equatorial Ltd. commissioned a hybrid solar mini-grid on Lolwe Island (Lake Victoria, Uganda), ensuring energy access to more than 3800 households and businesses in the local fishing community. ENGIE Equatorial is a joint venture between ENGIE, an international low carbon energy and services company, and Equatorial Power, a mini-grid developer based in Kampala and developing energy access projects across Uganda, Rwanda and DRC.

The Lolwe mini-grid generation unit consists of a 600 kWp solar plant coupled to a 360 kWh rated Li-ion batteries and a diesel generator to ensure high levels of reliability and availability.

Pictures: Lolwe power plant

ENGIE Equatorial's business model is not only based on electricity sales, but also on supporting the development of local value chains and providing multiple complementary services to the local community. For this reason, the company has deployed an agro-processing productive hub with ice machines and fish drying machines for fish processing and preservation, and water purification systems to provide affordable clean drinking water to the inhabitants of the island. In addition, charging stations for electric fishing boats and electric motorcycles have also been installed for e-mobility applications. All these activities are mainly powered by clean renewable energy. Furthermore, the company is also developing comprehensive business incubation and microfinance programmes to support entrepreneurs in setting up new businesses to facilitate the productive use of energy in the local community.


Jibu

Pictures: Lolwe Productive Hub

The e-outboards pilot project

The electric outboards pilot received funding from the PREO programme, which is co-funded by the IKEA Foundation and UK Aid via the Transforming Energy Access platform.

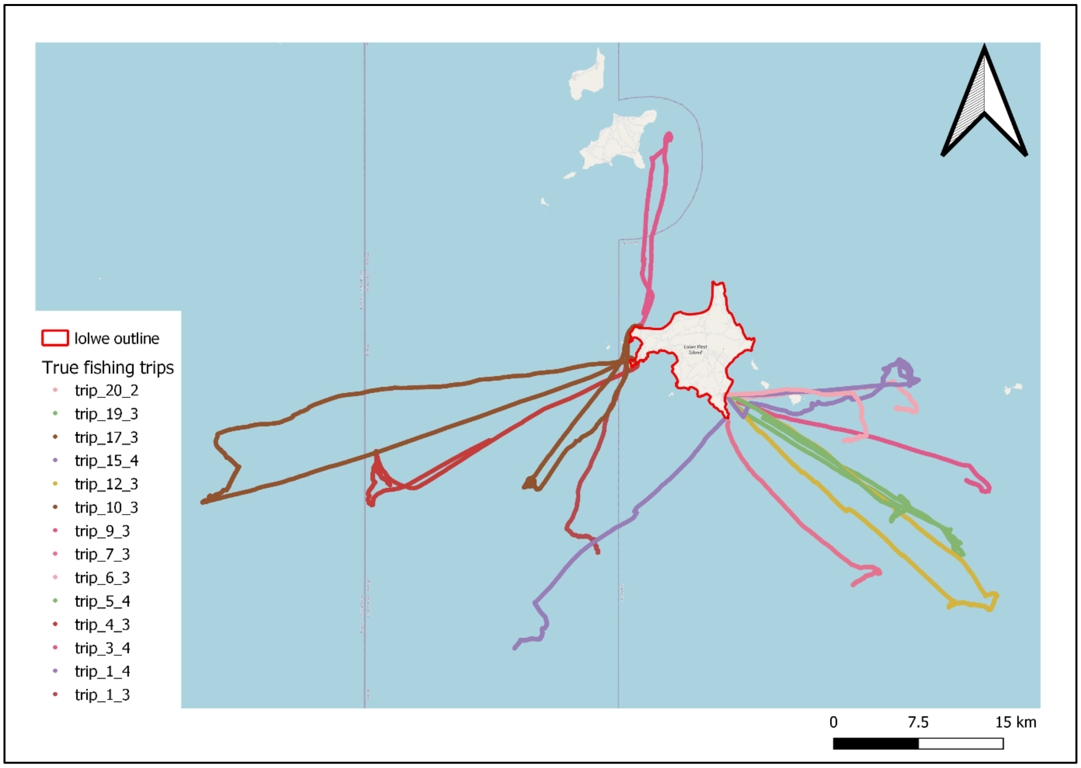
Via this blog, the ENGIE Equatorial team is providing information on the electric outboards (*e-outboards*) pilot for the fishermen community on the island. These articles are aimed at sharing our experiences and lessons-learnt designing and deploying transportation decarbonization technologies with a focus on the technical, environmental, social, economic, and commercial aspects of the systems.

Finally, the data collected will be analysed and the main findings will be published in a peer-reviewed academic publication accessible to the public. ENGIE Equatorial partners with STIMA Lab of the University of Massachusetts (UMASS) Amherst that will provide support on data collection, data analysis and results dissemination. By sharing the experience, ENGIE Equatorial intends to support similar projects and other developers to accelerate the global transition towards a more-sustainable, low-carbon mobility.

Picture: one of the landing sites on Lolwe island

Fishing boats on Lolwe island

In the preliminary phase of the project, interviews and surveys provided data to assess the fishermen needs and evaluate the value proposition of e-mobility. In this phase, complete GPS traces of several fishing trips were recorded, including arrival and departure time, gasoline consumption and fish catch.

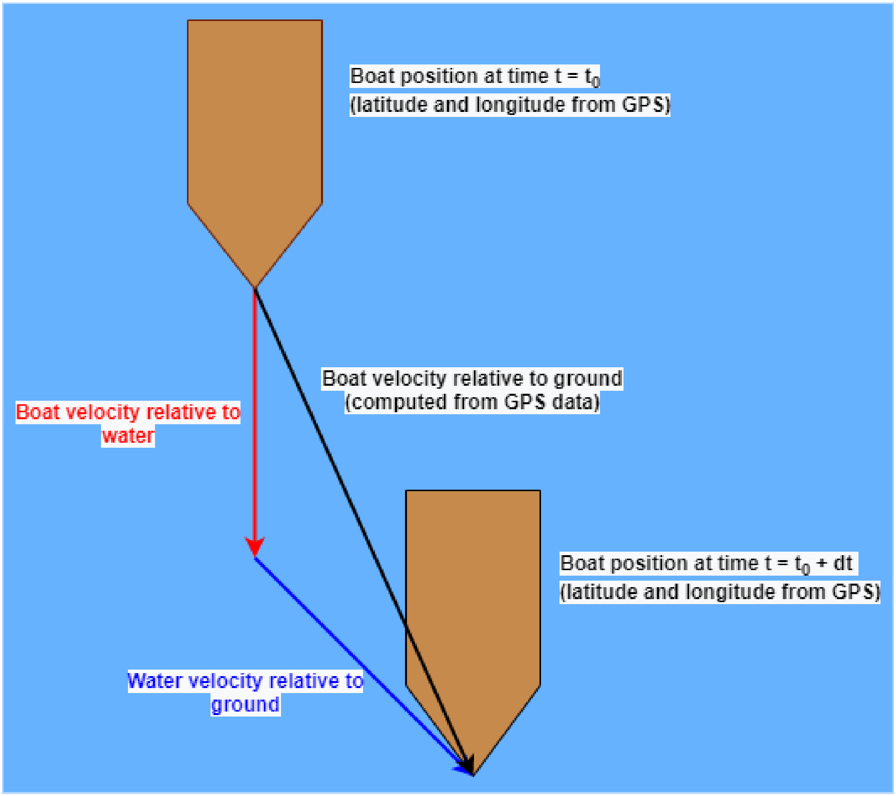


Picture: example of GPS tracking of fishing trips during the preliminary phase of the project

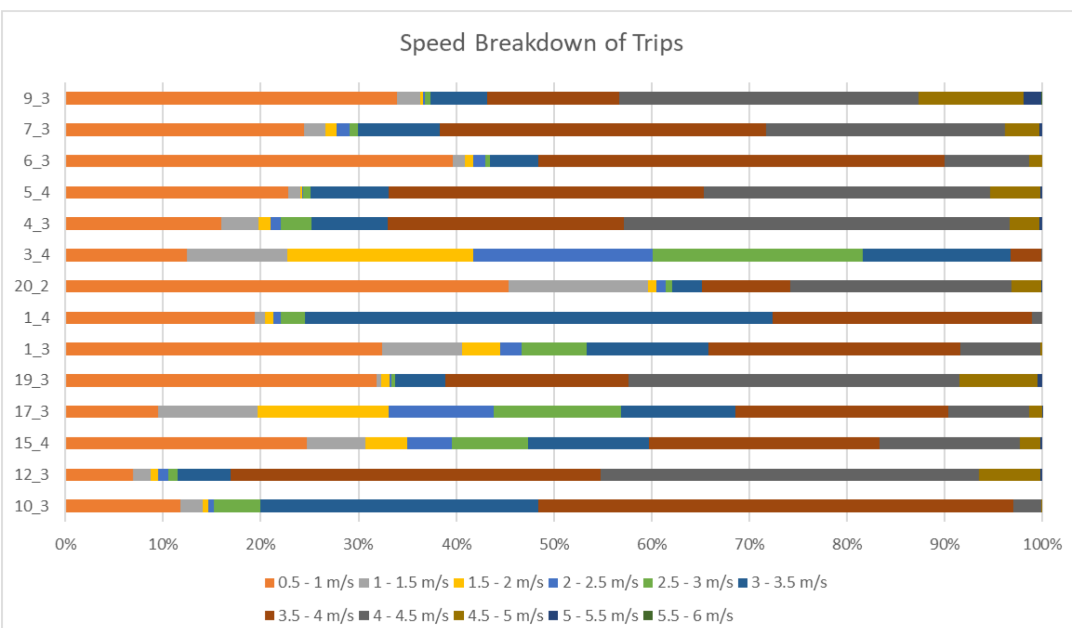
The mean distance of the fishing trips was estimated to be 29.8 km, with a range between 14 to 61 km and with cruise speeds that varies from 10 to 14 km/h (5.3 to 7.5 knots).

The speed values reported in this analysis refer to the velocity of the boat relative to the ground, which is though influenced by the velocity of water (see [1] for more information). In this analysis, the direction and speed of the lake water with respect to ground was not investigated. As a consequence, the accurate velocity of a boat relative to the water, which is indicative of the instantaneous power consumption of the propelling engine, is assumed to be equal to the boat velocity relative to ground. This assumption can bring to overestimations and underestimations of the actual vessel speed.

Starting from the GPS data, the boat velocity relative to ground is calculated as difference in position over difference in time between two consequent measurements.



Picture: boat velocity relative to ground is the vector sum of the boat velocity relative to water and the water velocity relative to ground



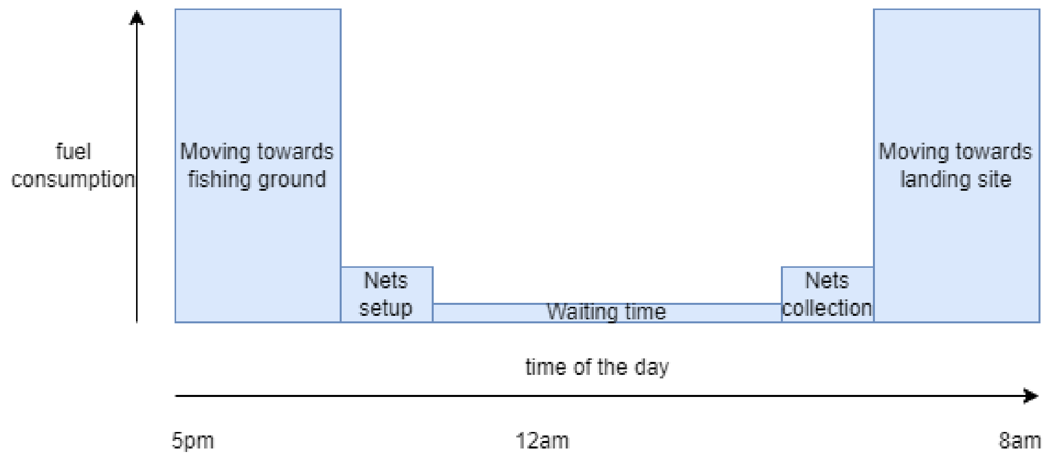
Picture: an example of speed analysis carried out in the preliminary phase of the project

The number of boats on Lolwe island is estimated between 600-1000, depending on the season. Most boats are equipped with two-stroke Internal Combustion Engines (*ICE*) powered by gasoline with rated capacity ranging from 9.9 to 15 HP. The boat length varies between 7 and 10 m, with a total weight estimated to be between 1.2 to 2.1 tons.

Picture: one of the first tests of the e-outboard, on an averaged size boat

Picture: example of existing ICE outboards in a local store

In general, the fishing trip starts in late afternoon and finishes in the morning. For the most time, the boat stays still in the proximity of the nets, and little fuel is consumed to keep boat near the fishing area. The peaks in fuel consumption are during movement from and to the landing sites.



Picture: indicative fuel demand across the night for this type of fishing application

More information can be found in the paper [2] by our project academic partner (STIMA Lab) that led the data collection and analysis.

Sizing and design phase

There are several papers and publications available online that assess the technical feasibility of electrifying small vessels [3] [4] [5]. According to [6], the Hull Speed, which for this type of boat represents the maximum theoretical speed, can be approximated with the following formula:

$$Hull\ Speed = \sqrt{LWL} \cdot 1.34 = \sqrt{31.5\ ft} \cdot 1.34 = 7.5\ knots = 13.7\ km/h$$

This output is generally in line with what was observed from the GPS data.

Different methodologies were investigated for sizing the outboard engine and the battery system with particular focus on the van Oortmerssen method [7]. The results were later validated with different electric outboards manufacturers, who supported in identifying the final system sizing based on their experience.

It was found that an outboard in the range of 3 to 4 kW would be sufficient to provide performances similar to that of an 9.9-15 HP system. For this pilot, we deployed a conservative outboard engine size of 6 kW to include some additional power capacity to operate in adverse water and wind conditions.

Electric outboards selected for the pilot

The e-mobility pilot involves the deployment of 15 e-outboards to replace an equal number of existing ICEs outboards in fishing boats on the island.

After a comprehensive market research, the equipment selected consists of two different e-outboard kits:

- 5 units of *EZ outboard* S10 with tiller, equivalent to a 10 HP ICE, equipped with two 48V-4.6 kWh battery modules from *Bodawerk International* connected in parallel.
- 10 units of *ePropulsion* Navy 6.0, equivalent to a 10 HP ICE, with tiller equipped with one battery module (E175) of 48V-8.96 kWh.

Pictures: from left to right: EZ outboard S10 [8], Bodawerk battery module [9], ePropulsion Navy 6.0 outboard [10], ePropulsion E175 battery module [10]

Picture: the two electric engine types on one of the Lolwe landing site

Picture: the EZoutboard kit mounted on a fishing boat during the preliminary tests

Picture: the ePropulsion kit mounted on a fishing boat during the preliminary tests

Preliminary tests - Introduction

The tests described aimed to assess the 3 different set-ups (EZ, ePropulsion, and ICE outboards) in similar conditions of vessel, weight, weather, route, and speed. A circumnavigation of the

Lolwe island was chosen as standard route, and the tests were conducted in 2 different speed modes:

- Sport Mode: boat propelled to the maximum allowable speed.
- Eco Mode: slightly reducing the speed to save fuel or energy and increase the overall coverable distance.

A total of 6 valid trips were recorded and will be discussed below.

It is important to understand that the purpose of the testing was to gather some valuable insight regarding operation in different conditions, to be able to provide guidelines to the final users, become more aware of the actual value proposition and verify whether the performances meet the expectations.

Preliminary tests – EZ e-outboard and ICE

A first round of tests aimed to compare performances and energy needs of an ICE and an equivalent e-outboard. A few trips around Lolwe island, first with a 10HP ICE and later with the EZ S10 were completed with each trip involving the same boat and similar loads. For this test, the EZ e-outboard was propelled to the maximum allowable speed (Speed Mode).

In Sport Mode, it was observed that the EZ e-outboard kit was able to maintain the maximum speed only for 8 km, after which the speed was reduced considerably, reaching performances equivalent to energy saving mode (Eco Mode). The reason for this behavior seems to be related to a voltage reduction in the battery modules. With the e-outboard being used at its maximum power, the speed kept on reducing coming to a complete halt when voltage reached 43V, which is the bottom admittable threshold for the EZ S10 input voltage. At that point the e-outboard was swapped with the backup ICE outboard to allow complete the trip.

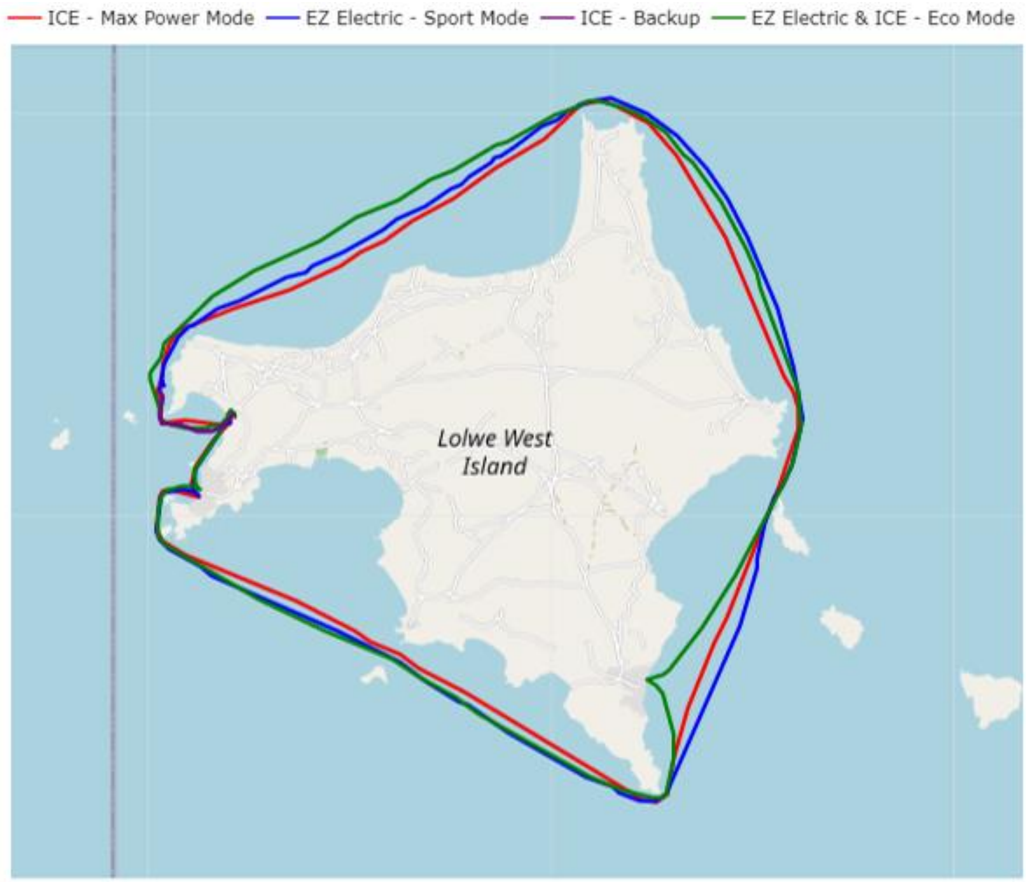
Another similar test was later performed with the same route, but with two boats of similar weight and length; the first vessel was equipped with the EZ e-outboard used in the previous test and the second with a ICE. Both vessels travelled together in close proximity, proceeding at the same cruise speed. This time the electric outboard was set in Eco Mode, which limits the power and the speed to around 8-10 km/h. The boat equipped with ICE followed at same speed rate. It should also be noted that in the last few kilometres the weather conditions got slightly adverse, with presence of waves and wind, imposing a higher power consumption and reduction in cruise speed.

As expected, the energy and fuel consumptions dropped compared to the previous Sport Mode, and the e-outboard successfully completed the trip with 50% of the usable battery capacity remaining (4.6 kWh).

When comparing the cumulative distance over time between the Sport and Eco Modes, it can be observed that the e-outboard presented similar performances in terms of covered distance and duration of the trip but consumed around half of the energy if operated in Eco Mode. From a preliminary assessment, the explanation for this phenomenon is that the high current required to navigate in Sport mode caused a significant drop in voltage supply from the Bodawerk batteries; because of the low voltage supply below the optimal range, the EZ outboard was not able to deliver full power and speed.

For this reason, the e-outboard kit was able to meet the ICE speed performances only for the initial 8 km.

Picture: one of first tests of the electric outboard



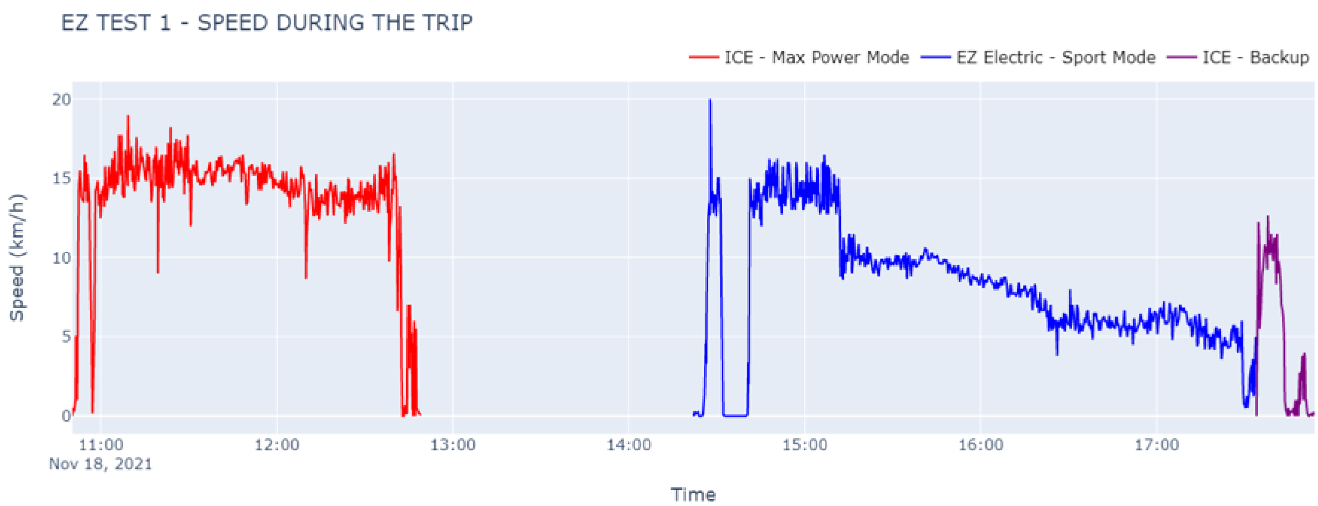


Figure: *the ICE engine in Sport Mode kept an average moving speed of 13.8 km/h. The EZ electric kit in Sport Mode was able to meet comparable speed performances only for the initial 8km, then the started reducing power output and speed to finally shut down. A backup ICE engine was used to complete the trip due to inoperability of the EZ electric kit.*

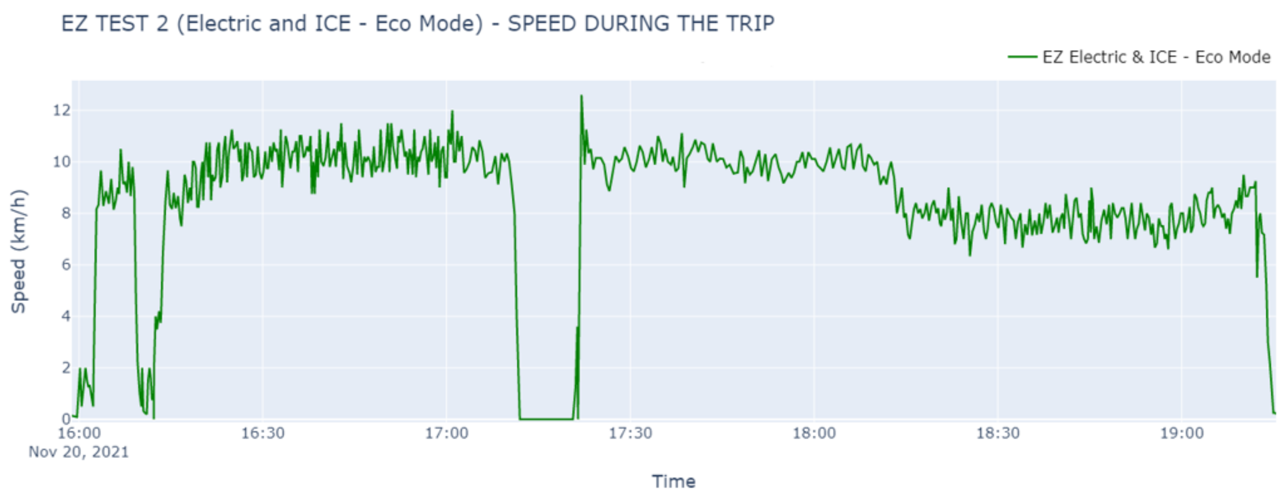


***Figure**: the chart represents the speed of ICE engine and EZ engine running in Eco Mode while proceeding in proximity on 2 separate boats. The outboards kept an average moving speed of 8.5 km/h. This time the EZ kit was able to complete the trip with 50% remaining battery charge.*

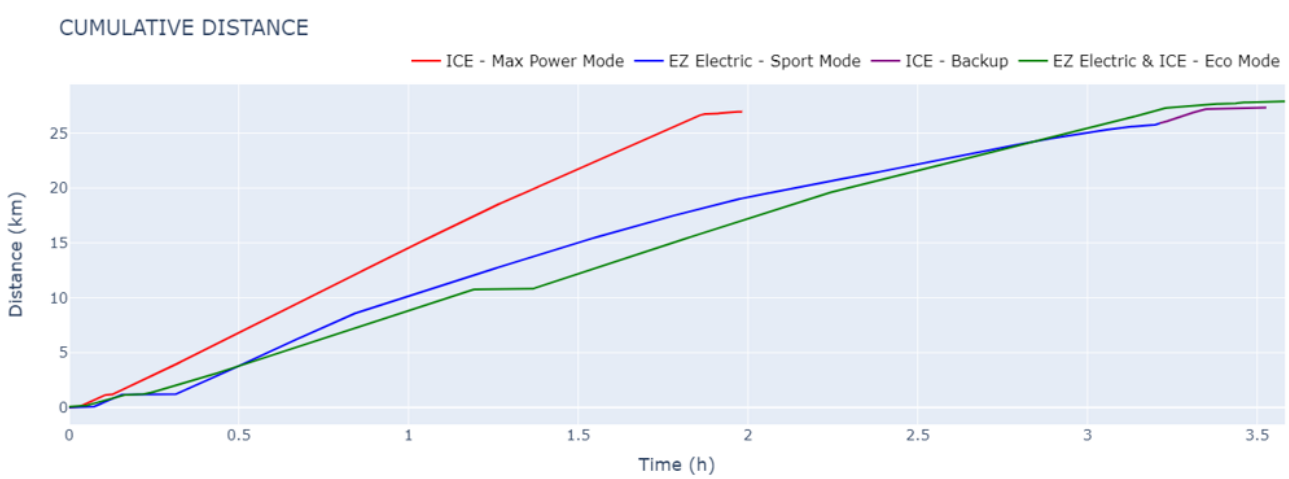


***Figure**: Cumulative distance with respect to starting time, for both Test 1 and 2. The ICE system running at maximum power was able to cover the total distance of 27 km in less than 1 hour.*

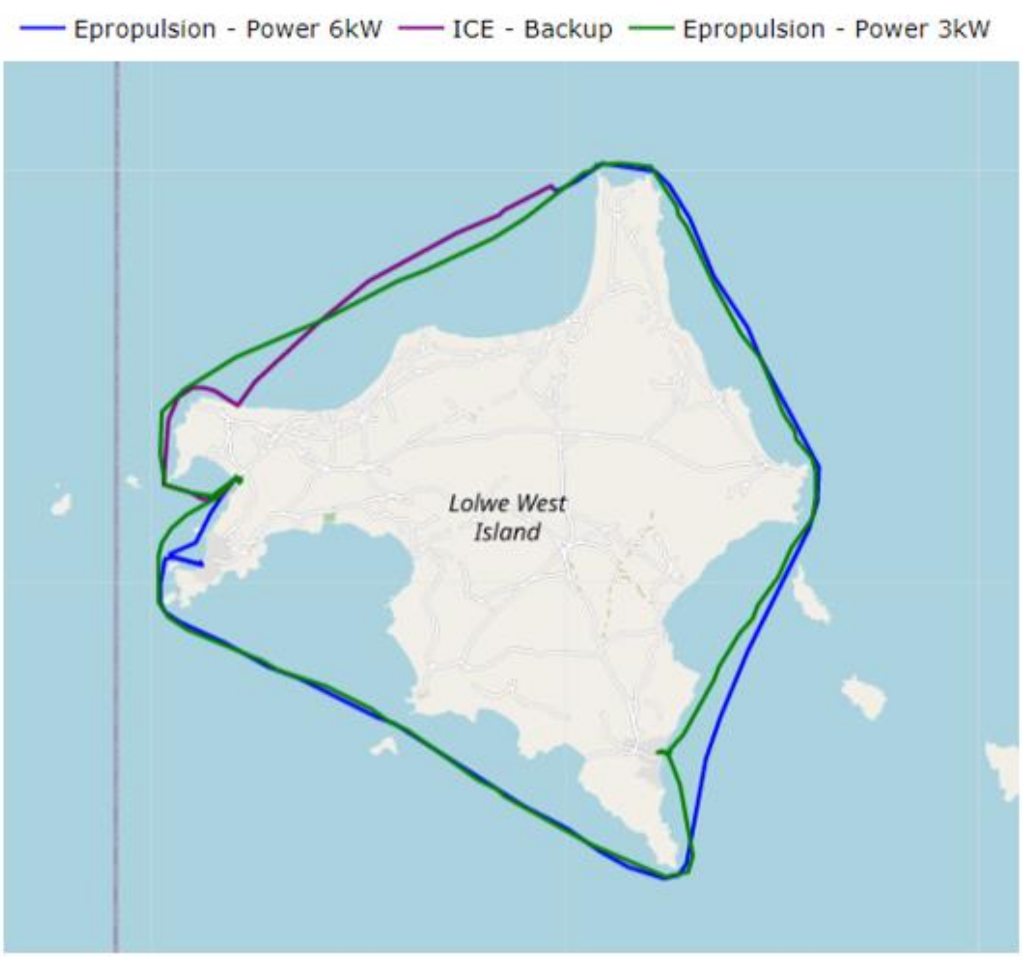
Preliminary tests – ePropulsion e-outboard

Similar tests were performed on the ePropulsion kit. Unfortunately, at the time of the testing, the data collection devices were still being assembled. For this reason, only GPS data was recorded and is used to obtain a preliminary overview on performances, without in-depth overview on system key parameters.

The tests were performed on different days, but with similar weather conditions (clear sky, calm water).

The first test was performed running the e-outboard at full power (6kW, equivalent to Sport Mode), the ePropulsion outboard with a fully charged battery bank was able to meet the ICE outboards speed performances for 20 km (more than twice of what observed with EZ kit), with a maximum value of around 14 km/h. The speed was maintained until the battery was fully discharged. In this case, in fact, the battery voltage remained stable at around 51V along the entire duration of the trip, and then fell drastically when the battery reached a low state of charge. The total distance covered was 20.2 km, when the battery was depleted. As done in the previous case, a backup ICE outboard was used to complete the trip.

For the second test, the ePropulsion outboard was set to 3kW (comparable to Eco Mode, but with higher speed), and was able to cover the entire distance of 27 km, remaining with 29% state of charge.



EPROPULSION TEST 1 - SPEED DURING THE TRIP

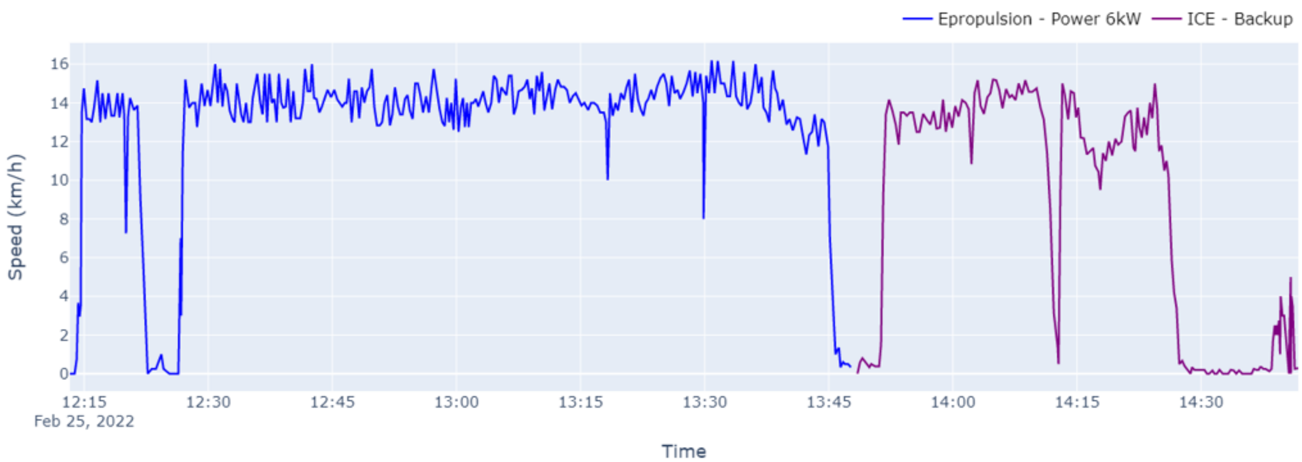


***Figure**: the Epropulsion kit running at full power (or Sport Mode) was able to maintain an average cruise speed of 13.6 km/h, comparable to the performances of the ICE system at maximum capacity. The battery was drained after 20 km and the backup ICE system was needed to complete the trip.*

EPROPULSION TEST 2 (Power 3kW) - SPEED DURING THE TRIP

***Figure**: the Epropulsion kit running at half capacity (Eco Mode) was able to maintain an average cruise speed of 11.6 km/h. Considering the reduced power consumption, the battery bank was able to deliver enough energy to complete the trip.*

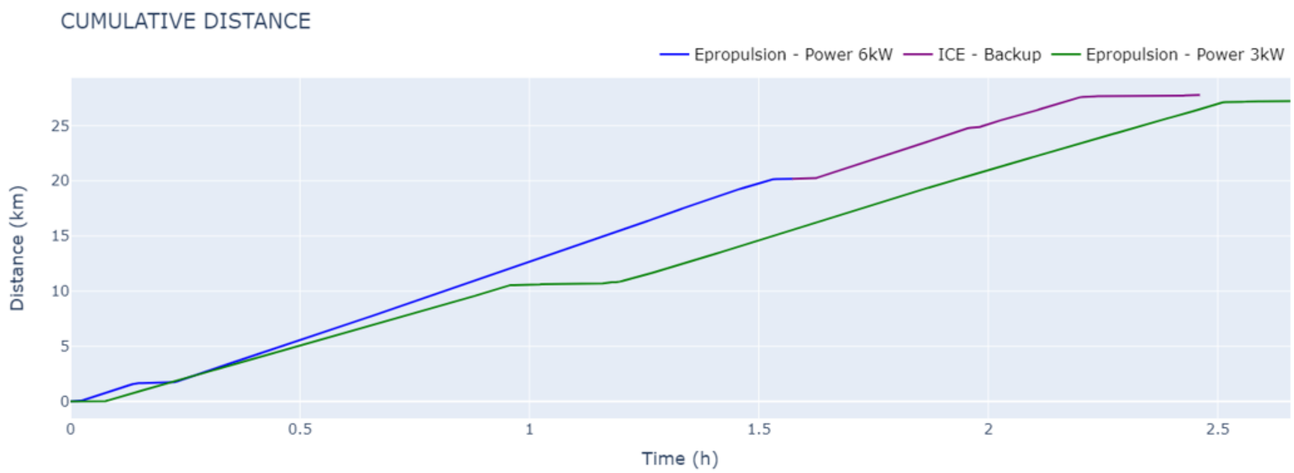


***Figure**: cumulative distance with respect to starting time. In both cases the boats took less than 2.5 hours to complete the trip.*

Preliminary results and findings

The following table reports the main findings of the mentioned tests, in terms of technical performances under the two mentioned speed modes.

SPORT MODE							
Propulsion	Lake conditions	Duration of trip [h]	Average speed in moving time [km/h]	Distance [km]	Gasoline used [kg] (accuracy ± 0.2 kg)	State of Charge upon arrival [%]	Energy consumed [kWh] (estimated accuracy ± 5%)
ICE	Calm	2.0	13.8	26.95	6.2	-	-
Electric – EZ	Calm	3.1	8.8	25.80	-	21 (unusable due to low voltage)	7.3
Electric - ePropulsion	Calm	1.6	13.6	20.19	-	0	8.9

ECO MODE							
Propulsion	Lake conditions	Duration of trip [h]	Average speed in moving time [km/h]	Distance [km]	Gasoline used [kg] (accuracy ± 0.2 kg)	State of Charge upon arrival [%]	Energy consumed [kWh] (estimated accuracy ± 5%)
ICE	Slightly adverse	3.3	8.5	27.90	3.8	-	-
Electric – EZ	Slightly adverse	3.3	8.5	27.90	-	50	4.6
Electric - ePropulsion	Calm	2.6	11.6	27.15	-	29	6.3

In general, it was observed that the power demand and the speed have a non-linear relationship, close to an exponential correlation (which has been already vastly documented in several other studies, for instance [11] [12] [4]). This means that, approaching the hull speed, slight increments in speed require increasingly higher amount of power, reducing the overall distance the boat can cover with a certain amount of energy or fuel. This fact seems to be well known also within the Lolwe fishermen community, as some of them usually choose to slightly reduce cruise speed to save fuel.

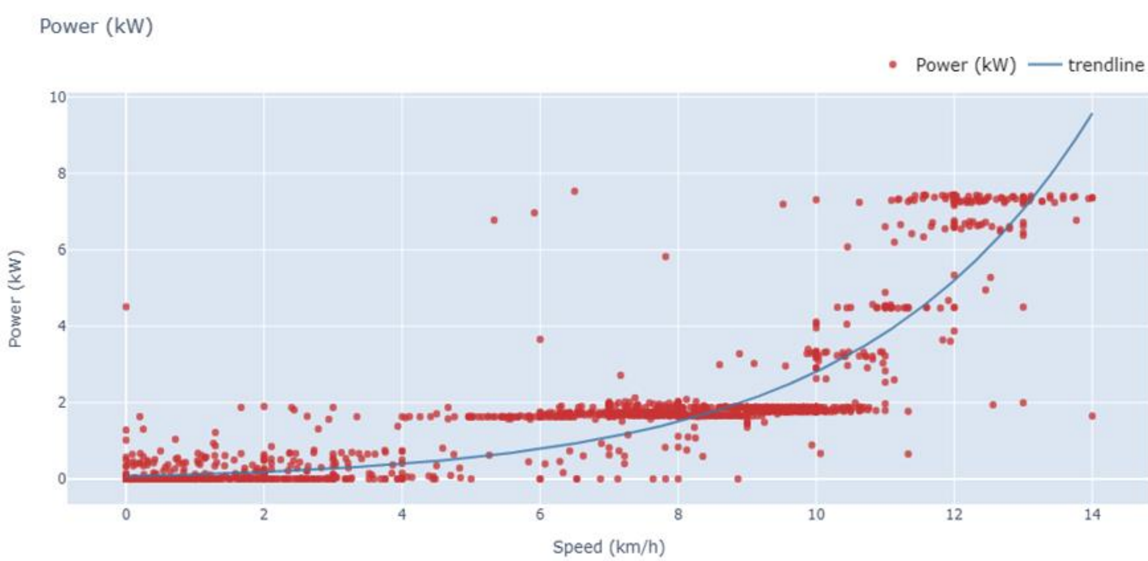


Figure: preliminary power-to-speed chart with cleaned datapoints available from the EZ outboard kit. The slope of the curve increases when moving towards the hull speed (around 13.7 km/h for this type of boat), meaning that increasingly higher amount of propelling power is needed to produce an increment of the vessel's speed.

More research on the optimum speed to be used will be the focus of testing in the next months.

Regarding the fuel demand, the tests showed that, when passing from Sport Mode to Eco Mode, the ICE outboard saves around 41% of the fuel while reducing the speed by 38%. This result does not match the expectations and the trends of the power-to-speed trends proposed above and observed in literature. However, it is important to notice that the data and measurement used for the calculation might be the source of the discrepancies, and further investigations shall be made.

On the contrary, the tests of the ePropulsion showed that reducing the cruise speed by a 15% would result in energy saving to around 50%, meaning doubling the coverable distance.

Propulsion	Speed Mode	Energy demand	Max distance with full battery cycle
		[kWh/km]	km
Electric – EZ	Sport Mode	0.283	25.7
	Eco Mode	0.165	44.1
Electric – ePropulsion	Sport Mode	0.441	20.3
	Eco Mode	0.232	38.6

Propulsion: gasoline ICE	Fuel consumption		Yearly fuel consumption
	kg/km	lts/km	lts/year/boat
Sport Mode	0.230	0.308	1650
Eco Mode	0.136	0.182	977

When investigating the impact of converting the propulsion from gasoline to electric, assuming an average distance of 29.8 km per trip and 15 fishing trips per month, **the amount of gasoline saved per year per boat would be between 977 and 1,650 litres per year** according to speed regime, assuming a gasoline density of 0.748 kgs/lt.

In the incoming months a consistent data collection on the 15 boats will be performed to validate these preliminary results and provide deeper insight in performances and the feasibility of electric mobility for fishermen on the island.

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