Economics of ADITYA – India's First Solar Ferry

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1. Executive Summary

In this article, Total Cost of Ownership (TCO) of ADITYA is compared with that of diesel ferry and it is established that solar ferry is economically better than diesel ferry not to mention that environmentally it wins hands down. The story of ADITYA, its particulars, and methodology of tracking the various costs that is used to arrive at this conclusion is explained.

2. Story of ADITYA

The State Water Transport Department (SWTD) of Kerala (https://www.swtd.kerala.gov.in/) operates about 100 ferry boats of different sizes from 75 to 100 passengers all over the state. They were all single hulled boats, either made of wood or steel, and powered by diesel engine. Around 2013, they were facing a big issue.

Although air and water pollution is a significant environmental problem, that was not the pressing issue. The noise and vibration from diesel engine that make the ride tiring for passengers and crew, although important, was not the prime issue. It was also not the smell of fuel that make the ride uncomfortable. The biggest issue they faced at that time was the high operating cost that made the boats unsustainable.

A typical ferry boat operating across the backwater in Vaikom-Thavanakkadavu sector, a distance of 2.8 km, with ticket price of only 4₹ for the journey, generates about 5,000₹ daily in revenue. However just its energy cost for 100 litres of diesel was higher than this figure (about 6,041₹). The direct cost of energy and maintenance is 6,645 ₹/day. Along with indirect costs of the crew and overheads of approximately 3,000 per day, the OPEX was 9,645 ₹/day.

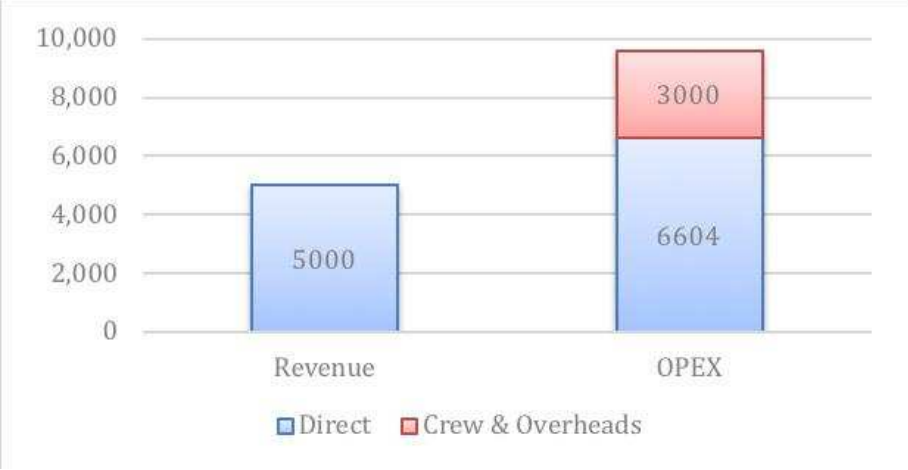


Chart 2.(i). Revenue versus OPEX of diesel ferry

This means that every day the boat ran, the department lost about 4,645₹ considering only OPEX. In this context, SWTD was looking for a solution using solar energy to solve this problem. Once CUSAT (Cochin University of Science and Technology) team led by Dr. Dileep Krishnan submitted the feasibility study for solar ferry in this route , the challenge to solve this problem using solar ferry was thrown to public in form of a government tender. We (www.navaltboats.com) accepted the challenge to design and build this boat, based on our experience and expertise.

When we did that, many people in the industry and academia expressed opinion that solar ferry operating 75 passengers was nearly impossible.

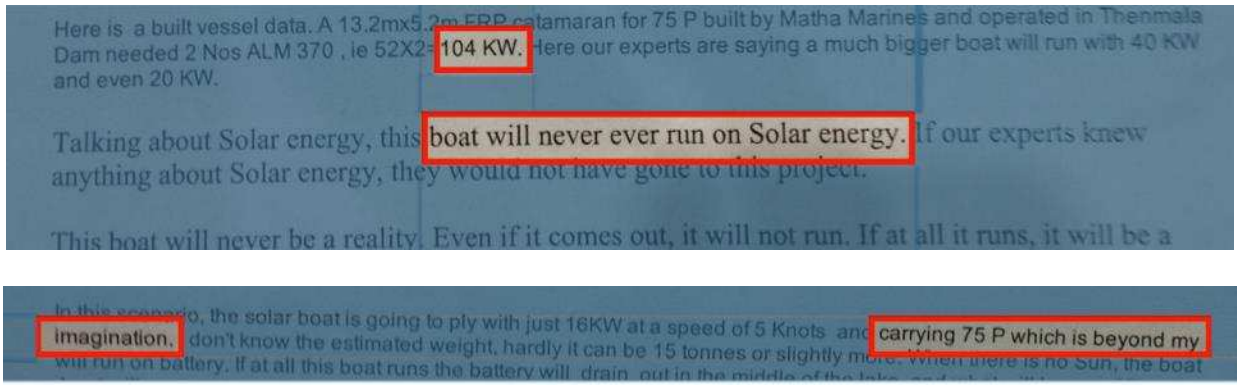


Image 2.(ii). Extract from comments by experts

It is not surprising that such a view was expressed, since existing ferry boats are heavy and with high drag, hence these cannot be retrofitted with solar-electric propulsion. Three things were needed to make solar ferry work. Firstly, the weight of the boat needed to be around 17 tonnes compared to 35 tonnes for typical diesel ferries. Secondly, along with weight reduction, the underwater shape was needed to be optimised to reduce the drag significantly so that just 20 kW motor power is needed instead of 60 kW for diesel ferries to run at 6 knots with 75 people onboard. Thirdly, the power train, consisting of lithium batteries, controllers, motors need to be rugged, reliable and marine grade.

After a year of design, six months of mould making, fifteen months of construction and three months of tests, a total of three years, ADITYA, India's first solar ferry, was inaugurated on 12th January, 2017 (http://bwdisrupt.businessworld.in/article/NavAlt-Launches-ADITYA-and-Gives-India-its-First-Solar-Ferry-/15-02-2017-113019/). It was done by Union Minister of Power, Sri. Piyush Goyal and Chief Minister of Kerala, Sri. Pinarayi Vijayan. In the first year of operation, ADITYA transported 365,000 people across backwaters, and travelled 22,500 km without a single drop of fuel thereby saving 34,800 litres of diesel. This eliminated 92.8 tonnes of carbon-di-oxide and 8 tonnes of harmful emissions.

Image 2.(iii). ADITYA along with diesel ferry at Vaikom jetty

3. About ADITYA

ADITYA is a catamaran ferry boat with GRP (Glass Reinforced Plastic also known as FRP (Fibre Reinforced Plastic)) hull and aluminium superstructure build under IR class (Indian Register of Shipping, a member of International Association of Classification Societies. http://www.irclass.org). The vessel particulars are as follows:

Length overall	20.0 m	
Breadth	7.0 m	
Breadth, demi hull	1.5 m	
Depth	1.6 m	
Draft	0.8 m	
Complement	75 passenger + 3 crew	
Maximum Speed	7.5 knots (14 km/hr)	
Solar panel	Main system	18 kW (poly-crystalline)
	Auxiliary system	2 kW (poly-crystalline)
Batteries	Main system	2 x 25 kWh (lithium-ion-phosphate)
	Auxiliary system	2 x 5 kWh (lead-acid)
Motors	AC induction	2 x 20 kW (asynchronous)
Shore charging	2 x 6 kW (32 A three phase connection)	

The boat has two energy and power train – from solar array, charge controller, battery bank, motor controller, motor, thrust bearing, stern gear, propeller. These are electrically isolated so that an issue in one system does not affect the other. Apart from this each motor is overpowered by 100% so that there is excess power available in need of emergency, high water current, or strong wind. ADITYA operates at service speed of 6 knots, however it can go at 7.5 knots at maximum power under fully load.

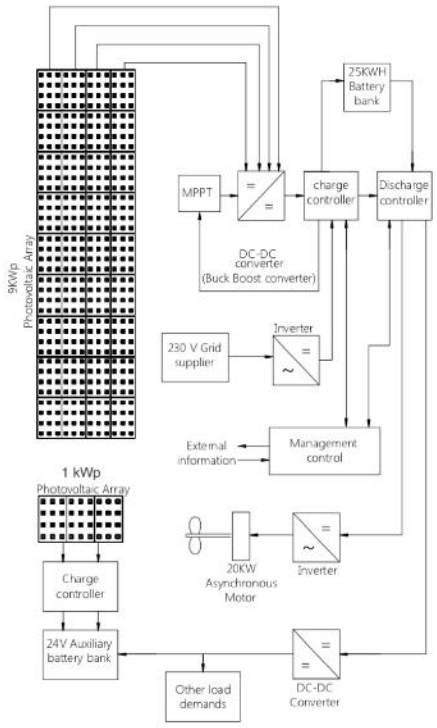


Image 3.(i). System diagram of one side

The battery system meets very high standards of safety, which is essential for public transportation. The battery is approved by DNV-GL as per DNVGL-CP-0418 and DNVGL-CG-0339. It is tested as per IEC 62133:2012 standards. The battery meets IP56 ingress protection and the ventilation system is designed for lifecycle at operating temperature higher than 30 degrees by monitoring charge and air cooling by PLC (Programmable Logic Controller).

The boat has three levels of safety, assigned as N1, N2, and N3. These are parameters in motor, battery and other critical systems in the boat. N1 indicates the level which are just information that do not need any action but indicates that we are approaching level N2. The next level indicates the state which triggers automatic slowdown of motors or some action. The final level, N3, is when the system is shutdown to protect critical equipment.

ADITYA, being catamaran, has high margin of stability. It meets all stability criteria for inland vessels even when overloaded with 200 passengers. In addition the boat satisfies damage stability requirements for single compartment damage. There are submerged bilge pumps installed in all water-tight compartments (ten of them) which will automatically start pumping out water when there is an ingress.

The boat is remotely monitored to ensure high safety and reliability. Apart from monitoring all the parameters necessary to check performance using automatic log (see 4.2), other critical parts like battery is monitored on cell level. Even trouble shooting can be done remotely.

ADITYA operates across the backwaters from morning 7 AM to evening 7 PM and takes twenty two trips daily. Each trip is about 2.8 km ride and takes 13-15 minutes depending on speed, which is around 6 knots. There are three diesel ferries operating in the same route. The boat spends about 5-7 minutes in a jetty for passenger embarkation and there are three longer breaks for tea and lunch for the crew.

4. Process

4.1. Manual log

A log book is maintained by the crew to note down all the important parameters for every trip. Some parameters are taken at the beginning and end of the trip. For eg. battery SOC (State of Charge), motor temperature, battery temperature. Some other parameters are taken at the midpoint of the journey during steady course, like solar

production, motor consumption, motor RPM and boat speed. At the end of the day battery SOC is noted before shore charging is connected and after completion it is ensured that battery is fully charged.

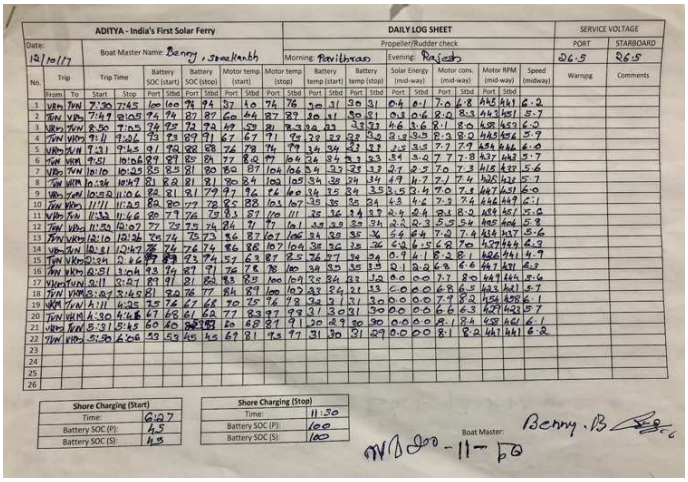


Image 4.(i). Manual log sample

Each operating day is one page in the log book and in the first year it has 347 pages of operating data.

4.2. Automatic log

ADITYA has the one of best features among inland ferries i.e., automatic data transfer to the cloud server. About one hundred forty parameters in the boat are monitored in the central computer of the boat. Every minute this data is transferred to the cloud server using internet present in the boat. The energy curve, 4.(iv), is made using the automatic data.

4.3. Grid cost

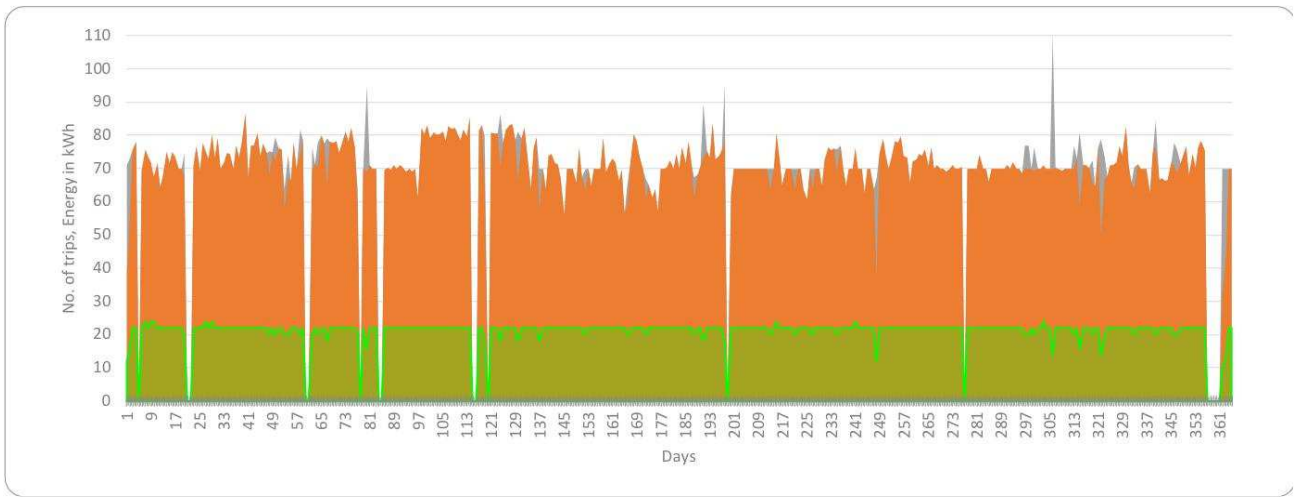
The grid cost was calculated by taking the cost of power from electricity bill of the shore charging facility. Since the power is utilized for jetty and office lighting, the amount of power consumed is taken from the energy meter in the boat. This is about 61% of the total consumption. A total of 13,030 units was consumed in the boat jetty of which 7,969 units was used by the boat (61%). At 7.81 ₹/unit, this comes to total energy cost of ₹62,235 for the whole year.

4.4. Diesel cost

The diesel cost has been rising since Jan 2017, following the global crude oil rise. The average cost of diesel for the first year of operation is 60.41 ₹/litre *(source:* https://www.mypetrolprice.com/*)*.

4.5. Daily Propulsion Energy

The daily consumption by propulsion motor is tracked in the automatic log. The actual consumption, correction for 22 trips, and number of trips is plotted below.

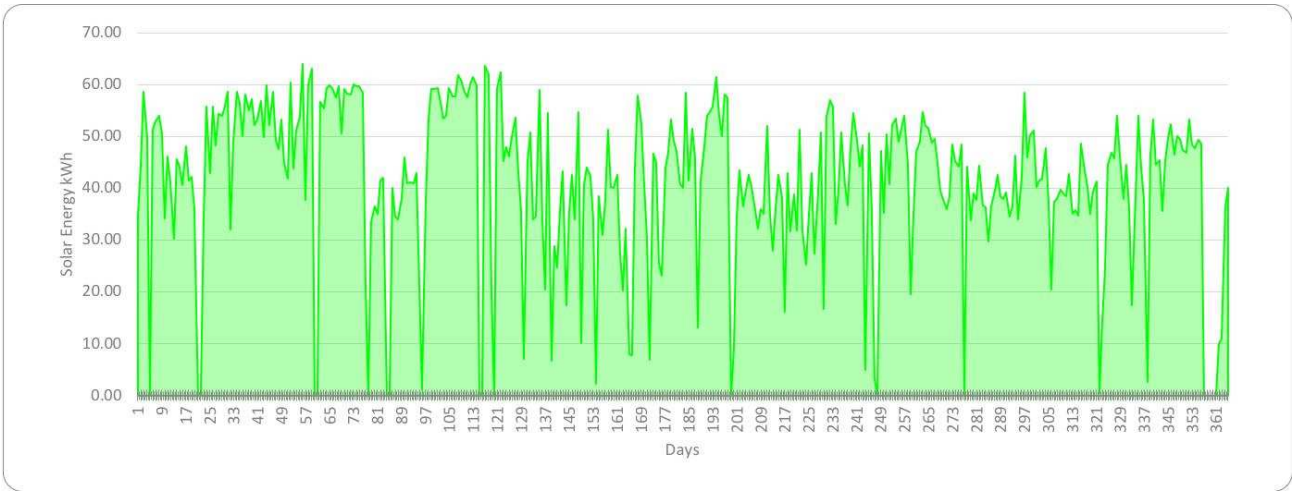


4.(ii). No. of trips and Energy consumption daily

In the first year, for 347 days of operation, the average consumption comes to 71.4 kWh. Once it is adjusted for 22 trips, the average consumption comes to 72.8 kWh per day. The low consumption are days with calm conditions whereas higher are days with adverse weather – current, wind, and waves.

4.6. Daily Solar Production

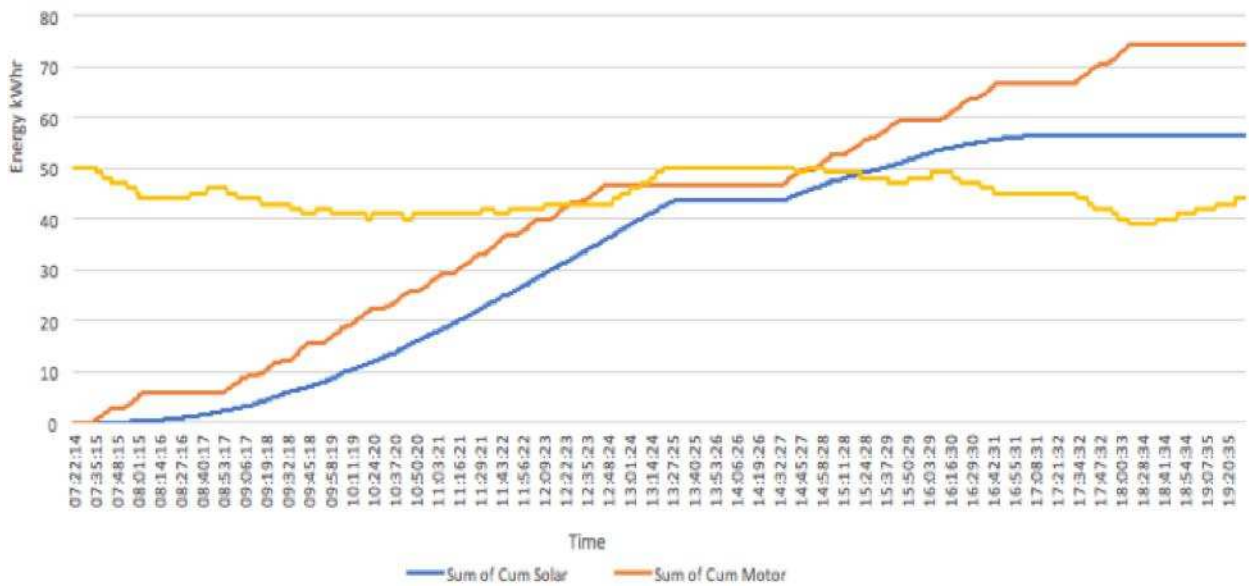
The daily solar power generation is tracked in the automatic log. It varies from extremely low value to maximum of 66 kWh.



4.(iii). Solar production daily

The average daily solar production in the propulsion array (18 kW) is 42.8 kWh for the whole year. This include the three months of monsoon (Jun-Aug) where the average drops to 38 kWh. For an 18 kW system, the energy produced is lower than expected, around 60 kWh. This is because by the mid part of the lunch break on most days, the battery is full and in the second part of the break there is no space to store the energy from the sun at its peak power. This can be solved with a larger battery bank, say 80 kWh. There were few days with practically not much sun which mostly occurred during monsoon.

The boat needs about 70 units (kWh) of energy for propulsion to perform 22 trips in the day. The below chart shows energy curve of the boat on a typical day. From a 50 kWh, 100% battery SOC (yellow) based on consumption by motor (orange) and production from sun (blue), the battery SOC goes down during the break, however, it once again reached full charge by midpoint of the lunch break.



4.(iv). Energy curve

4.7. Daily Battery SOC and Grid

The battery size for ADITYA is designed for average sunny day. Hence in most days there is no need to charge the battery from shore during daytime. In the below chart, there are two SOC – observed and real. The observed is the

reading in the display in the boat which computes the percentage leaving 10% as reserve. So the real SOC is slightly more.

Real SOC = (Observed SOC x 45+ 5)/50

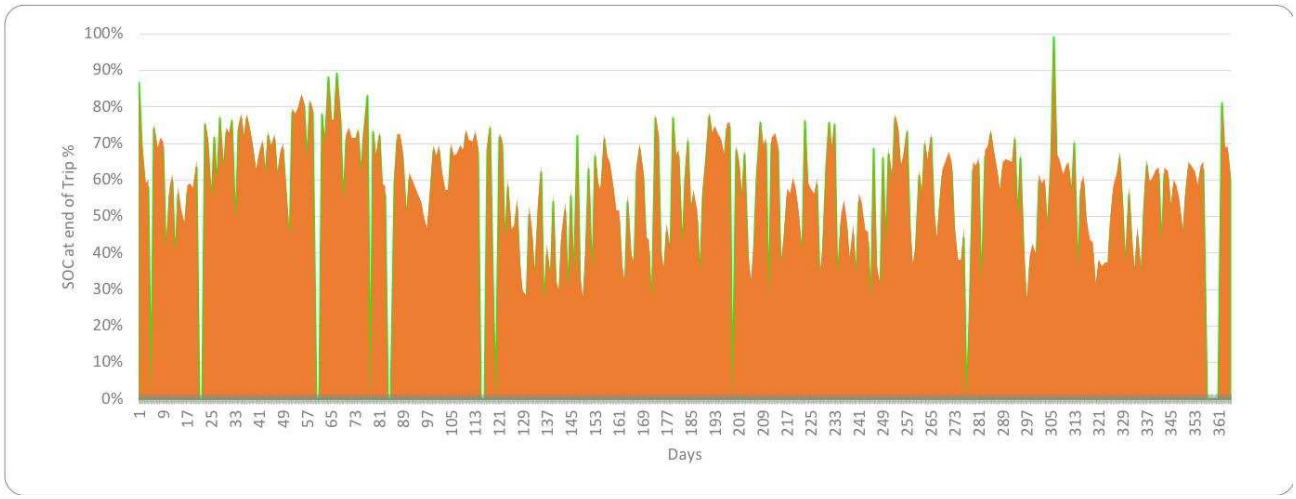


Chart 4.(v) – Observed and Real SOC

The lithium batteries are designed to go to SOC of 20%. If one sees the state of charge in the one year period, the average is 58%. This means that the battery will last longer, over seven years.

At the end of each day operation, the batteries are charged to 100% using grid power. This is the energy cost of the solar ferry. From Table 4.1, we have got the energy cost as 7.81 ₹/unit. Hence the daily cost of energy can be plotted. During the monsoon period from June to October the grid consumption is high.

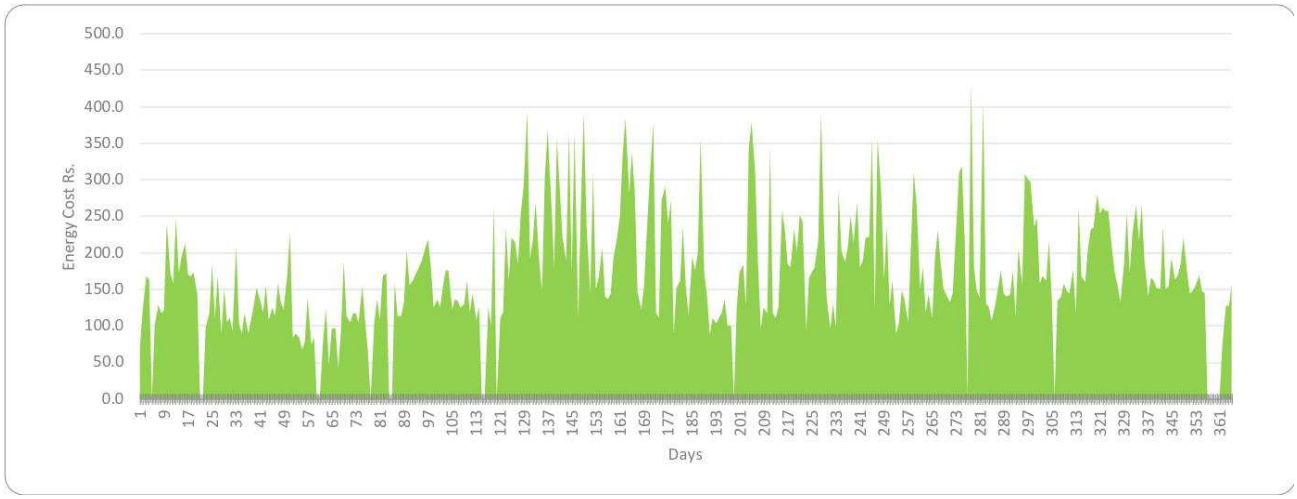


Chart 4.(vi) – Energy Cost

The spread of the grid energy consumption range from very low to ₹428 and the average for the whole year is ₹179. This is very low compared to ₹6,041. for diesel ferry.

5. Economic

5.1. Framework

When economics of a ferry boat is assessed there are two approaches. The first approach is to assess the total cost and see the returns based on the revenue from passengers. Here the ticket that can be charged and occupancy of the boat becomes important. This approach is used by a private investor in such a project.

The second approach is used by transport departments where the ferry is usually a public service and profitability is not important. Here the operating cost should be covered by revenues from passenger tickets. Also comparison between multiple options can be taken from a cost side. Here the second approach is taken and the total cost of ownership (TCO) is taken for both options.

There are four parts in TCO. They are:

1. CAPEX
2. OPEX
3. Recycling Cost

5.2. CAPEX

This is the initial cost of owning the boat. The cost of ADITYA was ₹1.95 Cr (At 2013 tender price. Five years later, in 2018 such a boat would be 3 Cr.). A diesel ferry with similar capacity (75 passenger), build under IR class (or any other IACS (International Association of Classification Societies) member class) was around ₹1.5 Cr. This is based on adjusting for size and specifications from a similar boat of 100 passenger capacity, build under IR class, awarded to Praga Marine by SWTD for ₹1.9 Cr (2016).

5.3. OPEX

In the total cost of operating the boat, there are three broad cost groups:

i. Energy
ii. Maintenance
iii. Crew and overheads

In the first year the boat operated for 347 days. This was lower because there were six days of motor vehicle strike and three hartals – a total of nine days lost. The other nine days were used for maintenance. We project 350 days operating days going forward.

5.3.(i) Energy cost

A typical ferry boat operating across the backwater in Vaikom-Thavanakkadavu sector, a distance of 2.8 km, charges only 4 rupees for the journey one side. Each trip take about 13-15 minutes (at speed of 10-12 km/hr). If it operates from 7 AM to 7 PM, taking 22 trips, and having sufficient time for passenger embarkation and breaks for crew, it would need about 100 litres of diesel (at 10 litres/hr).

It is the cost of fuel for running the boat and its systems i.e., running both main and auxiliary engines. For a solar ferry, without any fuel onboard, the energy cost is the cost of grid used to charge battery. From Sec. 4.3, for solar ferry, the total energy consumption is 7,969 units and energy cost was ₹62,235. This energy cost is expected to increase at 5% every year with increase in grid cost.

In a diesel ferry, energy cost is the dominant cost. The daily fuel consumption is 100 litres and for diesel price of ₹60.41, the daily energy cost ₹6,041 (at Rs. 60.41 per litre -- average price in Kerala for year 2017). For first year this was ₹21,02,429. The diesel price is also expected to increase at 5% every year.

5.3.(ii) Maintenance cost

These are all the cost to maintain the boat operational. There are three kind of maintenance activity. The first type is exclusively for diesel engines. This include replacement of consumables like lube oil and filters as well as engine overhaul charges – both of which are regularly done every 45 days for diesel ferries. For solar ferry, without any engines, this is not there. On an average the maintenance cost is about 3% for lube oil and 7% for filters and engine overhaul of fuel cost. The total is about ₹604 per day. In the first year this was ₹2,10,243.

The second type is the cost of replacing the battery cells. The propulsion battery has a warranty of five years. However based on the battery discharge level (Sec. 4.7), the replacement cycle for the battery would be seven years. It is important to note that at this time, the storage capacity of the battery is expected to be 80% of the new one, and not that it becomes unusable. The replacement cost of the cells is expected to be ₹25 lakhs at the current price. This would be lower considering the annual reduction in price of lithium cells due to increased adoption of electric vehicles.

The third type is cost of replacing or repairing damaged parts, equipment and cost of maintaining the boat in good condition. It is assumed that this is similar in both boats and hence not considered.

5.3.(iii) Crew and overheads

These are the cost of maintaining the crew as well as the overheads of the head office for boat operation. For these kinds of boats three crew members are needed to operate. Since these are similar in both kinds of boats, this is not considered for comparison.

5.4. Recycling Cost

Most passenger ferries are designed for twenty years. It is not prudent to design ferry systems for longer period since by then a far better technology would have come to enable replacement. At the end of its life, there is a recycling cost, but the residual value of materials and equipment in the boat may be higher than this and hence there might be a net

positive value of the boat. The batteries are recycled by the manufacturer as per the EU guidelines. At the end of its life the recycling cost of the boat is insignificant.

5.5. Finance Cost

To factor the time value of money, the difference in initial cost between the boats is financed and EMI for the same is taken as finance cost for solar ferry. The interest rate is assumed at is at 12% although Kerala government has lower cost. The cost difference of ₹45 lakhs (Sec 5.2) need to be financed. After iteration, we can see that in 36 months (3 years), with an EMI of 1.49 lakhs and annual cost of ₹17.94 lakhs this difference in cost can be repaid. The total finance cost for the ₹45 lakhs is ₹53.81 lakhs. After this period, it is huge savings every year.

5.6. TCO

Summarising the calculation, we can see that in its life cycle of twenty years, the TCO comparison is:

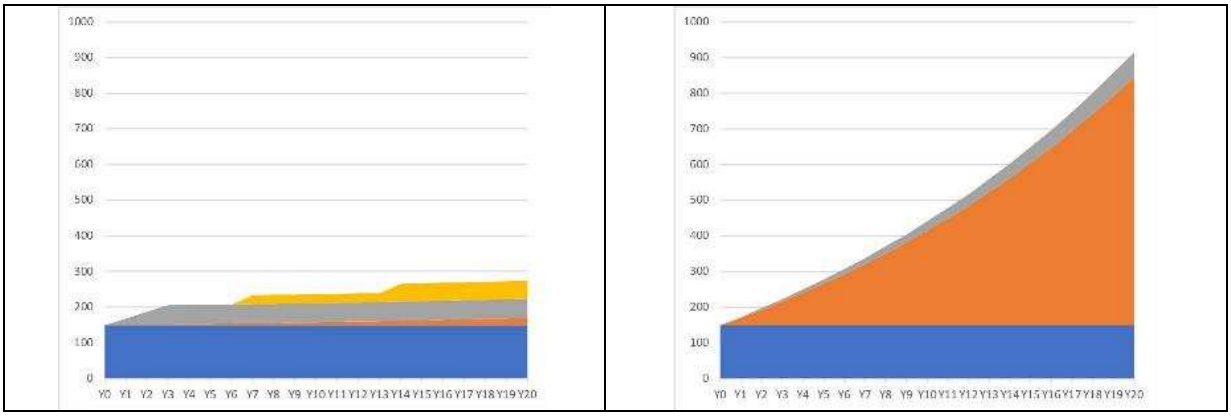


Chart 5.(i) – TCO of Solar ferry (CAPEX, Energy cost, Finance cost, Battery replacement cost) and TCO of Diesel ferry (CAPEX, Energy cost, Maintenance cost) in lakh ₹.

Solar Ferry – ₹274.4 lakhs
Diesel Ferry – ₹914.7 lakhs
The cost of diesel ferry is three times more than the solar ferry.

6. Conclusion

From the above calculations one can easily conclude that ADITYA solar ferry is far more economical than a diesel ferry. It is for this reason SWTD has ordered three more solar ferries for public transport. They have already announced plans to phase out all their diesel boats to solar in the next five years.

References:

- Sandith Thandasherry, *High fives for solar-powered ferry ops, Ship & Boat International,* Jan/Feb 2018

About the author: Mr. Sandith Thandasherry after his B. Tech in Naval Architecture from IIT Madras had done MBA at INSEAD with Elmar Schulte Diversity Scholarship. He is currently the CEO of NavAlt Solar & Electric Boats Pvt Ltd at Kochi, the only firm in India with experience of building large solar passenger ferries. Apart from pure solar with no fuel on board, for applications that needs higher speed, longer range, or heavier cargo they have hybrid solutions. The first tourism double deck ferry, 100 passenger capacity, with air conditioning is under construction and expected to be delivered end of this financial year (2018-19).

New robot can harvest crops in 24 secs, claim researchers

Researchers have developed a harvesting robot 'Sweeper' designed to operate in a single stem row cropping system. Preliminary test results claimed that by using a commercially available modified crop, the robot can harvest ripe fruit in 24 seconds with a success rate of 62%. The team said that additional research is required to increase Sweeper's work speed and success rate.