Techno-Economic Analysis of Photovoltaic Utilization for Lighting and Cooling System of Ferry Ro/Ro Ship 500 GT

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Abstract. The purpose of this study is to perform the techno-economic analysis of photovoltaic system utilization for lighting and cooling of Ferry Ro/Ro 500 GT. The world is facing a dilemma of increasing dependence on fossil energy with decreasing supply. This situation must be anticipated by all sectors by energy efficiency (EE) and utilizing renewable energy (RE). Especially for RE in the transportation sector, ships as consumers of oil energy can also take advantage of solar energy sources, for example for lighting and cooling. For that purpose, five steps must be taken. First, determine the design specifications. Second, determine the specifications of components of the PV system. Third, calculate the power required for lighting equipment. Fourth, calculate the power required for the cooling system. Fifth, make an investment comparison for propulsion systems between diesel engines and photovoltaic systems. The results show that the energy required for lighting and cooling system as well as for propulsion systems can be placed in the deck area of 148.8 m^2 for all system components, such as; PV modules, charge controllers, batteries, and inverter. This study can provide an overview of the use of PV system in designing the environmentally new or renovation ships.

Keywords: Green transportation, energy saving, solar energy, energy dilemma, ship design

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1 Introduction

According to IEA [1], the world is facing a dilemma of increasing dependence on fossil energy such as oil, gas, and coal with decreasing their supply. Especially for Indonesia, this situation must be anticipated by all sectors with implementing energy efficiency (EE) and utilizing renewable energy (RE). The RE included geothermal, biomass, hydro, wind, solar, wave and others, has the potential to be superior in comparison to fossil energy. For achieving EE, energy audits are important [2, 3]. Both EE and RE are very important to support national energy security [4].

Especially for RE in the transportation sector, ships as consumers of oil energy can also take advantage of solar energy sources, for example for lighting and cooling. In the utilization solar energy in Indonesia as equatorial and tropical areas with the land area of almost 2×10^6 km^2, endowed with irradiating the sun more than 6 h d^{-1} or about 2 400 h in a year. With a geographic location on the equator, Indonesia will always have sunlight for 10 h until 12 h a day and approximately daily irradiation of 4.5 kWh m^{-2} with the monthly variation of about 10 % [5]. Solar energy utilization for Indonesia has various advantages such as: The energy is available with large numbers in Indonesia. Strongly support the national energy policy of austerity. Verified and equitable energy. Allow built-in remote areas because it does not require the transmission of energy or transportation of energy resources.

Solar energy is an environmentally friendly energy source which can be converted to; electrical energy using solar cell or photovoltaic (PV), thermal with solar collector, or both electrical and thermal energy [6, 7]. Photovoltaic has been applied in Marine Engineering [8], such as; a passenger ferry [9, 10], cruise ship [11], bulk carrier [12], survey vessel or tanker [13]. Figure 1 shows a patented solution developed by Eco Marine Power that combines sail power (using rigid sails) with solar power. This wind-assisted propulsion (WAP) system also include marine solar power and is designed so that the practical limitations of using rigid sails and solar panels on ships are overcome [14]. As an archipelagic country, Indonesia is highly dependent on ferries for marine transportation and regional development [15]. The generator choice is specialized in idealizing systems in this role for planning because it involves a techno-economy problem. The purpose of this study is to perform the techno-economic analysis of photovoltaic system utilization for lighting and cooling of Ferry Ro/Ro 500 GT to be operated in Indonesian seas.

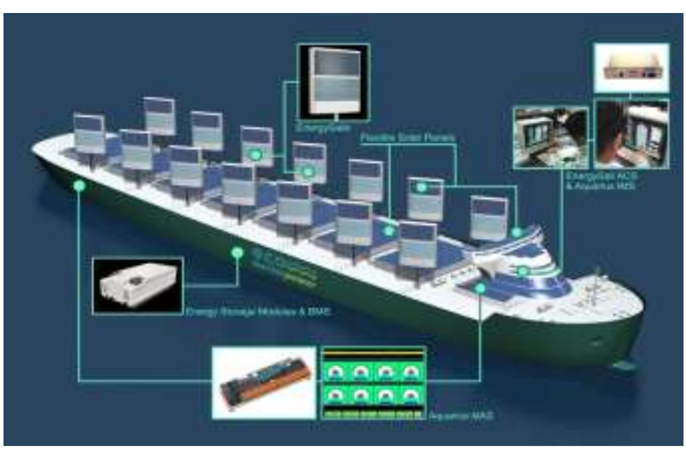

Fig 1. Sail power with solar cell in ship

2 Method

To realize the objectives of this research, there are five steps taken;
First, to determine the design specifications of the ship; Ferry Ro/Ro 500 GT, as shown in Table 1.

Table 1. Specification design of the ship

Length Over All (LOA)	45.05 m
Length between Perpendicular (LPP)	40.15 m
Length of Water Line (LWL)	42.00 m
Breadth (B)	12.00 m
Height (H)	3.20 m
Draft (T)	2.15 m
Velocity (V_s)	11 knot
Main Engine	2 × 800 HP
Auxiliary Engine	2 × 80 kVA
Gen-set emergency	25 KVa

This study focuses on Ferry Ro/Ro (Roll-on/Roll-off) with the horizontal transfer charge [4]. The power for lightings are distributed for; i). the main lighting using fluorescent and neon lamps. ii). emergency lighting lamps mounted at the steering wheel, desk maps, alleys, stairs, engine room, iii). lightings for the engine room, bathroom/toilet, kitchen and rooms open from types that are waterproof (watertight).

Second, determine the specifications of the main components for the PV system. The main components are included; PV module, inverter, charge controller, and battery. The details are shown in Table (2, 3, 4 and 5).

Table 2. Specification of PV module [16]

PV module type	PV Energy, FVG 240P − MC:
Dimension	(1650 × 990 × 35) mm
Power peak, P_{mpp}	240 W
Efficiency, η_{pv}	14.6 %
Voltage module, V_{mpp}	30.50 V
Current module, I_{mpp}	7.88 A
Open circuit voltage $V_{pv,\,oc}$	37.60 V
Short circuit current $I_{pv,\,oc}$	8.28 A

In designing this PV system, the current resulting from the PV module is the DC, while the current that is used to drive the compressor using the AC current. The DC from the PV module needs to be converted to AC using the inverter current. Table 3 shows the specification of the inverter:

Table 3. Specification of the inverter [17]

Inverter type	XANTREX model SW3024E
Power	3300 W
Voltage	24 V
Efficiency	94 %

Table 4. Specification of the charge controller [18]

Charge controller type	Marine Batteries, Rolls Series 5000
Charging current capacity, I_{cc}	60 A
Charging voltage, V_{cc}	12 V

Table 5. Specification of battery [18]

Battery type	Marine Batteries, Rolls Series 5000
Capacity, P_{bat}	370 Ah
Battery voltage, V_{bat}	12 V

The number of panels N_{pv} to meet the needs for a daily hour h of total energy E_{tot} calculated with:

$$N_{pv} = \frac{E_{tot}}{P_{pv} x h} \tag{1}$$

The number of the charge controller N_{cc} required can be calculated from;

$$N_{cc} = \frac{N_{pv}}{(I_{cc} / I_{pv})} \tag{2}$$

where, I_{cc} = 60 A, is the maximum current of the charge controller. The total output of charge controller can be calculated as;

$$I_{cc,tot} = I_{cc} \times N_{cc} \tag{3}$$

The power output of the charge controller $P_{cc,tot}$ with voltage V_{cc} (12 V) can be calculated as;

$$P_{cc,tot} = I_{cc,tot} \times V_{cc} \tag{4}$$

The energy saved by a battery E_{bat} with the capacity P_{bat} and voltage V_{bat} of 12 V can be calculated as;

$$E_{bat} = P_{bat} \times V_{bat} \tag{5}$$

The total battery required N_{bat} to support the total energy load E_{tot} can be calculated as;

$$N_{bat} = \frac{E_{tot}}{E_{bat}} \tag{6}$$

The total energy saved by the batteries $E_{bat,tot}$ can be calculated as;

$$E_{bat,tot} = E_{bat} \times N_{bat} \tag{7}$$

The number of inverters N_{inv} required can be calculated from;

$$N_{inv} = \frac{P_{pv,tot}}{(P_{inv,in})} \tag{8}$$

where, $P_{pv,tot}$ and $P_{inv,in}$ are the total power of the PV module and the power input of the inverter, respectively.

Figure 2 shows the placement of the PV module on the deck wheelhouse. The installation was parallel to optimize the solar energy with proper layout [19]. The PV module of FVG 240P-MC model was considered to address the needs of load for lighting, with sufficient area on the deck of 160 m^2.

Fig. 2. The placement of solar panel in deck house

Third, calculate the power required for the lighting equipment. The summarized detail of group lighting can be seen in Table 6.

Table 6. Power required for lighting

Deck	Load range (W)	Used hour (h)	Operation	Total (pcs)	Energy (kWh)
Bottom	5 to 20	12	18:00 to 16:00	8	1.74
Vehicle	5 to 40	12	18:00 to 16:00	44	9.36
Passenger	5 to 60	12	18:00 to 16:00	53	12.72
Navigation	5 to 60	12	18:00 to 16:00	34	9.78
			Total	139	33.6

Fourth, calculate the power required for the cooling system. As shown in Table 7, the power required for the cooling system is used for Steering Room, Passenger Rooms, Cabin Crew Rooms and the Control Room, installed air conditioning (AC) machine in the form of AC Split in each room. AC Blower must be arranged so that every part of the room to get the same temperature influence. Engine/generator AC should be placed outdoors and protected from direct weather influences and the sea air or given a construction for protection against the weather. The AC generators were placed on the vehicle load space must be given a protective fender, or construction to protect the generator from the possibility of a collision with a vehicle. There are 3 factors to consider when determining the need for PK of AC power conditioners, namely AC power (BTU h^{-1}), electrical power (W), and PK of the AC compressor. Number PK on AC power is a unit on the AC compressor, not AC cooling power, so to decide on the power need, we must look from the specification of AC.

Table 7. Power required for cooling system

Room's Name	Unit	AC Power (PK)	AC Power (BTU h^{-1})	AC Power (W)
Engine Room	1	½	± 5 000	220
Captain & Engine Room Operator	1	½	± 5 000	220
Passenger Executive Room	4	11/2	± 12 000	1 560
Medical Room	1	½	± 5 000	220
Mosque Room	1	½	± 5 000	220
Mess Room	1	½	± 5 000	220
			Total	2660

Fifth, make an investment comparison for propulsion systems between diesel engines and photovoltaic systems.

3 Result and discussion

3.1 Power for lighting system

From the selection of the solar panels, it can be calculated how many pieces of solar panels needed to meet the needs of power for lighting load. For conditions in Indonesia, even though the duration of the sun shines for 8 h d^{-1} (08.00-16.00), but the effectiveness of the photon beam obtained solar panels during the day is 5 h, h. Thus, the number of panels N_{pv} to meet the needs of daily energy E_{tot} of 33.6 kWh (see Table 6) is 28 unit with additional 7 unit as a backup to anticipate the low irradiation less than 1000 W m^{-2}. With extensive consideration of the deck, the platform is still able to accommodate the number of solar panels, in addition to the power generated will be greater or in other words the addition of solar panels to add the amount of power generated. The amount of power generated by the 35 solar panels in 1 h : 35 panels × 240 W = 8.4 kW. The amount of power generated by the solar panels is in 5 h is 8.4 kW × 5 h = 42 kWh. It has solar panels power largest enough to area on the bridge deck 20 m × 8 m = 160 m^2 and is installed with a slope of 150^o [13]. From the specification of the charge controller, the maximum current can be released is 60.0 A. The summary of the result can be seen in Table 8.

Table 8. Components and power required for lighting

Items	Eq.	Unit		Remarks
Number of PV panels, N_{pv}	(1)	pcs	28	With additional 7 pcs = 35 pcs
Number of the charge controller, N_{cc}	(2)	pcs	5	
Total current of the charge controller, $I_{cc,tot}$	(3)	A	300	
Total power of the charge controller, $P_{cc,tot}$	(4)	kW	3.6	
Energy saved by the batter, E_{bat}	(5)	kWh	4.3	
Number of battery required, N_{bat}	(6)	pcs	10	
The total energy saved by the batteries, $E_{bat, tot}$	(7)	kWh	43	
Number of inverters required, N_{inv}	(7)	pcs	11	

3.2 Power for cooling system

According to Table 7, The power requires for AC on board during the cruise of 10 h is 2.66 kW × 10 h = 26.6 kWh. With so many panels to meet the needs of power equal to 26.6 kW as many as the efficiency of solar panel hence: 240 × 14.6 % = 204.96 W. The number of solar panel = (26.6 kWh) / (204.96 W × 5 h) ≈26 solar panels. The amount of power generated by the solar panel in 1 h is 26 PV modules × 204.96 W PV^{-1} module = 5 328.96 kWh. The magnitude of the power generated by the PV module all over in 5 h is 5 328.96 kWh × 5 h = 26 644.8 kWh. From the existing controller charger specifications, the maximum current that can be issued charger controller is of 60 A. The current generated by a solar module with voltage of 30.5 V is 7.88 A. One charger controller can be used for 7 units of PV modules. The summary of the result can be seen in Table 9.

Table 9. Components and power required for cooling system

Items	Eq.	Unit		Remarks
Number of the PV modules, N_{pv}	(1)	pcs	7	With additional 7 pcs = 35 pcs
Number of charge controller, N_{cc}	(2)	pcs	4	
Total current of the charge controller, $I_{cc,tot}$	(3)	A	240	Max 60 A/charge controller
Total power of the charge controller, $P_{cc,tot}$	(4)	kW	5.76	
Energy saved by the batter, E_{bat}	(5)	kWh	4.4	
Number of battery required, N_{bat}	(6)	pcs	6	
Total energy saved by the batteries, $E_{bat,\,tot}$	(7)	kWh	24.5	
Number of the inverters required, N_{inv}	(7)	pcs	9	

The PV system components will be placed on the deck of the bridge or on the space under the deck of the vehicle with a total area of 12.4 m × 12 m = 148.8 m^2, as shown in Table 10.

Table 10. Dimensions and weight of system components for PV systems

Component	Dimension (cm)	Weight (kg $unit^{-1}$)	Lighting System		Cooling System	
			Units	Weight (kg total)	Units	Weight (kg total)
PV module	165 × 99 × 3.5	21.5	28 (+7)	752.5	7	150.5
Charge controller	37 × 15 × 15	0.45	5	2.25	4	1.8
Battery	55.9 × 17.8 × 6	123.4	10	1234	6	738
Inverter	53.4 × 38.1 × 22.9	16	11	176	9	144
		Total	61	2 164.75	26	1 034.3

Lighting and cooling with the PV system provide about 1.49 % savings compared to generators.

3.2 Economic analysis for driving force system

The cost comparative analysis for driving force system between the diesel engine and PV system can be explained in Table 11 and the investment cost analysis in Table 12. From the calculation for 10 yr time, the investment cost of the PV system is much lower only IDR 553 259 000 compare to diesel system IDR 3 814 025 000 or, PV system investment is only 15 % than the diesel system. Besides, it is necessary to consider the accident factor which is experienced by the diesel-engined ships [20].

Table 11 Cost comparative analysis for ship propulsion system component

• With motor diesel: - 1unit auxiliary 80 kVA - Tool kit engine • The calculation of fuel consumption using generator power planned 80 kVA, for 10 h cruise: W_{fo}: 80 × 210 × 10 × 10^{-6} × 0.6 = 0.1008 t The volume of fuel: W_{fo} / γ_{fo} = 0.10 / 0.85 = 0.11 m^3 = 110 L The price of diesel fuel for the total fuel shipping is 110 L and the price of 1 L of marine diesel is IDR 8 500 • The calculation for motor diesel: Investment for the purchase of diesel - Generator 1 unit: IDR 43 000 000 - Tool kit-engine 1 set: IDR 2 000 000 Operations: The fuel for the 5 trips for 1 d needs 110 L - 1 d cruise 110 L × IDR 8 500 = IDR 935 000 - For a year IDR 935 000 × 365 d = IDR 341 275 000 - For 5 yr IDR 341 275 000 × 5 = IDR 1 706 375 000 - For 10 yr = IDR 1 706 375 000	• With solar cell: - Use 26 PV modules - 4 charge controller - 6 battery - 9 inverter • For 10 yr usage performed 4 times engine maintenance and costs IDR 6 000 000 × 10: IDR 60 000 000 • Investment for the purchase of PV modules: - Using 26 units PV modules @ IDR 3 139 500 = IDR 81 627 000 - 4 pieces charger controller @ IDR 6 490 000 = IDR 25 960 000 - 6 batteries @ IDR 9 093 500 = IDR 54 561 000 - 9 inverter @ IDR 34 950 000 = IDR 314 550 000 - 1 tool kit set engine: IDR 2,000,000, - Operational battery backup 6 pieces @ IDR 9 093 500 = IDR 54 561 000 - Maintenance costs for 10 yr @ IDR 2 000 000 yr^{-1} = IDR 20 000000

Table 12. Total Investment

Year	Generator	PV System
1	IDR 341 275 000	IDR 434 329 500
5	IDR 1 706 375 000	IDR 10 000 000
10	IDR 1 706 375 000	IDR 20 000 000
After 10 yr	IDR 60 000 000	IDR 54 561 000
Total	IDR 3 814 025 000	IDR 553 259 000

Based on the above results, three technical points need to be discussed here;

First, the requirement or common rules electricity a ship for the power quality [21], such as; supply electricity to vessels needs and neutral body system of a ship grounded on may not except; zinc anode protection system must be a cathode or the outer part body of ship; system limited or local ground as system starting and starting motor in motor fuel combustion; a measuring monitor insulator instrument to the current that circulated no more than 30 mA in the worst of conditions; high voltage neutral ground to avoid dangerous areas were defined in requirements.

Second, power supply and distribution. Generator, switchboard and battery must be in a separate location from the fuel tank and oil pump, with a cofferdam or with sufficient distance. The cable that might be opened by the steam and gas needs to be protected with the proper insulation, with the possibility of reducing corrosion. Some requirements for the installation cable onboard based on the position where the cables will be placed, adapted to the structure of the ship so that the installation and buffer plate avoid the possibility of strains/stresses.

Third, when docking, ships can use the power of the land through shore connection to avoid emission by the generator [22]. If the generator is not active then the emergency source of electrical power (power source) is usually in the form of battery. Due to the nature of the emergency then only certain equipment and very important in the supply by the emergency source of electric power, for example, lights navigation, gangway lighting appliances, and others. The emergency power source will be stored automatically through the emergency switchboard, if all the generators are not active.

The results of this study can provide an overview of the use of PV system in designing the new or renovation ships, both for lighting and cooling systems as well as for propulsion systems. For environmentally friendly shipping [23], future ship design should consider the use of PV module as a technology for converting solar energy into electrical energy. According to the berthing location, the green ship concept can be integrated into the smart city concept with smart grid technology [24, 25]. For the future research direction, this analysis can be developed into a simulation tool with a variety of ship types with optimal placement on the ship [9].

4 Conclusion

The analysis of photovoltaic usage for the 500 GT Ferry-Roro has been carried out with several important points, as follows. To meet the energy needs of the lighting system with the existing component specifications; then it takes 28 PV modules, 5 charge controllers, 10 batteries and 11 inverters. As for the cooling system, it is needed 7 PV modules, 4 charge controllers, 6 batteries and 9 inverters. All system components can be placed in the provided deck area of 148.8 m^2. Lighting and cooling with the PV system provide about 1.49 % savings compared to generators. PV system investment is only 15% than the diesel system. For the propulsion, PV system investment is only 15% than the diesel system.

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