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Assessment of Solar Panel Array Utilization Applied to a Fishing Vessel 20 GT

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***Abstract*— Fishermen heavily depend on fossil fuels, around 95.4%, with no apparent decrease. Rising fuel costs and declining fossil fuel supplies challenge the fishing industry. The International Maritime Organization notes that ships using fossil fuels consume 277 million tons of fuel, contributing 2.5% to global emissions (961 million tons of CO2). TReducing reliance on fossil fuels and adopting alternative sources such as solar energy is suggested to address energy issues in Indonesia; solar energy, with an intensity of 0.6 to 0.7 kW/m2, is considered promising. This study uses an experimental design methodology to evaluate the installation of solar panels on a 20 GT fishing vessel at Muara Angke Port, Jakarta. Primary data, including ship size, was collected from the field. The economic focus is on the payback period, calculated through interviews with the crew. Exhaust gas emissions were calculated using factors established by the Ministry of Transportation. The results indicate that replacing CFL lamps with LED can save energy, specifically around 5 kW on this vessel. The feasibility of installing 14 solar panels is shown, costing over 20 years of Rp. 65,100,000. The payback period is estimated at three years, and the long-term analysis of Photovoltaic Solar Panels (PLTS) over additional engine investment. Cumulative emissions from the engine in one year are 155,007 tons, making PLTS environmentally beneficial without emissions.**

Keywords- Economic Calculation, Exhaust Emissions, Fishing Vessel, Renewable Energy, Solar Panel

I. INTRODUCTION

The geographical location of Indonesia significantly promotes the nation's fisheries sector. With an exclusive economic zone covering 2.55 million km2, Indonesia presents one of the world's most significant opportunities for marine capture. According to statistical data from the Ministry of Marine Affairs and Fisheries (MMAF), 589,182 marine fishing vessels operate in Indonesia [1]. Being the world's largest archipelago, with over 17,000 islands, Indonesia is home to numerous traditional fishing communities. These communities are spread nationwide and use conventional fishing boats and instruments, including purse seines, gill nets, and trawls [2]. In the context of global fisheries expansion, it is evident that the transition from coastal areas to offshore regions and eventually to the open ocean represents a recurring pattern in marine fisheries—a natural course in their growth.

Global ocean fisheries face increasing challenges, including rising oil costs and the imperative for environmental conservation. These challenges are exacerbated by the growing necessity to implement energy-saving measures and reduce emissions, especially as the world transitions to a low-carbon economy. In some remote regions, fishing lights traditionally consisted of kerosene pressure lanterns. These vessels are predominantly conventional and powered by fossil fuels. Each ship demands a significant amount of diesel fuel for a single trip, ranging from 500 to 17,000 litres, depending on the vessel's size and duration. This fuel propels the ship and operates an auxiliary diesel generator, providing electricity for onboard activities [1]. The recognition that the supply of fossil fuels is becoming rarer and more expensive is acknowledged. The increasing shortage of fuel oil for fishing vessels has had a significant and catastrophic impact on the maritime industry in Indonesia, especially among fishermen [4]. The fuel used in fisheries for energy creation constitutes a critical yet often overlooked aspect of environmental and economic sustainability [1]. Nevertheless, individuals from all socioeconomic backgrounds have experienced the consequences of the significant increase in crude oil prices on the global market, heightening the challenges. Addressing the challenges posed by fuel reliance requires the implementation of simplification movements across various industries, offering alternative solutions during times of crisis [6]. In the sea transportation business, ship operations are commonly linked to economic considerations, such as operating expenses and environmental factors, including the level of pollution generated during these operations [7].

While fishermen consistently grapple with the cost of fuels, delving further into the use of electricity on board is crucial for identifying the optimal cost-benefit solution for generating energy. In recent years, several studies have explored fuel solutions in fisheries. However, the consensus from these studies is that, at least for now, there are no viable fuel options for commercial fishing vessels that directly address the challenges of high fuel costs and emission intensity [1]. This could be seen as international marine authorities enforcing stringent regulations, exemplified by MARPOL's Annex VI on NOx (Nitrogen Oxides) and SOx (Sulphur Oxides) emission restrictions, targeting the most harmful pollutants.

The shipping industry is particularly concerned about this issue as it accounts for 15% and 4-9% of the worldwide emissions of nitrogen oxides (NOx) and sulfur

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oxides (SOx), respectively [6]–[8]. An economic model developed by Shafiee and Topal [9] estimated that oil, gas, and coal will be depleted in approximately 35, 37, and 107 years from 2008, respectively. Moreover, acknowledging the global warming impact on humanity, adopting renewable energy is a crucial responsibility [10]. A study by the Intergovernmental Panel on Climate Change (IPCC) [11] determined that the current atmospheric concentration of carbon dioxide (CO2) has increased by 100 parts per million (ppm), reflecting a 34% rise compared to levels observed during the pre-industrial era. Based on statistics from the Carbon Dioxide Analysis Centre (CDIAC), global annual carbon emissions from fossil fuels amounted to 35.9 billion metric tons of CO2, significantly surpassing the 15.4 billion metric tons emitted. Furthermore, it is crucial to note that the maritime sector substantially contributes to carbon dioxide emissions, a significant greenhouse gas. In 2012 this sector produced 796 million tons of CO2, representing approximately 2.2% of global emissions [5].

Nevertheless, reducing fossil fuel consumption in the fisheries sector, especially in Indonesia, remains achievable by replacing the energy source for vessel operations with renewable alternatives [1]. Thus, replacing traditional marine fuels — significant contributors to global warming — with renewable energy sources may be crucial for enhancing global sustainability [5]. Advancements in scientific understanding, increased awareness of environmental issues, and economic considerations have collectively heightened international interest in renewable energy sources. Integrating renewable resources requires substantial modifications to our energy infrastructure. Harnessing Wind, Water, and Sunlight (WWS) energy resources through diverse technologies, such as wind turbines, concentrated solar plants, solar photovoltaic (PV) power plants, rooftop PV systems, geothermal power plants, hydroelectric power plants, and tidal turbines, presents an opportunity to meet the energy needs of a prospective WWS-driven world by the year 2030. In this envisioned world, electricity and hydrogen produced through electrolysis would be the primary energy sources for all purposes.

Upon closer examination of our surroundings, it becomes evident that all types of energy, including fossil fuels, ultimately depend on solar power. Plants rely on solar power for photosynthesis, which enables them to synthesise food. Subsequently, animals consume these plants, forming a crucial link in the food chain. Furthermore, the organic matter derived from plants and animals can undergo fossilisation, ultimately contributing to the formation of fossil fuels. According to McLamb (2011), the existence of everything in our universe is contingent upon the presence of the Sun. The Sun is a unique renewable energy source in the form of heat and light, which may be transformed into electricity. Thus, changing the energy landscape and adopting new sources such as solar, wind, nuclear, biomass, and wave energy represents the future direction for fishing vessels. Due to Indonesia's geographical location in an equatorial region, it enjoys a substantial solar energy output of 4.5 kWh per square meter daily. This is mainly attributed to the country's prolonged exposure to sunlight, with 10-12 hours of daylight and approximately 2000 hours of sunshine annually. As a result, Indonesia is classified as a region rich in solar energy resources [4].

Many attempts have been made to help fishermen drastically reduce fuel oil usage. Solar energy, recognised as a sustainable source for over 20 years, has been successfully employed in various applications, including powering residential water heaters and traffic lighting [4]. Reducing engine power (and fuel needs) can be addressed during the design phase by creating an efficient hull design and propulsion system [9]. Simultaneously, the need for a practical propulsion system can be met by incorporating alternative energy sources, such as Hybrid Engine Ships, Solar Electric Ships, Sailboats, and Hybrid Engine Ships [8]. Numerous shipyards, ship operators, and owners are actively exploring methods to adopt greener energy as maritime fuel sources [5]. Greener shipping has become a significant global concern, driven by the anticipation that fossil fuel sources will be depleted in the not-too-distant future, given the critical stage of climate change [5]. While solar panels are increasingly visible in cities or the countryside, this technology has not yet been significantly deployed in the transport sector. Many articles have focused on solar panels, particularly their installation on top of buildings.

Despite the overarching challenges in scaling up solar-powered solutions, noteworthy examples of tangible prototypes have surfaced, notably within the marine sector. Building on the methodology previously employed by Ghenai and colleagues, a similar approach was adopted, implementing solar panels on a cruise ship to augment the electrical load. The results were promising, showcasing a significant 9.84% decrease in emissions [12]. Expanding the horizon to encompass commercial vessels, Karatug and team explored the advantages of integrating a solar photovoltaic (PV) system into a Ro-Ro (Roll-on/Roll-off) ship [13].

In addition, Wu et al. conducted research highlighting the utilisation of solar panels in offshore energy generation, involving the deployment of solar panel arrays off the coast, as demonstrated by the Chinese projects referenced in the article above [14]. However, few papers discuss both advantages. Indeed, Glykas et al. conducted a cost-benefit study of solar hybrid power installations on merchant marine vessels, yielding significant findings on the payback period and fuel savings [15]. This approach was later adapted to power small ships using a combined power system known as a hybrid engine. In this scenario, the vessel is propelled by a battery and solar energy is employed to replenish the battery's charge while the ship operates in open waters. The first electric boat driven by solar energy was created in England in the 1970s [16].

Significant advancements have been made on a global scale. One of the most remarkable achievements was the commissioning of Planet Solar, an enormous solar-powered yacht owned by Switzerland. Additionally, a smaller solar power boat developed in Indonesia, with a maximum length of 31 meters, has successfully navigated globally [4]. Ko and Chao [17] conducted further research to advance photovoltaic (PV) generation, recognised as a crucial renewable energy source. This concept presents numerous advantages, including cleanliness, affordability of repairs, and absence of noise. Powering vessels without engines and fuel oil has become increasingly popular, aligning with the green economy concept and addressing environmental concerns.

Various power systems have been devised, such as the combination of engines and sails, later known as an assisted engine. This technology has been applied in multiple contexts, including satellite power systems, solar power generation, solar battery charging stations, and solar-powered vehicles such as cars, ships, and aeroplanes [4]. Unfortunately, using most renewable energy sources in maritime applications still poses substantial challenges [15]. Despite this, solar energy takes precedence in various forms aboard ships [18]. Nevertheless, while solar energy systems are widely employed in crucial land applications, their integration into modern marine technology remains relatively restricted. They primarily serve as providers for small lighthouses, buoys, and battery chargers for small sailing ships. Moreover, storing electric energy is challenging, and the quantities needed to power naval vessels are immense. For this reason, an intensive exploration of a combination method involving fuel oil and electric power is underway.

1.1 Review of solar panel applications

Solar panels, a widely adopted technology for harnessing solar energy, demonstrate environmentally favourable attributes and a commendable track record globally. Eskew et al. [19] conducted a study assessing the environmental impact of rooftop photovoltaic solar panels in Bangkok, Thailand. Another study by Smith et al. [20] focused on a renewable energy island, evaluating the environmental effects of a hybrid microgrid integrating energy sources like diesel, solar, and wind. Solar photovoltaics, highlighted as one of the cleanest and most practical technologies for modern electricity generation, were central to Jacobson's group's renewable energy plan for Washington State, USA—this plan aimed at converting wind, water, and sunlight into electricity [21].

Numerous hybrid system models, incorporating oils and alternative energy sources, have been developed to replace traditional propulsion systems powered by oil products. According to studies [22], [23], hybrid ships equipped with diesel engines and onboard battery packs, which can be charged from greener energy sources, demonstrate excellent potential. The findings of their investigation underscored the benefits of deploying battery packs to reduce CO2 emissions. Alongside the development of applications utilising batteries, there has been a call for research into integrating renewable energy systems on board ships. Although there aren't many instances of people using onboard solar panel systems, photovoltaic solar systems have been implemented in severe offshore settings in the United States. Various forms of renewable energy systems, including wind, wave energy, and tidal and tidal energy, were compared with crystalline and thin-film solar energy systems.

According to Trapani et al. [24], their research indicated that a thin-film solar system would be more cost-effective than a crystalline one. To provide an overview of currently available hybrid boats, the Aitoku Maru, a cargo ship weighing 2100 tons, was constructed by Japanese naval architects in 1980, utilising wind power as its primary source of propulsion. The objective was to reduce energy usage by 50% compared to the most efficient traditional ships.

Due to significant advancements in solar energy, solar power is emerging as a potential and economically efficient means of reducing fuel consumption on pleasure boats, ferries, and tourist ships. However, using solar electricity for fuel conservation has a relatively minor impact on large vessels' energy efficiency compared with smaller ferries. Following this discovery, academics and technology developers shifted their focus to hybrid systems to mitigate fuel use.

In the 1990s, a patent was secured in the United States for integrating wind and solar energy sources. Although the conceptualisation and exploration of hybrid systems began before the 1990s, an operational large-scale commercial ocean-going vessel has yet to be functional. Newman and Schaffrin's team initiated the development of solar energy conversion technologies. In a study by Diab et al. [25], the advantages of employing a hybrid system, which combines diesel engines with battery packs connected to solar panels, were examined for both inland and on-board applications.

The research findings suggest that implementing solar panel systems and battery packs on a ship could reduce approximately 10,000 tons of greenhouse gas emissions over an average ship lifespan of 25 years. However, their primary focus is assessing the environmental impact during the operational phase of implementing a solar panel system and battery packs on a ship. The inquiry does not encompass a comprehensive examination of all stages of a ship's life to assess the potential advantages of implementing a marine solar system.

In another study, Glykas et al. [15] delved into the implementation and cost-benefit analysis of solar hybrid power systems on merchant marine vessels. The results revealed a significant correlation between the payback period's duration and fluctuations in gasoline costs. Another noteworthy observation is that, in contrast to the yearly escalation of gasoline costs, the payback period tends to reach a minimum of around ten years. Several studies have also explored the energy storage system, examining its potential to mitigate fuel consumption and emissions over the vessels' lifespan [23].

The investigation carried out by Yu et al. [26] scrutinised the energy efficiency and potential emissions reduction achieved by hybrid systems integrating solar panels, battery packs, and diesel generators. The research findings indicated that these hybrid systems could fulfil local emission reduction standards and generate financial advantages throughout a ship's operational lifespan. Numerous additional research studies on this subject have been conducted globally. Branker and his colleagues [27] comprehensively analysed various economic feasibility studies on solar panels. They argued that solar energy could increase economic advantages in specific geographic locations, supporting their claim with specific examples.

The authors also provided a valuable perspective on calculating solar panel costs, effectively addressing misconceptions and erroneous assumptions associated with cost studies. In their research on the economic viability of solar panels, Imtiaz and Ahsan [28] presented empirical data on the efficiencies achieved by four residential properties in two cities in Australia. Their study demonstrated positive results regarding the use of solar energy. However, it was observed that the effectiveness of solar panels varied, influenced by several factors such as current costs and dimensions of the solar system. The previously mentioned articles offer significant insights into the importance of meticulous design, careful selection of solar panels, and the necessity of accurate assumptions in assessing costs.

Additionally, previous research has attempted to investigate the effects of solar systems on the surrounding ecosystem through life cycle assessments. The following is a summary of some interesting potential outcomes: Kannan et al. [29] researched the efficiency of oil-steam turbine systems compared to the performance of photovoltaic (PV) systems. Current research shows that photovoltaic systems effectively cut greenhouse gas emissions. Still, their deployment may pose a significant financial burden due to high costs.

II. METHOD

2.1 Ship Dimension Data

Muara Angke Harbor, located in Jakarta, was where the data collection for ships was conducted. The primary dimensions of the fishing vessel investigated for this article are outlined in Table 1, which offers an overview of these measurements. A total of 20 gross tons make up the ship's tonnage overall.

2.2 Ship Electricity Data

The ship has determined its power requirements by examining the electrical equipment on board. This analysis considered, among other things, the GPS systems, fishfinders, VHF radios, navigation lights, anchor lights, work lights, crew room lights, spotlights, and other devices essential to the situation. As indicated, the findings are presented concisely in a table, with each characteristic of the vessel that was the subject of the inquiry receiving its distinct appearance.

The calculation of electrical energy requirements for fishing vessels with a gross tonnage of 20 GT is determined by considering the specific type and quantity of items on the boat. This calculation assumes the power consumption of each item and the duration for which each item is utilised on the fishing boat. Electrical requirements on fishing vessels can be categorised into three distinct components: navigation and communication equipment, interior lighting fixtures, and fishing-specific lighting apparatus.

The aggregate electricity consumption for navigation and communication devices amounts to 4.12 kilowatt-hours (kWh) per day. The combined electricity usage for lighting fixtures in each room totals 1.24 kWh daily. Furthermore, the electricity demand specifically attributed to lighting fixtures during fishing activities is 1.1 kWh daily.

2.3 Energy Resources

The total energy demand, denoted as Eload, covers the energy requirement for propulsion, referred to as Eprop, and the energy consumption associated with electrical equipment utilised for service purposes, represented as Eserv. The energy required for propulsion is determined by the propulsion system's power and the number of miles the ship makes the trip. On the other hand, the energy consumed by various services on the vessel is calculated by multiplying the power requirements of electrical equipment by the usage period for each piece of equipment. In this particular case, the total energy demand of the ship is represented by the equation Eq (1).

$$E_{load}(t) = \int_0^t P_{prop}(t)\,.\,dt + E_{Serv}(t); t = 0,1,2 \dots ,24 \quad (1)$$

2.4 PV Energy

Photovoltaic (PV) energy refers to the solar energy collected by the PV module, as denoted by Equation (2).

$$E_{PV}(t) = \frac{Ppv}{1000}.\eta_S.\eta_C.x_1 \int_0^t \frac{I_{rr}(t)}{G_{STC}} dt; t = 0,1,2, \dots ,24 \quad (2)$$

The variable PPV represents the maximum power output of the photovoltaic (PV) module, measured in watts. Irr denotes the solar radiation intensity, expressed in kilowatts per square meter (kW/m2), while GSTC refers to the solar radiation under standard test conditions, equivalent to 1 kW/m2. The symbol ηs denotes the efficiency of the photovoltaic (PV) system, which quantifies the energy losses resulting from converters, wires, temperature, and other factors. The variable ηc represents the charging efficiency, denoting the power dissipation that arises while charging photovoltaic (PV) energy into the battery. Additionally, x1 represents the quantity of PV panels that need to be modified.

2.5 Battery Energy

The equation calculates the energy of the battery. Other factors that influence the storage capacity of batteries, like temperatures, charging current, and discharging, have not been considered.

$$E_{batt} = \frac{V_{batt}.C_{batt}.x_2}{1000.\eta_d} \quad (3)$$

The nominal battery voltage, denoted as Vbatt, is measured in volts. The battery capacity, represented by Cbatt, is measured in Ampere-hours. The battery discharge efficiency, characterised as ηd, accounts for the energy loss during the discharge process. Lastly, X2 represents the quantity of batteries that need to be adjusted.

TABLE 1.
SHIP'S PARTICULARS

Main Dimension	Unit	20 GT
Length Over All (Loa)	M	18
Breadth (B)	M	3,60
High (H)	M	1,90
Draft (T)	M	1,30
Block Coefficient (Cb)	-	0,551
Crew	Man	5
Speed (Vs)	Knot	9
Power	HP	140

Figure 1. Fishing Vessel 20 GT

TABLE 2.
SHIP'S ELECTRICITY DATA

Electrical Items on 20 GT Fishing Vessel					
No	**Navigation & Communication Equipment**	**Watt**	**Sum**	**Duration (Hours)**	**Total (Watt Hour)**
1	Radio VHF	25	1	24	600
2	GPS MAP + Fish Finder	300	1	6	1800
3	Navigation Light DC 12 V	25	2	12	600
4	White Light	25	1	12	300
5	Bow Light	25	1	12	300
6	Stren Light	25	1	12	300
7	Chart Light	5	1	12	60
8	Must Light	25	1	12	300
9	Red Light	25	2	12	600
10	Green Light	25	1	12	300
	TOTAL				**5,16 kWh/Day**
No	**Room Lighting Items**	**Watt**	**Total**	**Duration Of Use (Hours)**	**Total (Watt Hour)**
1	Navigation Room	25	1	12	300
2	Outside	25	3	12	900
3	Kitchen	25	1	8	200
4	Toilet	25	1	8	200
5	Steering Gear Room	20	1	8	160
6	Crew Room	25	1	12	300
7	Engine Room	25	5	8	1000
8	Cargo Fish	20	2	8	320
	TOTAL				**3,380 kWh/Day**
No	**Fishing Gear**	**Watt**	**Total**	**Duration Of Use (Hours)**	**Total (Watt Hour)**
1	Search Light	500	1	1	500
2	Spotlight AC 220 Volt	300	2	1	600
	TOTAL				**1,1 kWh/Day**

2.6 Economic Calculation

Based on additional information obtained from Photovoltaic Solar Panels (PLTS) and existing auxiliary engines, as evidenced by survey findings conducted in the field, investment expenses related to PLTS on fishing vessels comprise vital components, including solar panels, inverters, MPPT Solar charge controllers, batteries, and cables. Additionally, these costs cover maintenance and operational expenses over a period ranging from one to twenty years. This study also examines investment costs associated with auxiliary engines, encompassing the initial purchase price, maintenance expenses, and operational costs over a period ranging from 1 year to 20 years.

Return On Investment (ROI) calculations are assessed according to the guidelines outlined in Minister of Energy and Mineral Resources Regulation No. 17 of 2013. This regulation, related to obtaining electricity from Photovoltaic Solar Power Plants (PLTS), stipulates that the purchase price for electricity from PLTS shall be established at 25 cents in United States currency per kilowatt-hour.

Assumption:

1 US $ = Rp. 15,680 (2023)

Then:

0.25 US $ = Rp 3.920 (2023)

The annual income from the photovoltaic (PV) system aboard this ship may be calculated by multiplying the total power the PV system provides per year by Rp.3920.

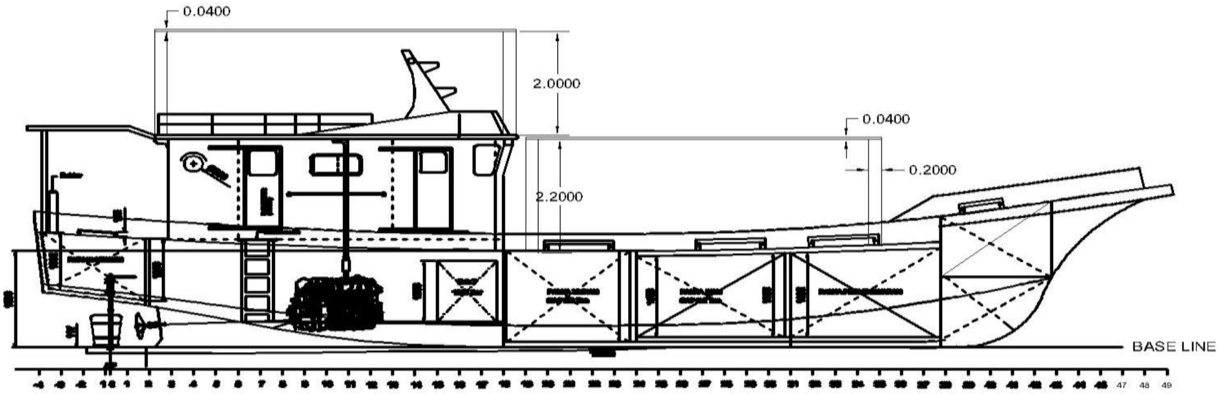

Figure 2. General Arrangement of Fishing Vessel 20 GT

Payback Period = Total Investment / Net cash flow (4)

To find exhaust emissions, each stage can be used as follows:

Ei (upstream) : t x k x d (5)

Ei (downstream) : t x k x d (6)

Ei (trip) : t x k x d (7)

Where

T : time

K : fuel consumption

d : engine power

Whereas to find the total emissions from pollutants are as follows:

Ei (Total) = Ei (upstream) + Ei (downstream) + Ei (trip) (8)

III. RESULT AND DISCUSSION

The energy used for onboard operations is generated by an auxiliary diesel generator, unlike the primary engine responsible for powering the vessel's machinery. The independent operation of this generator distinguishes it from the main generator, which is primarily used during daytime periods to provide lighting. The auxiliary diesel generator consumes 4 litres of diesel fuel nightly, resulting in an annual consumption of 1460 litres, assuming the vessel operates every night. The vessel's lighting and navigation equipment are powered by it. The total daily energy demand provided by the diesel generator amounts to 9.6 kWh/day. Based on this information, it can be inferred that the diesel generator operates inefficiently, as it consumes around 9 litres of fuel for each kilowatt-hour generated.

TABLE 3.
ENERGY DEMAND

Apparatus	Unit	Operating Hours		Load With FL (Watt)	Total	Energy Deman Perday		Load With LED (Watt)	Total	Energy Deman Perday	
		Min (h)	Max (h)			Min (Wh)	Max (Wh)			Min (Wh)	Max (Wh)
Equipment											
Navigation Light DC 12 V	2	10	12	25	50	500	600	2	4	40	48
White Light	1	10	12	25	25	250	300	5	5	50	60
Stren Light	1	10	12	25	25	250	300	5	5	50	60
Chart Light	1	10	12	5	5	50	60	2	2	20	24
Must Light	1	10	12	25	25	250	300	5	5	50	60
Red Light	2	10	12	25	50	500	600	5	10	100	120
Green Light	1	10	12	25	25	250	300	5	5	50	60
Lightning Room											
Navigation Room	1										
Outside	3	10	12	25	75	750	900	5	15	150	180
Kitchen	1	10	12	25	25	250	300	5	5	50	60
Toilet	1	10	12	25	25	250	300	5	5	50	60
Steering Gear Room	1	10	12	20	20	200	240	5	5	50	60
Crew Room	1	10	12	25	25	250	300	5	5	50	60
Engine Room	5	10	12	25	125	1250	1500	5	25	250	300
Cargo Fish	2	10	12	20	40	400	480	5	10	100	120

Total	24	140	168	540	5400	6480	106	1060	1272

3.1 Energy Saving Measure

The preliminary stage of the solar system design process is dedicated to evaluating the existing energy consumption requirements and pinpointing potential avenues for energy conservation. Adopting this methodology is expected to yield cost reductions when conducting financial analyses. To optimize energy efficiency and curtail operational expenses, a suggestion is put forth to exchange the presently utilized compact fluorescent lamps (CFLs) on the vessel with light-emitting diode (LED) lamps. LED lights not only offer a light hue comparable to, if not exceeding, that of incandescent lamps but also boast superior durability and reduced susceptibility to breakage compared to both incandescent and CFL bulbs. This substitution is envisioned to contribute to enhanced luminosity and prolonged operational longevity, aligning to augment sustainability and cost-effectiveness in the maritime energy framework.

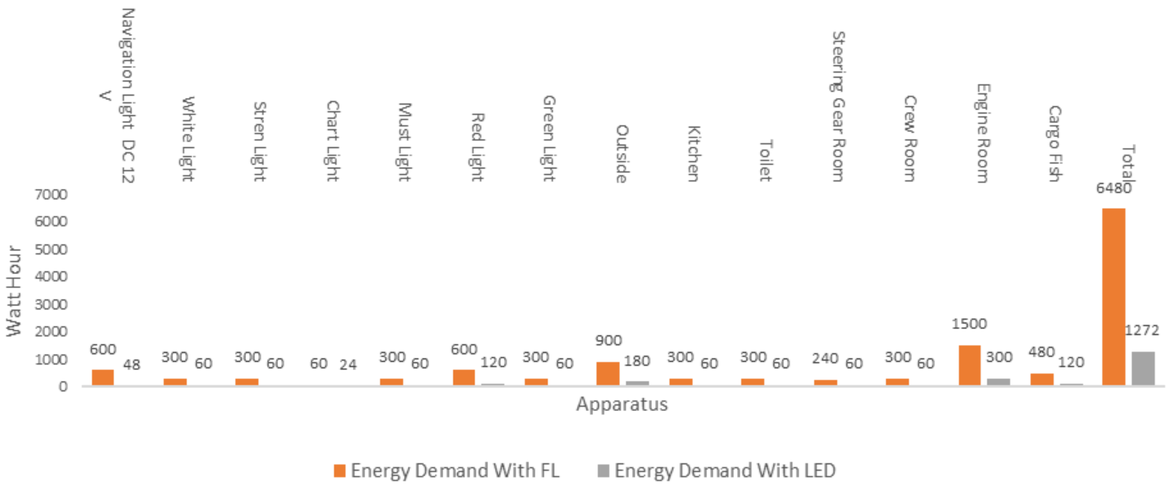

Figure 3. Comparison of daily energy demand

The initial cost of LED lighting is higher compared to CFL lighting, but LED lights have the potential to last up to five times longer than CFL lights. Specifically, in the context of compact fluorescent lamps (CFLs) and light-emitting diodes (LEDs), CFL lights need replacement every two years. In comparison, LEDs boast a significantly longer lifespan of up to ten years. LEDs also exhibit the advantage of utilizing around 75% less energy than CFLs. In a strategic move to enhance the efficiency of the new system design, LED implementation involves bulbs characterized by lower voltage requirements and extended lifespan. The following presents an assessment of the load on a 20 GT vessel for each operational day throughout a trip, utilizing both compact fluorescent lamps (CFLs) and light-emitting diodes (LEDs). Understanding the energy demand is crucial in determining the requisite system size for installation.

By substituting the current fluorescent bulb with an LED lamp, the daily energy consumption of the vessel can be significantly diminished to 5000 Wh/day or 5 kWh/day. This represents an approximate 80-fold reduction, as visually depicted in Figure 3. As previously highlighted, this value is significant, serving as the foundational metric for constructing the solar system.

3.2 Ssolar panel and Battery

It is assumed that the lighting bulbs on the vessel currently employ LED technology. The duration of lamp and other electrical equipment utilization is adjusted based on their respective functionalities. The total obtained is 1272 watts, equivalent to 1,272 kilowatts (kW). The aggregate power demand for this vessel encompasses both primary propulsion and electrical power. The data presented in Table 1 indicates that the propulsion power amounts to 104 kW.

Despite the sun providing eight hours of sunlight in Indonesia, specifically from 08:00 to 16:00, the operational efficiency of solar panels is limited to five hours each day. Given that solar panels are expected to provide power for 5 hours, the calculated power demand for the ship amounts to 1976 kW (104 multiplied by 19). The total power demand, as determined by Equation 1, is estimated to be 1,977,272 kilowatts (kW) through the average of 1,976 kW and 1,272 kW

TABLE 4.
SOLAR PANEL SPECIFICATIONS

Data	Unit	250 Wp
Max. Power (Pmax)	W	250
Max. Power Voltage (Vmp)	V	28.9
Max. Power Current (Imp)	A	8.7
Open Circuit Voltage (Voc)	V	34
Short Circuit Current (Isc)	A	9.2
Weight	Kg	16
Dimension	mm	1650 x 992 x 40

According to the provided diagram, the feasibility of installing solar panels on fishing vessels with a capacity of 20 GT is observed in two specific locations: the deck cargo area and the upper section of the ship's wheelhouse. The installation process for solar panels involves the laying phase, which includes providing a pole to support the solar panel. This pole undergoes modifications in terms of its length, diameter, and the number of bars required for the installation. Adjustments are made to the length and width dimensions, and the necessary number of solar panels is then determined.

The feasibility of installing solar panels on fishing vessels with a gross tonnage (GT) of 20 lies in the deck cargo region and atop the vessel's wheelhouse. The installation plan for solar panels on the cargo deck involves placing up to eight panels with a power capacity of 250 Wp and dimensions of 1650 x 992 x 40 mm. Additionally, six solar panels, each with a total capacity of 250 Wp, are installed on the roof of the wheelhouse. The collective ability for installing solar panels on 20 GT fishing boats is 14 units, each with a power capacity of 250 Wp and dimensions measuring 1650 x 992 x 40 mm. The positioning of solar panels is strategically altered, considering the fishing activities conducted aboard the boat. This adjustment minimises potential disruption to the fishermen's labour or fish-catching activities.

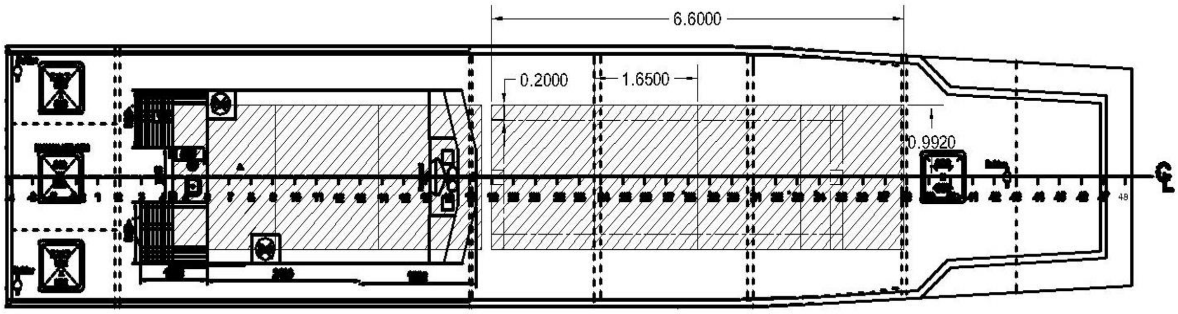

Figure 4. Solar Panel Placement Area

To calculate the power output of 14 solar panels, use equation (2), where ηs, ηc, represents 80% solar panel efficiency, and ηc represents 85% converter efficiency. The power output is 14.3 kWh. Solar energy in the solar system will enable nighttime lighting. Thus, the battery is essential. This voyage's length depends on the haul. Therefore, the battery specification is:

TABLE 5.
BATTERY SPECIFICATIONS

Nominal Voltage	Unit	12 V
Nominal capacity @ 1C	Ah	200 Ah
Cycleuse	V	14,4 – 15,0
Standbyuse	V	13,35 – 13,80
Initial Current	A	8,40
Weight	Kg	7,70
Dimensions L x W x H	mm	165 x 125 x 182

The number of batteries obtained is 2. We will use two batteries of 12 V, 200 Ah, connected in parallel to design a reliable system. Deep cycle gel battery because deep cycle battery ensures a quick recovery during use. With this feature, the battery can withstand the potentially damaging effects of continual deep discharge and recharge. Gel type is chosen because they are maintenance-free, spillproof, submersible, leakproof, and handle the highest lifetime charging cycles.

To prevent over-charging and over-discharging of the battery, a charge controller is needed to control the current flow and voltage flow. The charge controller must be rated for the correct current (Imax from the PV array) and voltage and be suitable for the chosen battery type. The charge controller acts as a big switch that disconnects or dumps the power from the PV array when the battery voltage is too high. Considering Indonesia's weather and climate situation, where the daily temperature can go up high, the charge controller has to have a temperature compensation and be fully encapsulated.

3.3 Economic Calculation

As a result of the world oil price rise, the government also increased the diesel fuel price in Indonesia.

TABLE 6.
EXPENDITURE OF FISHERMEN

No	Expenditures	Requirement Per Trip	Price Per Unit (IDR)	Cost Per Day (IDR)	Cost Per Day (USD)
1	Diesel Fuel for Engine	2250 liters	6800	15300000	976
2	Diesel Fuel for Generator	450 liters	6800	3060000	195
3	Ice	30 kg	1000	30000	2
4	Fresh Water	1000 litres	500	500000	32
5	Fisherman Food	Food For 5 Crew	50000	250000	16
		Total		19140000	1221

The replacement of diesel generators implies a potential cost savings of IDR 3,060,000 for each fishing trip, as indicated in Table 6. While that amount may seem relatively small compared to the overall expenses incurred on diesel fuel (constituting 15% of the fuel expenditure), it is essential to note that this cumulative value will amount to a significant sum over five years. One of the challenges encountered in implementing photovoltaic (PV) systems is the substantial upfront expenditure required. However, considering the extended lifespan of the PV system compared to the conventional electric power supply system aboard vessels and its zero operational cost concept, it becomes evident that the PV system offers greater long-term profitability.

Assuming a scenario in which the off-grid solar system is intended to replace the existing diesel generator system, it is essential to note that specific components, such as the VHF radio and associated cables, which are already installed and will continue to be utilized in the off-grid solar system, will not be factored into the financial calculations.

TABLE 7.
TOTAL INVESTMENT

No	Component	Unit	Price (IDR)	Total
1	PV Module	14	3500000	49000000
2	Battery	2	4500000	9000000
3	Charger Controller	1	2000000	2000000
4	LED Lamps	24	25000	600000
5	Inverter	1	4500000	4500000
	Total			65100000

In the current system, CFL bulbs need replacement approximately every two years, while LED lamps can last up to 10 years. The replacement of a diesel generator is required every three years. In contrast, the battery is the only component requiring repair within the solar system. The average battery lifespan in a solar system is around ten years, whereas photovoltaic (PV) modules have a longer lifespan of up to 20 years. The typical battery does not require any care, and regular cleaning is the only maintenance needed for the module.

The study of return on investment (ROI) calculations follows the regulations outlined in Minister of Energy and Mineral Resources No. 17 of 2013. These regulations specifically address energy procurement from photovoltaic solar power plants for a 20 GT fishing vessel. The annual cash calculation yielded a total of Rp.19,701,123. Table 8 shows that a 20-GT fishing vessel recovers its initial investment in 3.3 years.

3.4 Emission Calculation

The regulations governing emissions from motor vehicles and other forms of transportation are outlined in Table 9 below.

TABLE 8.
PAYBACK PERIOD

No	**GT**	**Total Investment**	**Cash Flow**	**Result**
1	20	Rp.65,1000,000, -	Rp.19,701,123, -	3,3

TABLE 9.
EXHAUST EMISSION STANDARDS

No	Air Quality Parameter	Element	Emission Factor (gr/litre)
1	Sulfur Dioxide	SO_2	0.5985
2	Lead Black	Pb	0.07
3	Oxidant	O_3	0.6821
4	Nitrogen Oxide	NO_2	13.542
5	Particulate matter< 10 µm	PM_{10}	0.6033
6	Dust	-	0.5985
7	Carbon Monoxide	CO	1.145
8	Carbon Dioxide	CO_2	32.000

The following table provides an overview of the fuel consumption needs for this fishing vessel in the meantime:

TABLE 10.
FUEL CONSUMPTION

Capacity	Type	Duration (h)	Power (kW)	SFOC
20 GT	Dongfeng	6	15	0.022878

TABLE 11.
EXHAUST GAS EMISSION

No	Parameter	Emission Factor (Ton/litre)	SFOC (Ton)	Emission of Auxiliary (Ton/Day)	Emission of Auxiliary per Year (Ton)
1	(SO2)	0.000599	0.0229	0.000013692	0.029
2	(Pb)	0.000070	0.0229	0.000001601	0.003
3	(O3)	0.000628	0.0229	0.000014370	0.030
4	(NO2)	0.013542	0.0229	0.000309814	0.652
5	(PM10)	0.000603	0.0229	0.000013802	0.029
6	Dust	0.000599	0.0229	0.000013692	0.029
7	(CO)	0.001145	0.0229	0.000026195	0.055
8	(CO2)	3.200000	0.0229	0.073209600	154.179
		Total		0.1	155.007

The emissions of auxiliary engines on 20 GT fishing vessels are determined by the emission factors and daily fuel consumption, resulting in a total computation of 0.1 tons per day, as indicated in the table. The annual exhaust emissions of auxiliary engines on the fleet are calculated by multiplying the emission factor of each auxiliary engine by the operational period for one year. The cumulative result of this calculation yields a total annual emission of 155.007 tons.

The most significant emissions in terms of exhaust gases are carbon dioxide (CO2). Carbon dioxide in the atmosphere leads to the depletion of the ozone layer, intensification of the greenhouse effect, and retention of solar radiation within Earth's atmosphere. This phenomenon results in a global rise in temperature by several degrees, causing the melting of polar ice and subsequent expansion of the Earth's water surface. Nitrogen dioxide (NO2) is a prominent air pollutant that can lead to the formation of Peroxy Acetyl Nitrates (PAN), inducing ocular irritation, discomfort, and increased lacrimation.

Carbon dioxide (CO2) is a significant contributor to air pollution, and its presence in the atmosphere can lead to the depletion of the ozone layer. This, in turn, exacerbates the greenhouse effect, as sunlight and heat entering Earth's atmosphere become trapped, preventing their release into space. Consequently, the global temperature rises by several degrees, resulting in the melting of polar ice and an expansion of the Earth's water surface. Excessive levels of carbon monoxide can inhibit oxygen delivery to the body, disrupting neuron and heart function. In cases of significant exposure, carbon monoxide poisoning may occur, manifesting as symptoms such as weakness, dizziness, and unconsciousness.

IV. CONCLUSION

The findings of this study affirm that solar photovoltaic (PV) systems can serve as a viable alternative energy source for fishing vessels. However, it is important to note that the current capacity of these systems is still insufficient to fully meet the energy needs of the large machinery on board. Nevertheless, this proposition is financially appealing and demonstrates technological feasibility. Furthermore, the increasing cost of fossil-based fuels worldwide makes this replacement advantageous for small-scale fishing vessels, as it reduces their vulnerability to fluctuations in fuel prices. From a broader perspective, this substitution is expected to reduce poverty among fishermen by facilitating increased income.

The analysis results can be summarized as follows: It can be inferred that the initial capital investment for PV systems is generally substantial, except for traditional national fishing vessels with a capacity of 20 GT, which cost approximately Rp 65,100,000. However, in terms of long-term profitability, the investment value of PV systems exceeds that of auxiliary engines on fishing vessels, as indicated by the Return on Investment (ROI) results, showing a payback period of 3 years. Replacing CFL lamps with LED lights can save energy by 5 kWh.

The analysis of exhaust emissions from photovoltaic (PV) systems yields a notable conclusion regarding environmental friendliness. PV systems exhibit a complete absence of exhaust emissions, unlike auxiliary engines used on ships that generate substantial exhaust emissions, totalling 155,007 tons per year. The latter can contribute to air pollution and harm the natural environment. As the vessel's dimensions expand, there will be a corresponding rise in energy requirements. From a financial and environmental perspective, the progressive use of solar photovoltaic (PV) systems is expected to become increasingly appealing.

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