

Technical Analysis of the Solar-Assisted Fish Cooling System for Fishing Boat

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KEYWORDS

*Fishing vessels;
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ABSTRACT Marine pollution associated with conventional fishing operations has encouraged the search for cleaner and more practical technologies for small fishing vessels. One potential solution is the use of Solar Power Systems (SPS) to supply electricity for onboard refrigeration, thereby reducing reliance on ice blocks for fish preservation. However, integrating an off-grid solar system into a fishing vessel is not straightforward. Limited deck and roof space must be considered alongside the additional weight of solar panels, batteries, inverters, and cooling boxes, all of which may influence vessel stability. This study therefore examines the technical feasibility of installing rooftop solar panels on a 13.5 m LOA fishing vessel with a breadth of 2.5 m, draft of 0.8 m, and a 5 m³ cargo hold capable of carrying up to 2.5 tons of fish. The optimization results show that the available roof area can accommodate eight 500 Wp solar panels, producing approximately 14.92 kWh/day. This energy output is sufficient to operate five refrigeration units, each measuring 0.9 × 0.6 × 0.85 m. Under this configuration, 40% of the fish cargo can be stored in refrigerated cool boxes, while the remaining 60% continues to be preserved using ice blocks. The stability assessment further indicates that the combined installation of rooftop solar panels, refrigeration boxes, and batteries remains compliant with IMO Standard A.749(18) Chapter 3. These findings demonstrate that the proposed system is not only technically feasible but also safe for practical application in maritime fishing operations.

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INTRODUCTION

As an archipelagic country with nearly 70% of its territory consisting of maritime areas, Indonesia holds substantial marine resource potential, particularly in the fisheries sector. However, this potential has not yet been fully translated into improved welfare for the wider population, especially for coastal fishing communities. Although fisheries represent one of Indonesia's strategic economic assets, the sector has often received less policy attention than land-based development sectors. This imbalance is reflected, among other things, in the relatively limited scale of Indonesia's fishing fleet. Data from the Ministry of Marine Affairs and Fisheries (KKP) indicate that only 4,470 vessels are officially registered, a figure that remains considerably low when compared with other major fishing nations. China, for example, operated more than 200,000 fishing vessels and recorded a total catch of 61.7 million tons in 2013. Even so, Indonesia's fisheries sector continues to contribute meaningfully to state revenue, as shown by capture fisheries production reaching 7.07 million tons in 2017 [1].

Effective cooling plays a central role in maintaining fish quality after harvest. Once fish die, deterioration begins through two main processes: enzymatic autolysis and bacterial growth. These processes occur naturally, but they are greatly intensified under high-temperature conditions. Enzymatic activity breaks down muscle tissue, causing undesirable changes in texture, taste, and odor. In parallel, spoilage bacteria originating from the fish itself and from the surrounding environment multiply more rapidly in warm conditions. Their metabolic activity produces compounds such as ammonia and trimethylamine, which are responsible for unpleasant odors and can make fish unsuitable for human consumption. Without adequate cooling, the quality of fresh catch may decline within only a few hours; this problem is especially critical in tropical regions, where the commercial value of fish may be entirely lost in less than 24 hours [2]. Previous studies have also shown that limited access to storage facilities often forces fishers to sell their catch immediately, frequently at lower prices [3]. In this context, high ambient temperatures, delays in marketing, and inadequate storage infrastructure are key drivers of

post-harvest losses in fisheries [4]. Strengthening the fish cold chain is therefore essential, not only to reduce spoilage but also to improve food security and increase the economic returns obtained from fishery products [5].

Maintaining fish at low temperatures is essential for slowing decomposition and preserving freshness after harvest. The ideal storage temperature is generally considered to be 0°C, which falls safely within the recommended range of -1°C to +4°C [6]. Within this temperature range, enzymatic reactions and the growth of spoilage bacteria are substantially reduced, allowing the fish to retain its quality for a longer period. For this reason, temperature control must be maintained consistently during both storage and transportation. Even small fluctuations may restart autolytic processes and accelerate quality degradation. When produced and handled under sanitary conditions, bulk ice, including flake ice or crushed ice, remains one of the most practical and effective chilling methods. Its direct contact with the fish enables rapid reduction of core temperature while also promoting an even distribution of cooling throughout the stored catch.

At the same time, marine capture fisheries also present an environmental challenge, particularly through emissions generated by fishing vessels. In Indonesia, where fish preservation still depends largely on conventional ice-based systems, fishing boats are often required to return to port within a relatively short period to avoid post-harvest quality losses. This operating pattern can increase the frequency of trips and, consequently, overall fuel consumption. Such conditions make fisheries part of the broader discussion on maritime decarbonization. At the international level, this concern has become increasingly urgent, as the International Maritime Organization (IMO) has strengthened its climate strategy by setting a target for international shipping to reach net-zero greenhouse gas emissions by or around 2050 [7].

The adoption of renewable energy represents an important strategy for reducing air pollution from maritime activities. Previous studies have explored several approaches to integrating renewable energy into fishing vessels. For example, Nikmatullah et al. [8] investigated the modification of fishing boat outriggers as a means of generating electrical power, although the resulting system produced relatively limited output. In another configuration, Setiyobudi et al. [9] assessed the use of a hybrid system combining solar photovoltaic (PV) panels and wind turbines to support the electric propulsion of a 14-meter Blue Swimming Crab (BSC) fishing vessel. More broadly, the integration of solar PV systems into small-scale fishing vessels has been shown to reduce fuel consumption and related emissions, particularly when the generated electricity is used to supply auxiliary loads [10]. For small fishing craft, solar energy offers a practical and environmentally friendly option for meeting essential onboard electrical needs, such as navigation, lighting, and refrigeration. Given the availability of abundant solar radiation, this technology provides a promising pathway for modernizing traditional fishing vessels in a more sustainable manner [11].

In this context, solar power can be used to supply electricity for onboard refrigeration units that preserve the quality of the catch. Proper handling of fish must begin immediately after capture and continue through the storage process. Maintaining strict temperature control is therefore essential to ensure food safety and preserve product quality. This requirement is based on the principle that fish quality cannot be improved after harvest; it can only be maintained through appropriate handling and storage practices [12] [13].

METHODS

The methodological framework of this study is presented in the flowchart in Figure 1. The process begins with the modification of the vessel's superstructure geometry. This stage is necessary because the superstructure must provide sufficient and efficient roof area for the installation of the maximum possible number of solar panels without compromising the overall vessel design.



Figure 1. Fishing Vessels that are Used as Research Objects

The baseline vessel used as the reference model for integrating the solar panel system and onboard cooling arrangement is shown in Figure 1. Its main hydrostatic characteristics are subsequently summarized in Table 1.

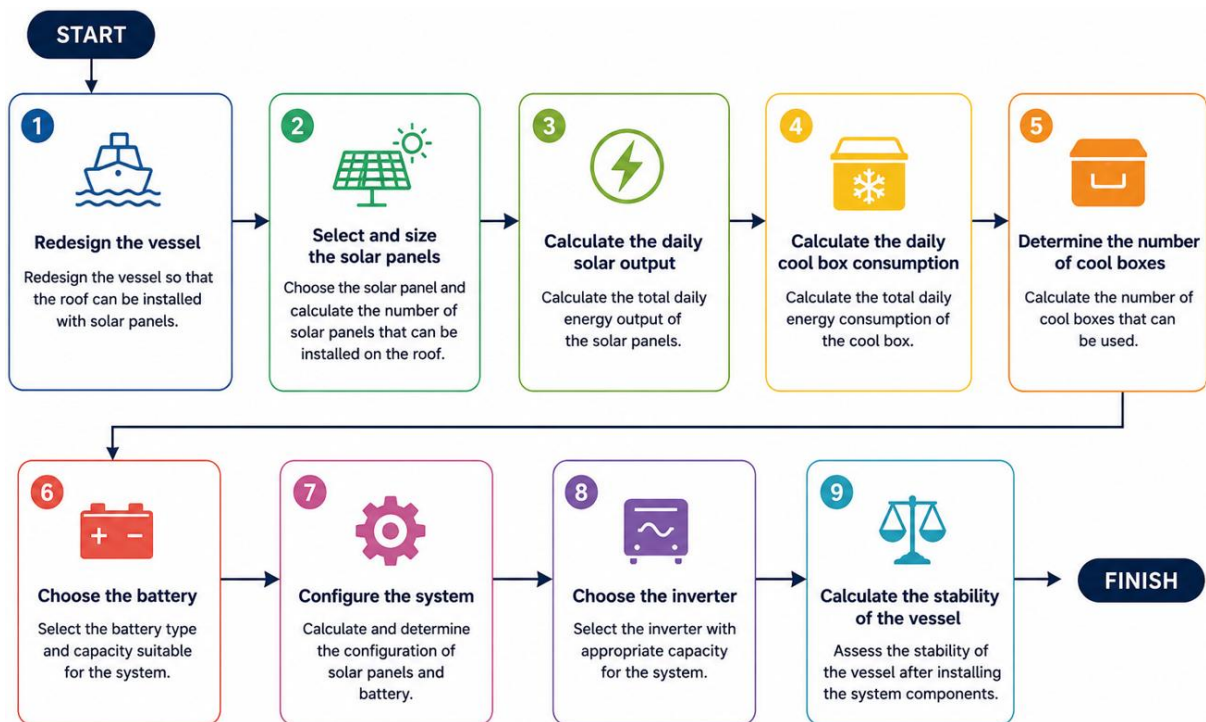


Figure 2. Flowchart of the research

The choice of the solar array was dictated by the surface area available on the vessel. Next, the potential of the system’s power production was examined based on the equatorial geographical coordinates of Balikpapan, and the solar radiation intensity was obtained from the Global Horizontal Irradiation (GHI) data. Using the data from the Global Solar Atlas, the Peak Sun Hours (PSH) can be obtained to calculate the daily energy output:

$$\text{Daily solar panel output} = \text{Solar Panel Capacity} \times \text{PSH} \times \text{Efficiency} \quad (1)$$

The power of the solar panels will be used to power cool boxes. The dimension of the cool box is 0.9 x 0.6 x 0.85 m for each cool box for length, width, and height, respectively. The power for the single cool box is 200 watts. The total daily consumption of cool boxes is

$$\text{Daily consumption a cool box} = \text{coll box consumption} \times 24 \text{ hours} \times \text{duty cycclle} \quad (2)$$

From the daily solar panel output, we can calculate how many boxes can be installed; this can be calculated as follows:

$$\text{Number of cool box} = \frac{\text{Daily solar panel output}}{\text{Daily consumption}} \quad (3)$$

Then we calculate the configuration of battery and the inverter. After the modeled installation of the solar panels on the roof, the cool box inside the storage hold and the batteries in the hull, a complete vessel stability analysis was performed strictly according to the IMO A.749 (18) Code standards

RESULTS AND DISCUSSION

Sizing the Solar Photovoltaic System Based on Available Vessel Roof Area

The fishing vessel was modelled using the student version of Maxsurf to determine an appropriate hull form and dimensional arrangement for integrating rooftop solar panels and a cooling system within the fish hold. Corresponding hydrostatic parameters are summarized in Table 1. In developing the model, the hull geometry was constructed to closely represent the actual vessel, so that the subsequent design and stability assessment could reflect realistic operating conditions.

Tabel 1. Hydrostatic data of the vessel

Measurement	Value	Units
Displacement	13.64	t
Volume (displaced)	13.305	m ³
Draft Amidships	0.800	m
Immersed depth	0.800	m
WL Length	12.231	m
Beam max extents on WL	2.486	m
Wetted Area	46.065	m ²
Max sect. area	1.370	m ²
Waterplane Area	26.980	m ²

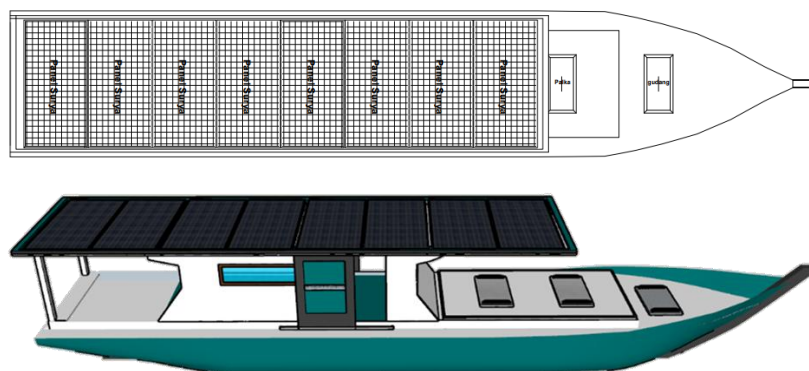


Figure 3. Installation of 8 Solar Panel on the Roof of the Vessel

Figure 3 presents the arrangement of the solar panel array installed on the vessel's roof. The available rooftop area measures 9.8 m × 2.2 m, which provides sufficient space for the installation of eight solar panels. Placing the PV modules on an open and unobstructed deckhouse roof allows the panels to receive greater exposure to solar irradiation, thereby supporting more effective energy generation. Based on the available roof dimensions, the system can accommodate eight panels, each with a rated peak capacity of 500 Wp. The detailed technical specifications of the selected solar panels are provided in Table 2.

Tabel 2. Battery Specification

Specification	description
Maximum Power (Pmax)	500 Wp
Tolerance	+/- 5%
Voltage at Pmax (Vmp)	42.8V
Current at Pmax (Imp)	11.69A
Open Circuit Voltage (Voc)	51.7V
Short Circuit Current (Isc)	12.28A
Normal Operating Cell Temp (NOCT)	43 +/-2°C
Maximum System Voltage	1500VDC
Maximum Series Fuse Rating	25A
Operating Temperature	-40°C to +85°C
Application Class	Class A
Fire Safety	Class C
Cell Technology	Mono-Si
Weight	26.5 kg
Dimension panel (mm)	2185 x 1098 x 35
Number of Cell	150cell (5 x 30)

Power generation from solar panel

The power output of photovoltaic (PV) systems is strictly proportional to solar irradiation in a direct connection. The Global Horizontal Irradiation (GHI) statistics were obtained from the platform of Global Solar

Atlas [14] to determine the daily energy yield of the proposed system. The average daily GHI for the Balikpapan area from this database is 4.608 kWh/m² per day as seen in Figure 4.

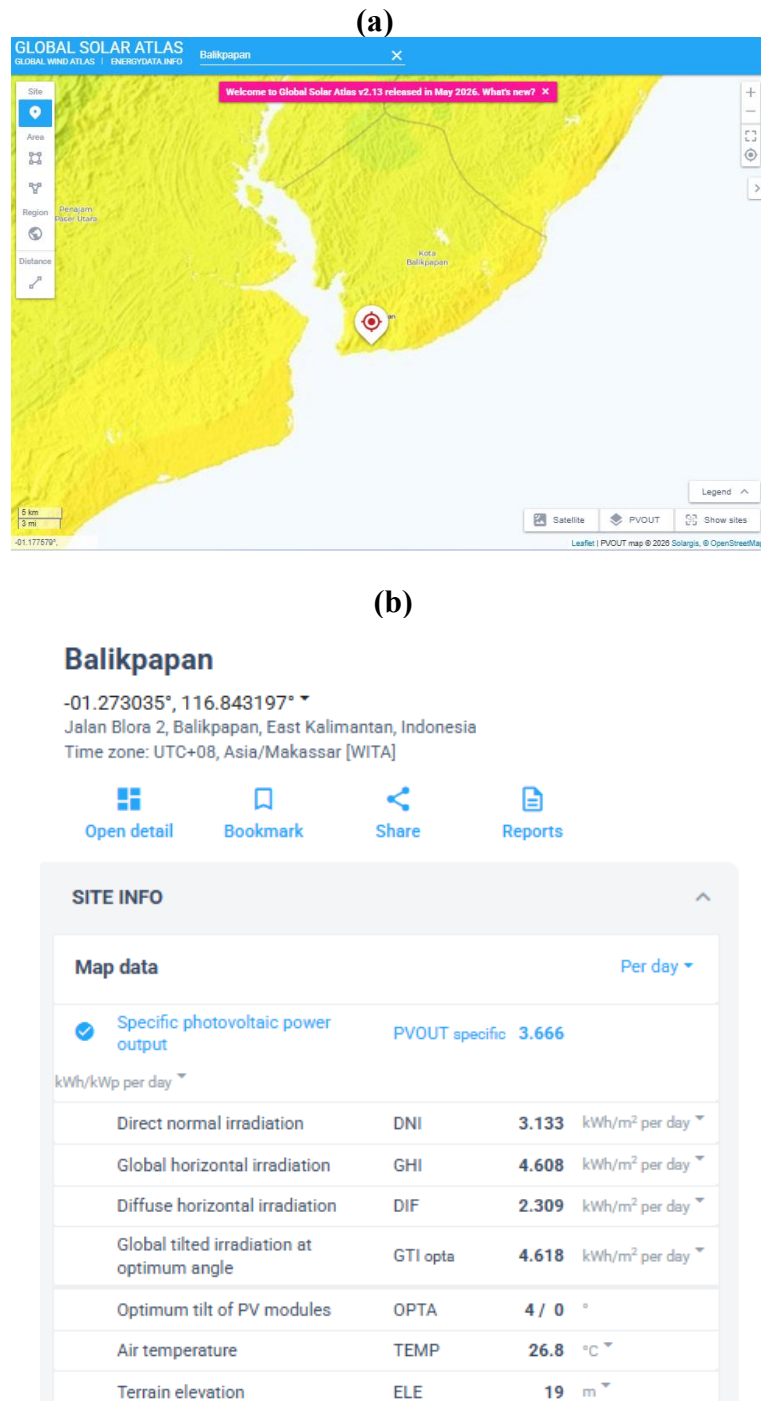


Figure 4. The map of sailing area of the vessel around Balikpapan (a) and The value Global horizontal irradiation (b)

The daily energy production of the photovoltaic system was estimated using Peak Sun Hours (PSH) data obtained from the Global Solar Atlas. By applying a solar panel efficiency factor of 0.8, the system is projected to generate approximately 14.92 kWh of energy per day. Each cool box requires 200 W of power, resulting in a daily energy demand of 2.88 kWh per unit. Since the duty cycle of refrigeration units typically ranges from 50% to 60%, this study adopts a conservative duty cycle of 60% to ensure reliable system performance.

Based on this energy demand, the photovoltaic system can theoretically support up to 5.18 cooling units. For practical and reliability considerations, this value is rounded down to five cool boxes. The solar panel

arrangement is configured as two panels in series and four strings in parallel, producing a string voltage of 85.6 V and a total current of 46.76 A. With five cool boxes in operation, the total daily energy requirement is 14.4 kWh, which remains slightly below the estimated photovoltaic generation of 14.92 kWh per day.

To ensure efficient power delivery to the Solar Charge Controller (SCC) or inverter, the solar array configuration must be matched with the maximum input voltage limit of the selected components. For a standard 48 V system architecture, a series-parallel configuration is applied, resulting in a design voltage of 342.4 V, calculated from 8×42.8 V, and a total design current of 23.38 A, calculated from 2×11.69 A.

Battery capacity was then determined to provide system autonomy during two consecutive days without solar irradiation. Under this condition, the battery bank must be able to supply a total load of 28.8 kWh, based on 14.4 kWh per day for two days. By applying a conservative Depth of Discharge (DoD) limit of 80%, the required nominal battery storage capacity increases to 36 kWh, obtained from 28.8 kWh divided by 0.80. At a system voltage of 48 V, this requirement corresponds to a battery capacity of 750 Ah, calculated from 36,000 Wh divided by 48 V. To meet this storage requirement, the system uses a battery bank consisting of standard 48 V 100 Ah LiFePO₄ battery modules. The technical specifications of the selected batteries presented in Table 3.

Table 3. Battery Specification

Specifications	Description
Weight	56 kg
Dimension	600 x 430 x 42.5 mm
Capacity	100 Ah
Terminal	T19
Charging Voltage	52.5 V

Battery capacity determines the duration for which the system can operate independently, while inverter capacity is governed by the total power demand of all devices operating simultaneously. In this study, the configuration of the five cooling units is fixed; therefore, both the continuous load and the associated starting surge are treated as constant design requirements. Based on these conditions, the system requires a hybrid inverter equipped with an integrated MPPT-type Solar Charge Controller (SCC), with a recommended charging current capacity of at least 60 A to 80 A. The selected inverter incorporates a high-capacity MPPT controller to optimize the power harvested from the eight solar panels, enabling the system to supply the cooling load while also recharging the 800 Ah battery bank, particularly when the batteries are operating from a low state of charge.

Stability Calculation

To assess the hydrostatic safety of the vessel after the installation of the solar photovoltaic system and refrigeration units, stability analyses were carried out under several operational loading conditions. This is important because ship stability that does not comply with IMO standards will cause the ship to capsize during operation [15]. The quantitative results for the no-cargo, 50% cargo, and 100% full-load conditions are summarized in Table 4 and compared with the relevant international stability requirements. The results indicate that the modified vessel maintains strong righting lever characteristics under all evaluated loading scenarios. These values remain above the minimum criteria specified by the International Maritime Organization (IMO) in Code A.749(18), Chapter 3. The dynamic stability criterion, represented by the area under the righting lever curve between 0° and 30°, ranges from 5.43 m.deg in the no-cargo condition to 5.84 m.deg under full-load condition. These results exceed the required minimum value of 3.15 m.deg. In the same manner, the total area up to 40° also remains higher than the regulatory threshold of 5.16 m.deg in all loading conditions, reaching a maximum value of 9.03 m.deg when the vessel is fully loaded.

Table 4. the stability criteria under no-cargo, 50% cargo, and 100% full-load scenarios

Criteria	Unit	Min	No cargo	50 %	100%	Description
Area 0° - 30°	m.deg	3.15	5.43	5.68	5.84	Pass
Area 0° - 40°	m.deg	5.16	8.53	8.88	9.03	Pass
Area 30° - 40°	m.deg	1.71	3.09	3.19	3.19	Pass
Max GZ at 30 or greater	m	0.2	0.31	0.32	0.32	Pass
Angle of maximum GZ	deg	25	33.2	33.2	32.3	Pass
Initial GMt	m	0.25	0.77	0.82	0.87	Pass

CONCLUSION

This study confirms the technical and structural feasibility of installing a solar photovoltaic (PV)-powered refrigeration system on a traditional fishing vessel operating in the Balikpapan region. Based on the engineering design process and optimization analysis, two main conclusions can be drawn. The optimization of the vessel's superstructure provides sufficient roof area for the installation of eight solar panels, with a total installed capacity of 4,000 Wp, derived from eight 500 Wp panels. This arrangement is capable of producing an estimated daily energy output of 14.92 kWh, which is adequate to supply five onboard refrigerated cool boxes, each requiring 1.88 kWh. To support reliable off-grid operation and maintain continuous cooling during periods of limited solar irradiation, the system is equipped with an energy storage bank consisting of eight 48 V, 100 Ah batteries. The integration of rooftop solar panels, internal battery banks, and refrigeration units changes the vessel's overall weight distribution. Nevertheless, the hydrostatic assessment and stability calculations show that the modified vessel remains within acceptable safety limits. The results confirm that the proposed configuration complies with the international stability requirements specified in IMO Standard A.749(18), Chapter 3.

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