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Design and Energy Cost Evaluation of a Portable Cold Storage Unit for Tuna Fish Using the LCOE Approach †

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Abstract

Indonesia has significant fisheries potential; however, limited cold chain infrastructure at small-scale fishing ports contributes to post-harvest losses and quality degradation of fishery products. This study presents the design and techno-economic assessment of a modular portable cold storage unit for tuna fisheries integrated with renewable energy systems. The system (7 × 3 × 5 m) uses polyurethane sandwich panels and requires a maximum cooling load of 6.14 kW with peak power consumption of 7.93 kW. The estimated capital cost is approximately USD 34,100, while the operational cost is about USD 198 per cycle. A comparative analysis using the Levelized Cost of Energy (LCOE) method indicates that diesel generators provide the lowest cost at approximately USD 0.56/kWh, whereas standalone photovoltaic (PV) systems exhibit the highest cost at around USD 0.89/kWh. However, hybrid PV systems offer the best balance between cost efficiency and environmental performance by reducing carbon emissions. The results demonstrate that integrating hybrid renewable energy into modular cold storage enhances cold chain reliability, reduces fish losses, and supports sustainable coastal development. This approach contributes to low-carbon fisheries infrastructure and aligns with global sustainability and renewable energy transition goals.

Keywords: modular cold storage; renewable energy; hybrid PV; fisheries sustainability; LCOE

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1. Introduction

Indonesia is widely recognized as one of the world's largest maritime nations, with marine waters covering more than two-thirds of its total territory. According to the Food and Agriculture Organization (FAO), Indonesia consistently ranks among the top global fish-producing countries, contributing significantly to capture fisheries and aquaculture production worldwide [1]. The fisheries sector plays a strategic role in national food security, employment generation, and export earnings. Data from the Ministry of Marine Affairs and Fisheries of the Republic of Indonesia (KKP) indicate substantial annual landings of high-value species such as tuna, which represent an important commodity in both domestic and international markets [2].

Tuna fisheries, in particular, are economically vital due to their high-protein content, export value, and global demand [3]. Indonesia is one of the major producers of tropical

tuna species, supplying key markets in Asia, Europe, and North America [4]. However, despite high production potential, post-harvest losses remain a persistent challenge in many coastal and island regions [5]. The main contributing factor is the limited implementation of an effective cold chain system, especially at small-scale fishing ports and remote landing sites [6].

Fish is a highly perishable product with rapid biochemical and microbiological degradation processes occurring shortly after capture [7]. Without adequate temperature control, quality deterioration can occur within 4–5 days under ambient tropical conditions [8]. Cold storage technology is therefore essential to slow microbial growth and enzymatic activity, thereby extending shelf life and maintaining product quality [9]. At temperatures between 0 °C and 5 °C, fish freshness can be preserved for short-term storage, while freezing below 0 °C significantly prolongs storage life up to several months [10]. Proper refrigeration systems not only maintain quality but also stabilize market prices by reducing oversupply during peak fishing seasons [11].

Nevertheless, cold storage infrastructure in many Indonesian coastal districts, including small fishing communities and archipelagic areas, remains inadequate [12]. High capital investment, energy consumption, and dependence on grid electricity often limit cold storage deployment in remote regions [13]. Several studies have proposed hybrid or renewable-energy-based cold storage systems to address energy reliability and sustainability issues, particularly solar-powered or hybrid photovoltaic–diesel configurations [14,15]. These systems demonstrate potential in reducing operational costs and greenhouse gas emissions while improving cold chain resilience.

Although hybrid cold storage solutions have been explored, most existing designs are fixed installations with limited portability and scalability [16]. There remains a significant gap in the development of modular, portable cold storage units specifically designed for small fishing ports and island communities, where infrastructure constraints and mobility needs are critical considerations [17]. Modular systems offer advantages in ease of transportation, rapid installation, scalability, and adaptability to varying catch volumes [18]. Furthermore, evaluating the economic feasibility of such systems using the Levelized Cost of Energy (LCOE) approach provides a comprehensive assessment of lifecycle cost performance and long-term sustainability [19].

The Levelized Cost of Energy methodology is widely applied in energy system analysis to compare total lifecycle costs relative to energy output, enabling objective evaluation of capital-intensive systems such as refrigeration facilities [20]. Applying LCOE in cold storage design allows stakeholders to assess not only initial investment but also operational, maintenance, and energy costs over the system's lifetime [21]. This economic perspective is particularly important for fisheries infrastructure projects in developing regions, where financial viability strongly influences adoption rates [22].

Therefore, this study aims to design a modular portable cold storage unit for tuna fish products tailored to coastal and island conditions in Indonesia. The design incorporates structural analysis, cooling load calculations, and power consumption estimation, followed by economic evaluation using the LCOE approach. By addressing technical and economic aspects simultaneously, this research seeks to provide a feasible and scalable solution to strengthen cold chain infrastructure and reduce post-harvest losses in Indonesia's fisheries sector.

2. Research Methods

The research methodology adopted in this study follows a systematic engineering design approach, beginning with problem identification and ending with economic feasibility evaluation as shown in Figure 1. The primary problem addressed is the limited

availability of adequate cold chain infrastructure at small-scale fish landing and auction facilities, which contributes to rapid deterioration of tuna and other fishery products after landing. To ensure contextual and technical relevance, a case study location was selected at the Fish Auction Place (Tempat Pelelangan Ikan–TPI) Cituis, located in Surya Bahari Village, Pakuhaji District, Tangerang Regency, Banten Province, Indonesia as shown in Figure 2. TPI Cituis, established in 2003 and fully operational since 2012, serves as a central hub for local fishermen operating small-scale vessels, where landed catches are auctioned to traders and distributors. As the third-largest fish auction facility in Tangerang Regency, it plays a strategic role in supporting the regional fisheries supply chain and coastal economy. The proposed cold storage design site is located at coordinates −6.1180129886142955 latitude and 106.22667894814602 longitude, in a coastal lowland area adjacent to the Java Sea, where fisheries activities dominate the local livelihood structure as shown in Figure 2.

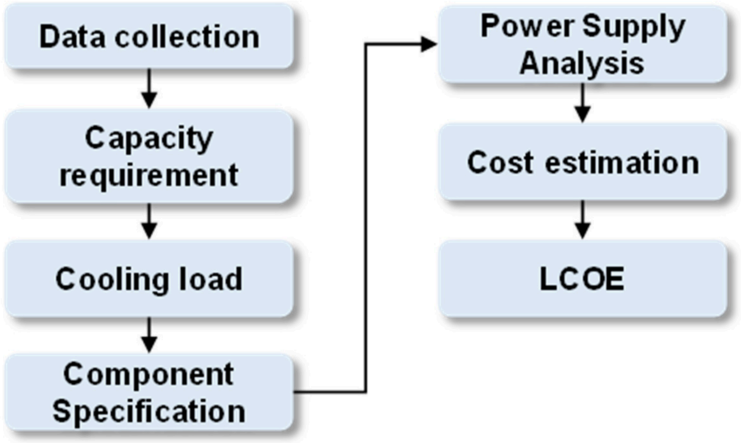


Figure 1. Research methods.



Figure 2. Map of case study. The map illustrates the location of the study site in coastal Indonesia, highlighting the selected small-scale fishing port and surrounding operational area. Source: adapted from Google Maps (2026).

A site feasibility assessment was conducted in accordance with Standard Number 8661:2023 concerning warehouse and cold storage facility requirements [23]. The selected location complies with the standard criteria, as it is free from flood, tidal inundation (rob), and landslide risks; spatially separated from surrounding buildings to ensure safety, health, and environmental protection; and located away from potential contamination sources that could affect the quality of stored fishery products. In terms of transportation

access classification, the site falls under Special Class II, indicating adequate accessibility to support fisheries logistics and distribution activities.

Following site determination, environmental data such as ambient temperature and humidity, along with fisheries production data, were collected to establish design parameters. The engineering design phase began with the development of a preliminary layout and estimation of cold storage dimensions based on production capacity requirements and site constraints. Structural considerations included the use of polyurethane sandwich panels for thermal insulation, steel framing for structural support, and insulated flooring systems to minimize heat gain. Cooling load calculations were then performed to determine the total refrigeration requirement. The total cooling load consisted of transmission loads through walls, roof, and floor; infiltration loads due to door operation; product loads from incoming fish; and internal loads from lighting and equipment. The peak cooling load value was used as the basis for selecting refrigeration system components and determining compressor capacity. Based on the installed refrigeration system, total electrical power consumption under maximum operating conditions was estimated.

Cold storage is planned to have dimensions of 7 m × 3 m × 5 m with a volume of 105 m^3. The entire volume cannot be utilized for product storage, as allowances must be made for air circulation, structural elements, and handling space to ensure effective thermal performance. For small-scale cold storage systems, an effective volumetric utilization factor in the range of 50–60% is commonly adopted. Accordingly, the usable storage volume is estimated to be approximately 52–63 m^3. Assuming a bulk density of boxed tuna, including packaging and interstitial voids, in the range of 200–250 kg/m^3, the corresponding storage capacity is estimated to be between 10.4 and 15.8 tons. Based on this range, a nominal design capacity of 13 tons is selected as a representative and operationally feasible value. This capacity accounts for practical stacking configurations, adequate airflow distribution to prevent thermal non-uniformity, and the intended short-term storage regime prior to auction.

Polyurethane is used as wall insulation while stainless is used as a frame. The polyurethane has a thickness of 80 mm and a density of 43 kg/m^3. Polyurethane panels have a thermal transmittance (U-value) of 0.28 $W/(m^2 \cdot K)$. The design of the proposed cold storage is shown in Figure 3. In the distribution flow for tuna fish, fishermen will store the fish they catch while waiting for the auction. This is done to ensure the freshness of the fish at auction. For the case study in the northern coastal region of Banten, all input parameters used in the thermal load calculation are defined based on typical environmental and operational conditions of small-scale fisheries in tropical coastal areas. The ambient air temperature is assumed to range between 30 and 34 °C with relative humidity of 70–85%, reflecting the hot and humid climate of the region.

The fish cooling scheme is carried out with pre-cooling and main cooling. Pre-cooling starts from an initial temperature of 30 °C and is cooled to a temperature of 5 °C; the cooling process lasts for 3 h; the cooling preparation process and the fish storage process are also included. The main cooling stage consists of the fish being put into cold storage, cooled to a temperature of −10 °C; the product is released when the auction starts.

Based on the Load Calculation Application Manual released by ASHRAE [24], to determine the amount of transferred load, it is important to estimate the heat transmission from inside or outside the space using three modes of heat transfer-conduction, convection, and radiation-in cold storage and in between the building envelope and its surroundings. Transmission loads are loads that originate from heat transfer to walls, roofs, and floors.

This load calculation can be separated based on the differences in the insulation material used for walls, floors, and roofs. In analyzing transmission loads using Equation (1).

$$Q = U \times A \times (T_{External} - T_{Internal}) \times \frac{24}{100} \left(\frac{\text{kWh}}{\text{day}} \right) \quad (1)$$

The calculation formula based on ASHRAE using Equation (2).

$$Q = A \times Sun\ Gain\ or\ \Delta T \times Factor \quad (2)$$

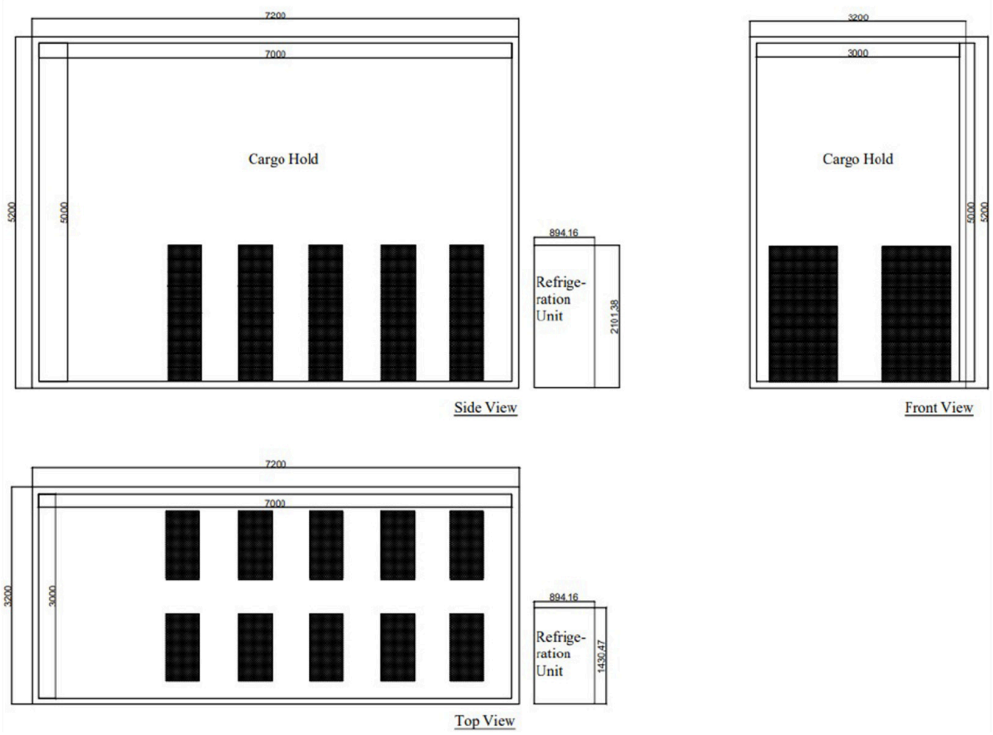


Figure 3. Layout of cold storage.

Product load is the amount of heat generated from stored products and input in cold storage. This calculation is divided into two, namely the calculation when the product experiences a decrease in temperature (sensible heat) and when the product undergoes a phase change (latent heat). The calculation of the heat transferred when the temperature decreases is carried out using the following formula:

The product heat load is not based on respiration, as this does not apply to fish such as tuna. Instead, it is calculated from sensible cooling of the product, potential latent heat and contributions from packaging, following standard refrigeration load methods (ASHRAE). If cold storage is used to store mixed commodities, then this calculation needs to be divided based on the number of types of products stored.

The heat produced by human presence in cold storage can be calculated using Equation (3).

$$Q = m \times C_p \times \frac{\left(T_{product} - T_{Internal} \right)}{3600} \left(\frac{\text{kWh}}{\text{day}} \right) \quad (3)$$

Heat is a constant heat that can be produced by humans. The magnitude of this constant depends on the work done. However, 340 kJ can be used as a human heat standard according to the location in the Carrier manual.

Internal load is the amount of heat that comes from components and people inside the cold storage. Also, for the components included in the calculation, namely lights,

compressors, and evaporation fans. The heat produced by human presence in cold storage can be calculated using Equation (4).

$$Q = number\ of\ employees \times work\ time \times \frac{Heat}{1000}\left(\frac{\text{kWh}}{\text{day}}\right) \tag{4}$$

Infiltration load is the heat load resulting from the flow of outside air entering inside accidentally. This commonly occurs when doors or other access points are opened, there are cracks in walls, or from ventilation. Different air densities will cause the fluids to rub against each other and generate heat. The heat produced can be calculated using Equation (5).

$$Q = V_{Changes} \times V_{Storage} \times Energy \times \frac{(T_{External} - T_{Internal})}{3600}\left(\frac{\text{kWh}}{\text{day}}\right) \tag{5}$$

The parameter U represents the overall heat transfer coefficient ($W/m^2 \cdot K$), and A denotes the heat transfer area (m^2). The term m refers to the mass of the product (kg), while C_p is the specific heat capacity ($kJ/kg \cdot K$). Furthermore, $V_{Changes}$ indicates the volume of air exchanged due to infiltration or air change (m^3), and $V_{Storage}$ represents the total internal volume of the cold storage (m^3). The Levelized Cost of Energy (LCOE) is employed in this study as the primary metric for comparing different energy supply configurations for cold storage systems. LCOE represents the ratio between the total lifecycle costs of an energy system and the total energy produced over its operational lifetime, discounted to present value. The general formulation is expressed as:

$$LCOE = \frac{\sum_{t=0}^{N} \frac{C_t}{(1+r)^t}}{\sum_{t=0}^{N} \frac{E_t}{(1+r)^t}} \tag{6}$$

where C_t is the total cost in year t, E_t is the energy produced or consumed in year t, r is the discount rate, and N is the project lifetime (years). The total cost component includes capital expenditure (CAPEX), operation and maintenance (O&M) costs, fuel costs for diesel-based systems, component replacement costs (such as inverters and generators). In this study, the project lifetime is assumed to be 20 years, with a discount rate of 8% reflecting typical energy infrastructure investment conditions in Indonesia. Fuel price assumptions are based on current national diesel prices, with an annual escalation rate of 3% to account for future price uncertainty. Operation and maintenance costs are estimated as a fixed proportion of the initial investment, varying depending on system configuration. Component replacement is incorporated into the analysis, with inverter replacement assumed at year 10 and generator overhaul or replacement occurring every 8–10 years depending on usage intensity. The annual energy consumption is derived from the cold storage load profile, including compressor, fan, and auxiliary system demands, while the capacity factor is determined based on system characteristics, where photovoltaic (PV) systems are modeled using local solar irradiation data and diesel generators are assumed to operate with high availability.

3. Result and Discussion

The cooling load analysis indicates a maximum refrigeration demand of 6.14 kW, which serves as the basis for subsequent system design and component selection. This total load is obtained from the combined contributions of transmission, infiltration, product, and internal heat loads, including an appropriate safety factor, as detailed in the load breakdown table. Based on this requirement, the refrigeration system components are selected using Danfoss Coolselector® version 2 software to ensure adequate capacity and

performance. In addition, a market assessment is conducted to identify suitable evaporator units. The detailed specifications of the selected components are presented in Table 1.

Table 1. Component specification of cold storage.

1. Condensing Unit	
Refrigerant	R404A
Cooling (kW)	6.75
COP Cooling (kW)	1.64
Power (kW)	4.12
2. Compressor	
Type	Scroll
Refrigerant	R404a
Capacity Control	Fixed
Speed (RPM)	5778
Cooling (kW)	6.75
COP Cooling	1.66
Power (kW)	4.07
3. Evaporator	
Fan Pcs	1
Fan Input (W)	90
Air Flow (m^3/h)	1500
Air Throw (m)	9
Coil Tube Defrost. (kW)	1

Cold storage performance is analyzed based on the distribution scheme that occurs in the fishing port area, which is considered constant whether additions or reductions in the number of products have an effect on cooling load. In this paper, cold storage performance is seen based on power consumption as shown in Figure 4. It is known that under peak load conditions of 13 tons, power consumption reaches 7.93 kW. Some applied technology can be achieved for energy efficiency by experiment and simulation.

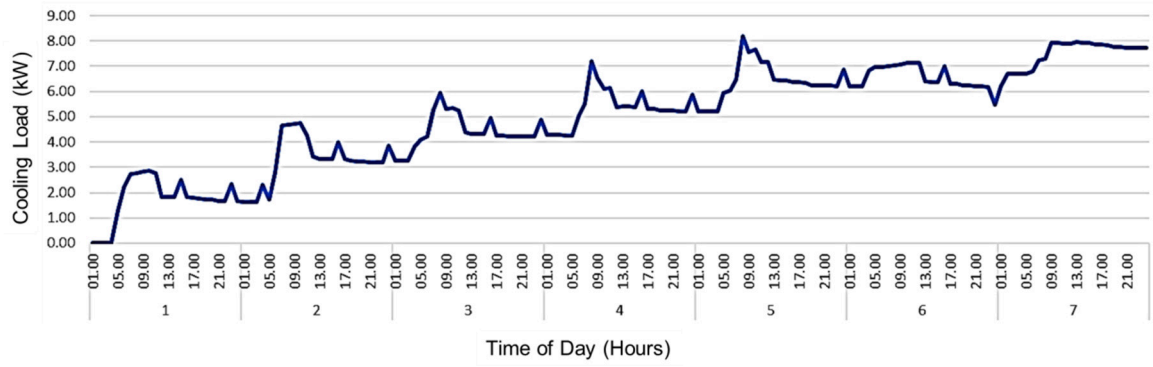


Figure 4. Pattern of power consumption.

In the graph, it can be seen that in product loading and unloading conditions there is an increase in power consumption due to an increase in heat flow, and it starts to decrease when there is no activity. Spending and adding products in the afternoon and evening.

Based on this pattern it is also avoided defrost occurs during loading and unloading hours to avoid additional power consumption. In the planning, a combination of solar energy and a generator is used. The intermediate power performance pattern cold storage, solar energy, and generator as shown in Figure 5. Based on the revised power analysis, the photovoltaic (PV) system capacity has been clarified as a total installed capacity of 3000 Wp (10 panels × 300 Wp each), rather than 300 Wp. Under peak solar conditions, this system is estimated to supply approximately 30% of the peak electrical demand. The remaining load is supported by a generator set to ensure reliable operation. The system operation follows a hybrid scheme in which PV generation is utilized as the primary source during daytime, while the generator compensates for any power deficit. No battery storage is considered in this design; therefore, the system relies on real-time power balancing between PV output and generator supply.

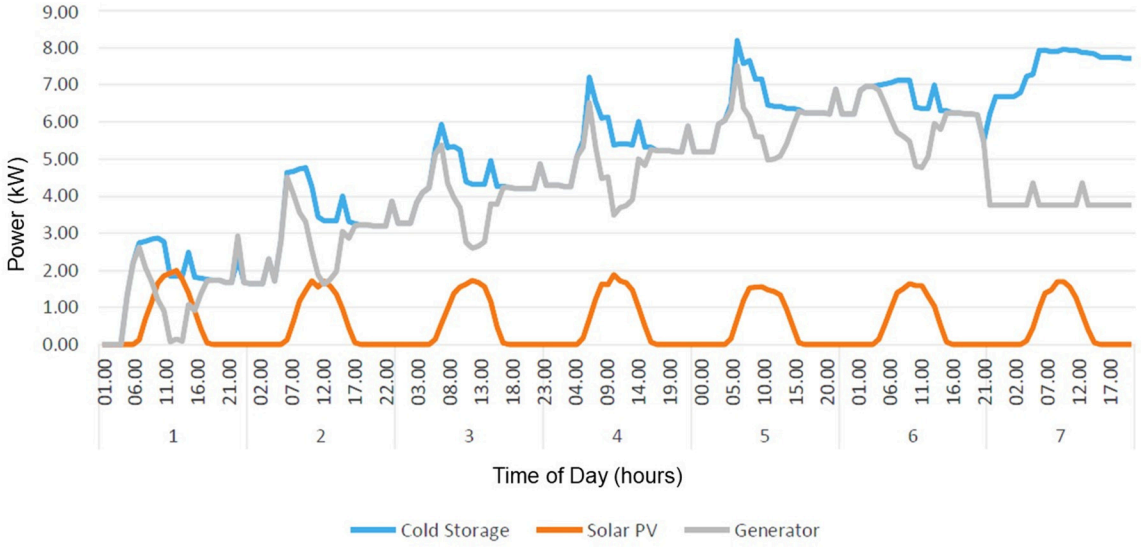


Figure 5. Comparison of cold storage, Solar PV, and generator.

Referring to the design that has been made, research is carried out on the prices of goods and materials on the market so that the cost of making cold storage is estimated as shown in Table 2.

In the same way, cold storage operational costs are also estimated as shown in Table 3. The additional unexpected costs are calculated at 10% of the total fuel and maintenance costs. This is intended for things outside the pattern such as additional maintenance.

Levelized Cost of Energy (LCOE) is one way to determine electricity resources and alternatively by comparing the amount of power produced with the costs incurred during usage. In this design, 5 alternative resources are used, namely grid or connected to the government electricity network, using a generator set, Hybrid PV, which is a combination of solar energy with a generator, off-grid PV, which is full use of energy to support cold storage power, and the latter by using a combination of solar energy and the use of the government electricity network or on-grid PV. Based on this comparison, as shown in Table 4, the generator exhibits the lowest LCOE at approximately USD 0.56/kWh, followed by the grid at USD 0.59/kWh, and the PV hybrid system at USD 0.71/kWh. Considering accessibility and associated emissions, the PV hybrid system is selected to support the cold storage power supply.

Table 2. Production cost of cold storage.

Component		pcs	Unit Cost (USD)	Total Cost (USD)
Cold Storage	PU Panel	66	29.61	1954.45
	Frame	1	10,000.00	10,000.00
	System Refrigeration:			
	(a) Condensing Unit	1	10,423.50	10,423.50
	(b) Evaporator	1	3018.39	3018.39
	(c) Thermostat	1	3.23	3.23
	(d) Humid meter	1	19.35	19.35
	(e) Psychrometer	1	193.55	193.55
Solar PV	Solar Panel	10	115.42	1154.19
	Inverter	1	5328.46	5328.46
Generator Set		1	2055.48	2055.48
		Total Production Cost (USD)		34,150.00

Table 3. Operational cost of cold storage.

Component	Quantity	Unit Cost (USD)	Total Cost (USD)
Diesel fuel	166.09 L	0.61	100.73
Maintenance	–	–	64.52
Additional cost	–	–	33.05
Total Operational Cost			198.30

Table 4. LCOE of cold storage.

Power Supply	LCOE (USD/kWh)	PV Year (kWh)	Power Used (kWh/Years)	Electricity Cost (USD/Years)	Fuel Cost (USD/Years)	Maintenance Cost (USD/Years)	Product Cost (USD/Years)
Grid	0.59	47,994.72	–	3226.49	–	–	1834.97
GenSet	0.56	47,994.72	–	–	5408.25	29.03	6599.31
PV Hybrid	0.71	47,994.72	–	–	100.42	45.16	1900.92
PV Off-Grid	0.89	47,994.72	–	–	–	64.52	4089.97
PV On-Grid	0.72	47,994.72	4312.72	3139.97	–	45.16	3191.60

4. Conclusions

The Levelized Cost of Energy (LCOE) analysis has been conducted for a modular cold storage unit with dimensions of 7 × 3 × 5 m. The calculated maximum cooling load is 6.14 kW, with a corresponding maximum electrical power consumption of 7.93 kW. The estimated capital investment required for construction and installation is approximately USD 34,150, while the operational cost is about USD 198 per operating period. The economic evaluation indicates that the lowest LCOE is achieved using a generator set system at approximately USD 0.56/kWh, whereas the highest LCOE is observed for the off-grid photovoltaic (PV) system at around USD 0.89/kWh. However, when considering both economic and environmental aspects, particularly the balance between lifecycle cost and emission reduction potential, the hybrid PV system emerges as the most suitable energy

supply option for the proposed cold storage design. Overall, the results demonstrate that integrating hybrid renewable energy systems into modular cold storage infrastructure provides a feasible and sustainable solution for supporting fisheries cold chain development in coastal areas.

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References

1. FAO. *The State of World Fisheries and Aquaculture 2022*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2022. Available online: https://openknowledge.fao.org/server/api/core/bitstreams/a2090042-8cda-4f35-9881-16f6302ce757/content (accessed on 1 January 2026).
2. Suherman, A.; Hernuryadin, Y.; Suadela, P.; Furkon, U.A.; Amboro, T. Transformation of Indonesian capture fisheries governance: Review and prospects. *Mar. Policy* **2025**, *174*, 106619. [CrossRef]
3. Kawamoto, T. A challenge to estimate global canned tuna demand and its impact on future tuna resource management using the gamma model. *Mar. Policy* **2022**, *139*, 105016. [CrossRef]
4. Peter, S.M.J.; Blomberg, S.P.; Holden, M.H.; Hoffman, L.C.; Tibbetts, I.R. Is Mushy Tuna Syndrome a Growing Problem for the Tuna Industry? *Foods* **2023**, *12*, 3590. [CrossRef] [PubMed]
5. Affognon, H.; Mutungi, C.; Sanginga, P.; Borgemeister, C. Unpacking postharvest losses in sub-Saharan Africa: A meta-analysis. *World Dev.* **2015**, *66*, 49–68. [CrossRef]
6. Mauli, S.; Thow, A.-M.; Mulcahy, G.; Andrew, G.; Ride, A.; Tutuo, J. Opportunities to Strengthen Fish Supply Chain Policy to Improve External Food Environments for Nutrition in the Solomon Islands. *Foods* **2023**, *12*, 900. [CrossRef] [PubMed]
7. Cortés-Sánchez, A.D.J.; Diaz-Ramírez, M.; Torres-Ochoa, E.; Espinosa-Chaurand, L.D.; Rayas-Amor, A.A.; Cruz-Monterrosa, R.G.; Aguilar-Toalá, J.E.; Salgado-Cruz, M.d.l.P. Processing, Quality and Elemental Safety of Fish. *Appl. Sci.* **2024**, *14*, 2903. [CrossRef]
8. Rathod, N.B.; Nirmal, N.P.; Pagarkar, A.; Özogul, F.; Rocha, J.M. Antimicrobial Impacts of Microbial Metabolites on the Preservation of Fish and Fishery Products: A Review with Current Knowledge. *Microorganisms* **2022**, *10*, 773. [CrossRef] [PubMed]
9. Palumbo, M.; Attolico, G.; Capozzi, V.; Cozzolino, R.; Corvino, A.; de Chiara, M.L.V.; Pace, B.; Pelosi, S.; Ricci, I.; Romaniello, R.; et al. Emerging Postharvest Technologies to Enhance the Shelf-Life of Fruit and Vegetables: An Overview. *Foods* **2022**, *11*, 3925. [CrossRef] [PubMed]
10. Budiyanto, M.A.; Shinoda, T.; Nasruddin. Study on the CFD simulation of refrigerated container. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *257*, 012042. [CrossRef]
11. Abbas, H.; Zhao, L.; Gong, X.; Jiang, M. Environmental and economic influences of postharvest losses across the fish-food products supply chain in the developing regions. *Environ. Dev. Sustain.* **2024**, *26*, 28335–28366. [CrossRef]
12. Pramudya, D.S.; Pamitran, A.S.; Ardiyansyah; Budiyanto, M.A. Design and calculation of cold storage capacity of 10 tons for tuna commodity. *Marit. Technol. Res.* **2024**, *6*, 268270. [CrossRef]

13. Peng, S.-H.; Lo, S.-L. Hybrid (Optimal) Selection Model for Phase Change Materials Used in the Cold Energy Storage of Air Conditioning Systems. *Energies* **2024**, *17*, 63. [CrossRef]
14. Faris, A.; Budiyanto, M.A. Design and Analysis of Small-scale Agriculture Cold Storage: A Case Study in Agriculture Region. *J. Adv. Res. Fluid Mech. Therm. Sci.* **2025**, *129*, 154–167. [CrossRef]
15. Taghizad-Tavana, K.; Esmaeel Nezhad, A.; Hagh, M.T.; Canani, A.; Safari, A. Hybrid Renewable Energy Systems for Off-Grid Electrification: A Comprehensive Review of Storage Technologies, Metaheuristic Optimization Approaches and Key Challenges. *Eng* **2025**, *6*, 309. [CrossRef]
16. Meyer, J.; von Solms, S. Design Considerations for Reducing Battery Storage in Off-Grid, Stand-Alone, Photovoltaic-Powered Cold Storage in Rural Applications. *Energies* **2022**, *15*, 3468. [CrossRef]
17. Yenare, R.R.; Sonawane, C.R.; Sur, A.; Singh, B.; Panchal, H.; Kumar, A.; Sadasivuni, K.K.; Siddiqui, M.I.H.; Bhalerao, Y. A comprehensive review of portable cold storage: Technologies, applications, and future trends. *Alex. Eng. J.* **2024**, *94*, 23–33. [CrossRef]
18. Budiyanto, M.A.; Imamudien, O.; Alhamid, M.I.; Shinoda, T. Design and analysis of a 20-feet modular cold storage system. *Therm. Sci. Eng. Prog.* **2024**, *50*, 102587. [CrossRef]
19. Rami, Y.; Allouhi, A. Design, Economic, and Environmental Accounting Assessment of a Solar-Powered Cold Room for Fish Storage in Traditional Markets. *Sustainability* **2024**, *16*, 3080. [CrossRef]
20. Mulder, S.; Klein, S. Techno-Economic Comparison of Electricity Storage Options in a Fully Renewable Energy System. *Energies* **2024**, *17*, 1084. [CrossRef]
21. Rahman, M.M.; Gemechu, E.; Oni, A.O.; Kumar, A. The development of a techno-economic model for assessment of cost of energy storage for vehicle-to-grid applications in a cold climate. *Energy* **2023**, *262*, 125398. [CrossRef]
22. Colarossi, D.; Principi, P. Optimal sizing of a photovoltaic/energy storage/cold ironing system: Life Cycle cost approach and environmental analysis. *Energy Convers. Manag.* **2023**, *291*, 117255. [CrossRef]
23. *SNI 8661:2023*; Requirements for Fish Commodity Cold Storage Warehouses. National Standardization Agency of Indonesia (BSN): Jakarta, Indonesia, 2023.
24. ASHRAE. *2022 ASHRAE Handbook—Refrigeration*; ASHRAE: Atlanta, GA, USA, 2022. Available online: https://www.ashrae.org/technical-resources/ashrae-handbook/2022-ashrae-handbook-refrigeration (accessed on 1 January 2026).

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