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PREFACE

The Journal of Emerging Supply Chain, Clean Energy, and Process Engineering (JESCEE) is published by the Faculty of Industrial Technology at Universitas Pertamina. It fosters communication among researchers, disseminates research findings, cultivates an academic culture, and encourages the development of new ideas in the fields of mechanical, electrical, chemical, and logistics engineering. The journal's Volume 5, Issue No. 1, has attracted significant attention from numerous researchers eager to publish their work.

On behalf of the Editor-in-Chief, I would like to extend my gratitude to everyone who supports this journal, especially the Dean of the Faculty of Industrial Technology for their direct and indirect assistance. I also appreciate the dedicated editors, the reviewers who provide valuable suggestions and constructive feedback on each submitted paper, and the authors who trust JESCEE with publishing their research.

We hope that this publication will continue to grow and present the latest information in the fields of mechanical, electrical, chemical, and logistics engineering. We also welcome collaborations from individuals and organizations that value this journal and wish to contribute to its ongoing development.

Jakarta, June 2026
Editor-in-Chief

Assoc. Prof. Dr. Eng. Ir. Muhammad Abdillah, S.T., M.T., IPM, ASEAN Eng.

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EXTRACTION OF FLAVONOID FROM MANGOSTEEN PEEL (*GARCINIA MANGOSTANA*) USING ULTRASOUND–ASSISTED (UAE) EXTRACTION AND ITS SPF VALUE

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Abstract
In this study, the peel of mangosteen (Garcinia mangostana) will be extracted to develop a natural sunscreen formulation. Mangosteen peel is rich in natural antioxidants, including flavonoids, tannins, triterpenoids, and phenolic compounds. The primary objectives are to determine the yield, Total Flavonoid Content (TFC), and to evaluate the Sun Protection Factor (SPF) of the ethanolic extract obtained from the mangosteen peel. Ultrasound-Assisted Extraction (UAE) will be employed, with a fixed extraction time of 45 minutes. Two consentrations of ethanol are used, 96% and 70%, respectively. The ratio of the material to the solvent used are 1:15, 1:25, and 1:35 gr/mL. This study reports the highest SPF value was obtained from the 70% ethanol extract, using a material-to-solvent ratio of 1:35 g/mL, which yielded 15.111% and exhibited an SPF of 16.009 (unitless). In contrast, the highest TFC was observed in the 96% ethanol extract, with a concentration of 2,549 mg quercetin equivalents (QE) per gram of extract.

Keywords:
Mangosteen Peel Ultrasound-Assisted Extraction; Total Flavonoid Content; Sun Protecting Factor

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1. Introduction

The ozone layer which is located in the stratosphere, contains ozone molecules that are crucial for Earth's protection. It forms a protective shield around the Earth to filter out the harmful sun's ultraviolet (UV-B) radiation [1]. The ozone layer is naturally created through a photochemical process with 90% and 10% of the concentration found in the stratosphere and the troposphere, respectively [1]. Every year, the ozone layer is shrunken by chemicals, such as Chlorofluorocarbons (CFCs), which are carried by the winds into the stratosphere after being emitted from the surface. Chlorofluorocarbons (CFCs) are gaseous substances that play a role in the depletion of the ozone layer [2]. When CFC substances are released into the atmosphere, they are broken down by ultraviolet (UV) radiation from sunlight, releasing chlorine atoms that catalyze the destruction of ozone molecules. A single CFC molecule can ultimately destroy up to 100,000 ozone molecules [3].

The mangosteen fruit offers a variety of benefits including antioxidant and antibacterial properties [4]. Notably, the peel—often considered a byproduct also harbors bioactive compounds, among which flavonoids are particularly abundant and contribute significantly to its biological effects. Catechin, a subclass of flavonoids, is among the bioactive compounds identified in mangosteen (*Garcinia mangostana L.)* peel. Flavonoids are known for their strong ultraviolet (UV)-absorbing and antioxidant properties, which make them promising natural candidates for use in sunscreen formulations as contributors to sun protection factor (SPF). In mangosteen peel, the TFC has been reported to reach up to 4.08 mg per 100 grams of fresh peel, highlighting its potential as a sustainable source of photoprotective agents [5]. Flavonoid compounds can be efficiently extracted using Ultrasound-Assisted Extraction (UAE), a method that enhances mass transfer and cell wall disruption through acoustic cavitation, thereby improving yield and reducing extraction time [4], [6–8]. Despite its advantages in terms of time efficiency and reduced solvent consumption, UAE remains underutilized in Indonesia for the extraction of flavonoids.

2. Material and Method

A. Materials

The materials used in this study include mangosteen peel (*Garcinia mangostana L.*), analytical-grade ethanol, distilled water (aquadest), magnesium powder, 1 M potassium acetate, 2 M hydrochloric acid (HCl), quercetin (as a flavonoid standard), and aluminum chloride ($AlCl_3$).

B. Mangosteen Peel Preparation.

The mangosteen peel was first washed thoroughly under running water and air-dried at ambient temperature for 24 hours. Subsequently, it was further dried in a drying oven at 45 °C for 2 hours. The dried peel was then ground into a fine powder and sieved through an 850-μm mesh sieve to obtain a uniform particle size for subsequent analysis.

C. Extraction of Flavonoid Content in Mangosteen Peel

The previously prepared mangosteen peel powder was accurately weighed and transferred into Erlenmeyer flasks containing ethanol–water mixtures as extraction solvents. Three solid-to-solvent ratios were evaluated: 1:15, 1:25, and 1:35 (w/v, g/mL). In addition to the solid-to-solvent ratio, the ethanol concentration was varied at 96% and 70% (v/v), prepared by diluting analytical-grade ethanol with distilled water. These two factors solid to solvent ratio and ethanol concentration were systematically investigated to optimize flavonoid extraction efficiency.

Extraction was performed using an ultrasonic water bath at 45 °C and atmospheric pressure for 45 minutes. The resulting extract was immediately filtered under vacuum using a Büchner funnel and filter paper. The filtrate was then concentrated to dryness using a vacuum oven at 40–50 °C and 0.2 bar pressure for approximately 40 hours, then yielding a dry extract for further analysis.

The extraction yield was calculated by comparing the mass of the dried extract obtained after evaporation with the initial mass of the dried mangosteen peel used. The yield (%) was determined according to Equation 1.

$$Yield(\%) = \frac{Evaporated\ extract\ mass\ (g)}{Mangosteen\ peel\ mass\ (g)} \times 100\% \quad (1)$$

D. Determination of Total Flavonoid Content (TFC) using $AlCl_3$ Method - Quercetin Standard Curve Creation

A stock solution of quercetin (1000 µg/mL) was prepared by accurately weighing 25.0 mg of quercetin standard and dissolving it in ethanol to a final volume of 25 mL in a volumetric flask. A series of working standard solutions with concentrations of 40, 60, 80, 100, and 120 µg/mL were subsequently prepared by appropriate dilution of the stock solution with ethanol. For the calibration assay, 0.5 mL of each standard solution was transferred into separate test tubes and mixed with 1.5 mL of 96% (v/v) ethanol, 0.1 mL of 10% (w/v) aluminum chloride ($AlCl_3$), 0.1 mL of 1 M potassium acetate, and 2.8 mL of distilled water. The reaction mixtures were incubated at 25 °C for 30 minutes to allow complex formation. Absorbance was then measured at 438 nm using a UV-Vis spectrophotometer. A calibration curve was constructed by plotting absorbance (y-axis) against quercetin concentration (x-axis, µg/mL), and the resulting linear regression equation was used for quantification of flavonoids in the samples.

E. Determination of Total Flavonoid Content (TFC) using $AlCl_3$ Method

A blank solution was prepared following the same procedure as the standard solutions, except that 0.5 mL of ethanol was substituted for the quercetin standard solution. The blank mixture consisted of 0.5 mL of ethanol, 1.5 mL of 96% (v/v) ethanol, 0.1 mL of 10% (w/v) aluminum chloride ($AlCl_3$), 0.1 mL of 1 M potassium acetate, and 2.8 mL of distilled water. The solution was incubated at 25 °C for 30 minutes under the same conditions as the standards. Absorbance measurements for all samples and standards were recorded against this blank using a UV-Vis spectrophotometer at 438 nm.

The test solution was prepared by mixing 0.5 mL of the mangosteen peel ethanol extract (for each extraction condition) with 1.5 mL of 96% (v/v) ethanol, 0.1 mL of 10% (w/v) aluminum chloride ($AlCl_3$), 0.1 mL of 1 M potassium acetate, and 2.8 mL of distilled water. The mixture was incubated at 25 °C for 30 minutes to allow flavonoid–$AlCl_3$ complex formation. Absorbance was measured at 438 nm using a UV-Vis spectrophotometer, with the blank solution used as the reference. All analyses were performed in duplicate.

The TFC was calculated based on the quercetin calibration curve and expressed as milligrams of quercetin equivalents per gram of dry extract (mg QE/g), using equation 2:

$$F = \frac{c \times V \times f \times 10^{-3}}{m} \quad (2)$$

Where F is the number of flavonoids content using the $AlCl_3$ method, c is quercetin equivalence (μgQE/mL), V is total extract volume (mL), f is dilution factor (1) and m is sample weight (g).

F. Calculating SPF Value

The collected data is absorbance data which is measured to determine the potential of sunscreen. The extract was scaled and then the solvent was added to it and put in a measuring cup to obtain a concentration of 300 ppm. The absorbance and absorption values were measured at a wavelength of 290-400 nm using a UV-Vis spectrophotometer. The area under the absorption curve or AUC is obtained from the absorbance value at a wavelength of 290 – 400 nm with an interval of 5 nm which is calculated using equation 3 [6].

$$AUC = \frac{Aa + Ab}{2} \times dP(a - b) \quad (3)$$

Where Aa and Ab represent the absorbance values at wavelengths and (nm), respectively, $dp(a - b)$ denotes the difference between the two wavelengths (a and b).

After determining the area under the curve (AUC) at each wavelength across the UV range, the individual AUC values were summed to obtain the total AUC. The sun protection factor (SPF) was then calculated using the following equation:

$$Log\ SPF = \frac{[AUC]}{\lambda_n - \lambda_1} \quad (4)$$

Where λ_n is the largest wavelength (400 nm), and λ_1 is the smallest wavelength (290 nm).

3. Result and Discussion

A. Yield of Mangosteen Peel Extract

In this study, both qualitative and quantitative analyses were conducted, including extraction yield, phytochemical screening, total flavonoid content (TFC), sun protection factor (SPF) assessment, and Fourier-

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transform infrared (FTIR) spectroscopy. The extraction yield was evaluated to determine the influence of solvent concentration and solid to solvent ratio on extract production. Two ethanol concentrations (96% and 70%, v/v) were tested, each combined with three solvent volumes 15 mL, 25 mL, and 35 mL corresponding to solid to solvent ratios of 1:15, 1:25, and 1:35 (w/v), based on a fixed mass of dried mangosteen peel.

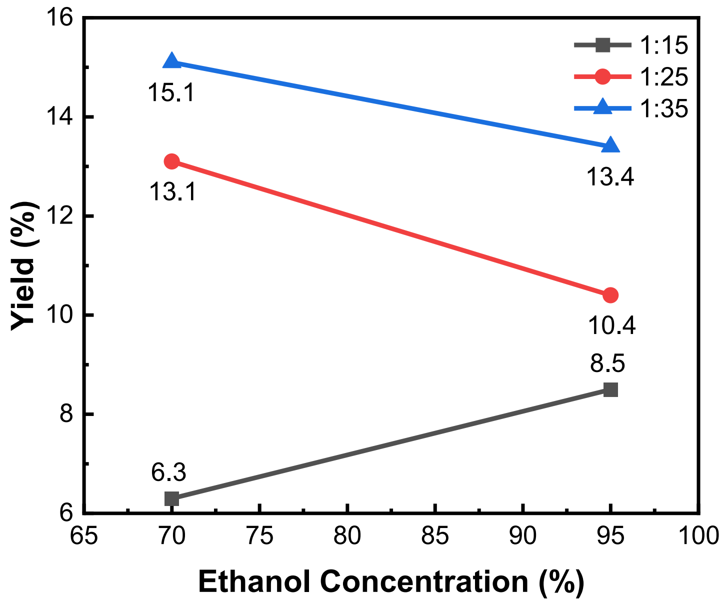

Figure 1. Effect of concentration and ratio of ingredients/solvents on yield.

As demonstrated in Figure 1, increasing the ratio of raw material to solvent significantly improved the overall extraction yield. Mechanistically, a higher solvent volume relative to the solute promotes superior solvent penetration (diffusivity) into the cellular structures, thereby accelerating the dissolution kinetics and subsequent mass transfer of the desired compound [9]. Means, the larger the volume of solvent, the faster the diffusion process and facilitates the mass transfer process [10]. Furthermore, the increased material-to-solvent ratio synergistically enhanced the effects of ultrasonic treatment. A larger solvent volume relative to the material intensified the ultrasonic cavitation, leading to greater fragmentation, erosion, and pore formation within the plant matrix. This physical disruption, combined with the resultant increase in the material-solvent contact area, significantly improved mass transfer rates and consequently boosted the final extraction yield [10]. Conversely, higher ethanol concentrations resulted in lower extraction yields, suggesting that a greater proportion of water in the hydroethanolic solvent enhances the extraction efficiency. This observation is consistent with literature findings [11]. The increased yield is likely due to the co-extraction of highly polar, non-phenolic compounds, such as proteins and carbohydrates, which exhibit significantly greater solubility in water than in ethanol [12].

B. Phytochemical of Mangosteen Peel Extract

To assess the extract's capacity to support antioxidant activity, a qualitative phytochemical screening was performed to determine the content of major secondary metabolites, shows in the Table 1. The procedure involved the addition of class-specific chemical reagents to a small sample of the extract to identify the presence of phenols, flavonoids, tannins, alkaloids, and triterpenoids [6-7].

Table 1. Phytochemical test result on mangosteen peel extract.

Test Parameters	Observation Result	Test Results	Compound Examples
Flavonoid	Formed orange color	+	Quercetin, catechin, gallocatechin [13]
Triterpenoids	No red color formed	-	Lupenone [14]
Tannins	Formed blackish green color	+	Tannin [14]
Phenol	Formed black color	+	Chrysin, caffeine acid, and cinnamic acid [15]
Alkaloids	An orange precipitate is formed	+	Phenylalanine [16]

C. Total Flavonoid Content (TFC) of Mangosteen Peel Extract

The quantification of total flavonoids relies on the formation of a stable acid complex between the target compounds and $AlCl_3$. This complexation specifically occurs through chelation between the Al^{3+} ion and the keto group at the (C-4) position alongside a hydroxyl group at either the (C-3) or (C-5) position found on flavones and flavonols [17]. Quercetin, a representative flavonol possessing both the (C-4) keto and hydroxyl groups at (C-3) and (C-5) (Figure 2), was therefore chosen as the reference standard for the calibration curve, making it an ideal candidate for total flavonoid determination [17].

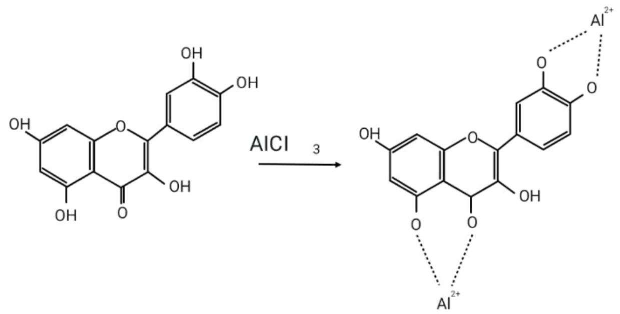

Figure 2. Chemical Reaction of Quercetin and $AlCl_3$ [18].

The TFC was quantified following the addition of 1M potassium acetate, a step specifically included to confirm the presence of flavonoids bearing a 7-hydroxyl group. A 30-minute incubation period was applied to ensure the reaction reached completion, thereby guaranteeing maximum color intensity and accurate quantification [19]. The TFC value can be calculated using a standard Quercetin curve and the results are expressed in mg QE (Quercetin Equivalent)/gr mangosteen peel. The standard curves were made by 96%, and 70% ethanol concentrations, respectively, with the absorbance measurement wavelength used, which was 438 nm [20]. The following equations for each standard curve are:

$$Etanol\ 96\% \rightarrow y = 0.0033x + 0.0181\ ;\ R^2 = 0.9852 \quad (5)$$
$$Etanol\ 70\% \rightarrow y = 0.0035x + 0.0242\ ;\ R^2 = 0.985 \quad (6)$$

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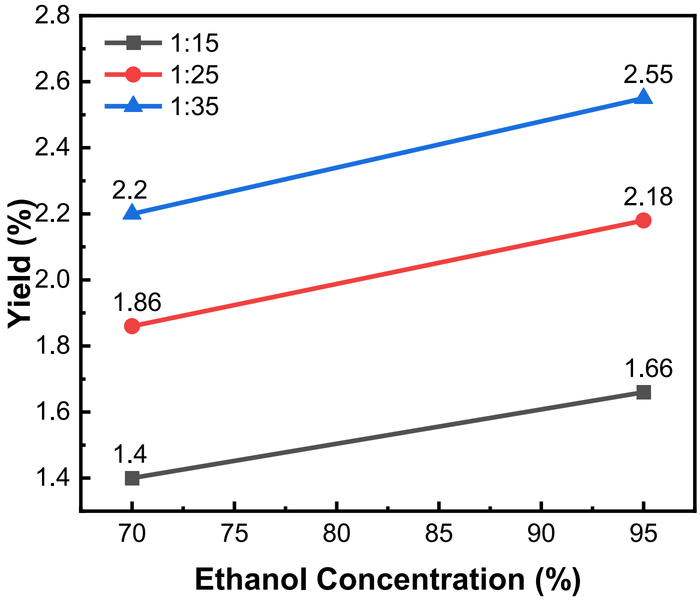

Figure 3. The concentration and solvent ratio affect the TFC of Mangosteen Peel Extract.

Figure 3 shows that the (TFC) value increases with the addition of more solvent, which corresponds to a decreased solute-to-solvent ratio at the same solvent concentration. The observed effect is due to the solvent's enhanced diffusivity into the cells, which facilitates the dissolution of the flavonoids [9]. During increasing solute/solvent ratio, the viscosity and concentration of the extraction medium will decrease, thereby increasing the cavitation effect in the UAE method and maximizing the extraction process [10]. Meanwhile, if the material/solvent ratio is too small, it can lead to not optimal extraction process.

The solvent volume also influences the contact area between the material and the solvent, specifically, increasing the solvent volume widens the contact area and improves solvent distribution [21]. According to Mas'ud, an even distribution of the solvent, coupled with an increased solvent volume, enhances the extraction yield by reducing solvent saturation, thereby facilitating the complete extraction of target components [21]. Furthermore, increasing the solvent volume enhances the solvent's extractive capacity and prolongs the effective contact time between the material and the solvent [22]. Moreover, because UAE relies on the cavitation principle for mass transfer, an increase in solvent volume will enhance the extraction efficiency [23]. Consequently, the highest TFC of mangosteen peel extract in this study was achieved using the 96% ethanol concentration with a 1:35 g/mL material-to-solvent ratio. This optimum result aligns with the "like-dissolves-like" principle, indicating that the polarity of 96% ethanol is highly effective for dissolving the dominant flavonoids in the peel.

D. SPF of Mangosteen Peel Extract

In this study, a Sun Protecting Factor (SPF) test was conducted to determine the potential of mangosteen peel extract as a basic ingredient for making sunscreen. Mangosteen peel extract with a ratio of 1:35 which has been separated from the solvent (after using a vacuum oven) was scaled and dissolved with each solvent to obtain a concentration of 300 ppm. The mangosteen peel extract absorbance was measured across the 290-400 nm range. The Area Under the Curve (AUC) value was subsequently obtained, and the Total AUC can be used to determine the Sun Protection Factor (SPF) value. The SPF results obtained are different from those for the TFC. Similar results were also obtained from a study by Ebrahimzadeha, where the SPF value correlated in parallel to the Total Phenolic Content (TPC) in Crataegus pentagonal extract, using methanol as a solvent via the UAE method [24].

Although flavonoids are widely studied and generally considered superior in UV radiation protection, phenolic compounds as a whole also demonstrate photoprotective potential [25-26].

The low TFC obtained in this study meant that the resulting Sun Protection Factor (SPF) value, which was primarily driven by the high Total Phenolic Content (TPC), was not quantitatively tested. The purity of the ethanol solvent had contrasting effects on the compounds extracted: higher ethanol purity led to a higher TFC value, but lower TPC values. Specifically, the maximum TPC was achieved with 50% ethanol [9]. This means that the total phenolic compounds in the mangosteen peel extract have a higher polarity than the TFCs so in 70% ethanol, there are more phenolic compounds, and in 96% ethanol, there are more flavonoid compounds. The presence of these compounds in the extract is influenced by the solubility of each compound in the solvent used for the extraction process. The polarity of the solvent has an important role in increasing the solubility of each of these compounds [11]. The results was ethanol with a concentration of 96% and 70% has an SPF value of 14.074 and 16.009, respectively. From the SPF value, it can be concluded that the potential of sunscreen for ethanol concentrations of 96% and 70% can be categorized as maximum protection.

E. Fourier transform infrared (FTIR)

The results of mangosteen peel extraction using solvents with ethanol concentrations of 96% and 70% were tested using FTIR to identify the compounds contained in the chemical groups of these compounds, the tests were carried out on variations in the ratio 1:35 gr/mL.

Fourier-transform infrared (FTIR) spectroscopy (Figure 2) revealed that the functional groups present in both extracts across all tested concentrations were nearly identical to those of the quercetin standard. Key functional groups characteristic of flavonoids were identified, including hydroxyl (O-H), carbonyl (C=O), aromatic (C=C), and aromatic (C-H) stretching vibrations (Table 2) [27]. The peaks observed in the Fourier-transform infrared (FTIR) spectra were consistent with the characteristic wavenumber ranges of flavonoid compounds, confirming the presence of key functional groups including hydroxyl (O-H), (C-H), carbonyl (C=O), aromatic (C=C), (C-O), and the fingerprint region. Interestingly, a specific functional group (C-H) appear in a small intensity in 96% consentration of the FTIR results. Meanwhile, the aliphatic (C-H) stretching vibration was higher intensity present, being identified in 70% consentration of the spectra with a peak centered at 2974.41 cm^{-1}.

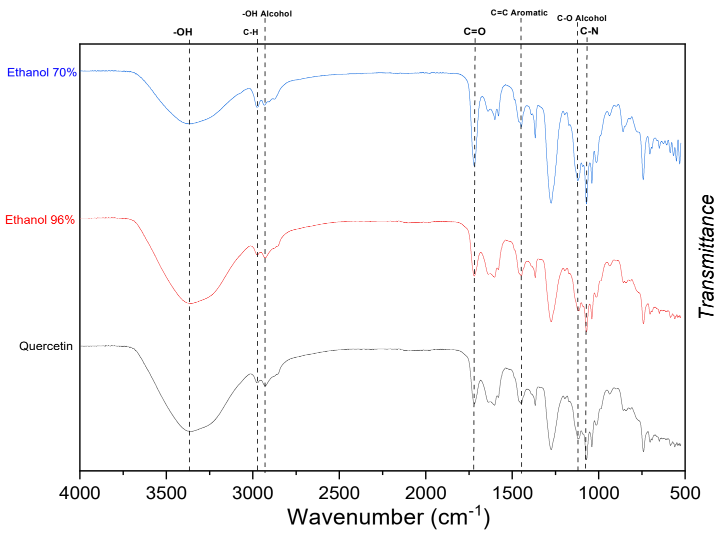

Figure 4. FTIR of Mangosteen peel extraction using solvents with ethanol concentrations of 96% and 70%.

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Table 2. FTIR references to identify the functional groups compound in Mangosteen Peel Extraction.

Functional groups	Wavenumber Frequency (cm^{-1})	Mangosteen Peel Extract Wave Number (cm^{-1})		References	Identification Results
		96%	70%		
-OH	3200-3500	3356,09	3366,30	[28-32]	Phenol, Flavonoid, Tannin, Alkaloid, Saponin
C-H	2700-3000	-	2974,41		Ethanol, Tannin, Saponin
-OH alkohol	2700-3000	2928,76	2933,43		Ethanol
C=O	1650-1900	1719,89	1719,64		Flavonoid, Tannin, Phenol, Saponin
N-H	1680-1550	1601,90	1600,52		Alkaloid
C=C aromatic	1475-1500	1447,51	1447,48		Flavonoid, Tannin, Phenol, Alkaloid, Saponin
C-O eter	1085-1150	1014,46	1013,23		Flavonoid, Tannin, Phenol
C-O alcohol	1000-1260	1119,31	1120,75		Alcohol, Flavonoid, Tannin, Alkaloid, Saponin
C-N	1020-1250	1070,93	1070,95		Alkaloid
Fingerprint region of flavonoid	900-1300	1039,68	1039,55		Flavonoids

4. Conclusion

In conclusion, this research shows that mangosteen peel can be one of the potential raw materials for sunscreen production due to its unique components, including the SPF value and the flavonoid content. The study indicates that the increasing amount of solvent can lead to the inclining trend of yield and Total Flavonoid Content (TFC). The highest yield and TFC were discovered at the ratio of material to solvent 1/35 gr/mL. Furthermore, the solvent concentration showed an effect on the yield result. It shows that the smaller amount of the solvent concentration leads to the greater the yield, namely at 70% ethanol concentration. In contrast, the effect of concentration on TFC showed a declining trend. The smaller yield is observed at the smaller concentration of TFC produced. The largest yield of TFC is at an ethanol concentration of 96% and the lowest is at 70% ethanol concentration. The highest flavonoid content in mangosteen peel was obtained at a concentration of 96% with an ingredient/solvent ratio of 1/35 gr/mL, which is 2,549 mg QE/gr. The highest Sun Protecting Factor (SPF) value of mangosteen peel extract was obtained at 70% ethanol concentration, which was 16.009 in the ultra-protection category.

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SUITABLE FUEL TERMINAL PERTAMINA PULAU SAMBU BUSINESS AND MARKETING STRATEGY FACING THE IMPACT OF PERMANENT ESTABLISHMENT TAXATION POLICY IN OIL & GAS STORAGE TERMINAL BUSINESS

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Abstract
Singapore's declaration to participate as a pioneering country in the energy shift and become the first Southeast Asian country to implement a carbon pricing scheme on January 1, 2019, by imposing a carbon tax, has led several major players in this business to divest their terminal or refineries in the Singapore area or shift their businesses to green energy, such as Shell and Advario. This phenomenon, however, does not eliminate dependence on fossil fuels. Therefore, demand for storage tank rental and bunkering services will remain and continue to increase, especially in the Strait of Malacca. This creates an opportunity for Pulau Sambu Fuel Terminal, to become an alternative storage location, strengthened by its strategic location in the Singapore Strait and its currently unutilized condition. Regulatory challenges related to tax regulations directly impact to the competitiveness of Pulau Sambu, becomes less attractive when compared to existing terminals in Singapore and Malaysia.
This research uses a mixed methods approach, combining qualitative methods as well as analysis of secondary data. This research is structured using several analytical frameworks such as PESTLE analysis, Porter's Five Forces, VRIO, and SWOT-TOWS matrix, to obtain a comprehensive picture of internal and external conditions as part of an effort to obtain precise business and marketing strategies. Finally, this research gives a clear visual across both academic literature and industrial practices. For practitioner, the findings offer a blueprint for a phased business model, uniting investment strategies along with government engagement.

Keywords:
oil storage; Permanent Establishment tax; terminal business strategy; terminal competitiveness; Southeast Asia; regulatory policy

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1. Introduction

The Singapore Strait area is one of the world's busiest shipping routes connecting the Indian Ocean and the Pacific Ocean. The strategic location of the Singapore Strait is passed by more than 100,000 ships per year, this what makes Singapore one of the market leaders in the bunker business and oil storage business become unavoidable.

The conditions mentioned above are clearly seen as a business opportunity for storage provider players, but this actually does not work according to the theory of supply and demand where demand will control the amount of supply. The number of oil storage providers that are shifting their business to clean energy business since the last 5 years, or more popularly known as green energy, has caused the amount of oil storage availability to decrease drastically. Some big players such as SHELL, Advario, and Oil Tanking have started selling their oil storage assets in several countries, especially Asia, indicating that the hydrocarbon trading trend is shrinking for the next 20 years. However, it cannot be denied that traditional fossil fuels are still the main source of energy in several countries for the next few decades, including Japan and Indonesia. Therefore, it is inevitable for the oil and gas industry to adapt and increase agility response to address this phenomenon (Loya, 2021)

The vacancy of such players in the presentation above is a great opportunity for PT Pertamina Energy Terminal as a new player in the storage provider business to be able to take advantage that can not only provide solutions to fuel oil management needs, but also provide efficient distribution network, especially for bunker businesses in the Malacca Strait area, specifically Pulau Sambu Fuel Terminal.

Unfortunately, uncertain government policies and regulations on taxation, 11% VAT on storage lease business, and corporate income tax for business duration more than 3 months that been imposed as the consequence on the obligation create/establish a company with a legal entity of the Republic of Indonesia / Permanent Establishment (Indonesia, 2015), has created huge obstacle regarding the competitiveness in pricing. In other hand high infrastructure investment that should done to overcome the demand need, has become mandatory key word for all the success global player, where idle possibility when downturn on demand occur.

The urgency of the condition of Pulau Sambu Fuel Terminal to immediately get a market is a priority for the management of PT Pertamina Energy Terminal, especially in 2025 considering the effect of impairment with a significant value due to idle status, even though business exploration with several consumers in the Singapore area and its surroundings has been carried out. In addition, the effect of operational expenses that must be borne by the company every year up to ± IDR 64 billion causes a sustainable erosion of profits.

2. Method

This research uses a mixed methods approach, combining qualitative methods obtained through interviews with PET's top management including commercial and business development managers, oil trader management, and cargo owner company management, as well as analysis of secondary data. This research is structured using several analytical frameworks such as PESTLE analysis, Porter's Five Forces, VRIO, and SWOT-TOWS matrix, to obtain a comprehensive picture of internal and external conditions as part of an effort to obtain business and marketing strategies that are in accordance with macro environmental conditions, competitive dynamics, and internal resource capabilities. The primary data collection gathered through semi-structured fashion interview, these included PET's senior management, such as the Chief Executive Officer and Operation Director, commercial and business development managers, as well as oil traders, and cargo owners who actively operate in Singapore and Southeast Asian markets. These interviews were held to capture the gap between the internal perspectives of PET leaders and the requirements of oil traders and cargo owners as external parties that represent the business need. Interview transcripts were analysed thematically using axial coding to identify repeating issues, a generally accepted opinion, and points of concern.

Secondary data were obtained from internal company reports including market analyses that conducted internally and regulatory correspondences. All the documentary evidence provided quantitative backing for the qualitative insights gathered from interviews and allowed for triangulation of findings. Additional data were sourced from industry publications, consultancy reports, and government documents relevant to the oil and gas storage sector in Southeast Asia.

The research offers a structured methodology for strategic prioritization that combines stakeholder voice with structured decision frameworks. A PESTLE analysis was conducted to provide an analysis in the early stages of political, economic, social aspects, the influence on the use of advanced technology, environmental regulations, and legality aspects. The VRIO framework was used in order assessing whether Pulau Sambu Fuel Terminal's internal resources and capabilities can be a source of sustained competitive advantage. PET may determine what makes its assets valuable and how hard it is for rivals to replicate or acquire them by looking at the factors of Value, Rarity, Imitability, and Organization. While the SWOT-TOWS matrix was carried out to identify internal strengths and weaknesses, as well as opportunities and threats from outside.

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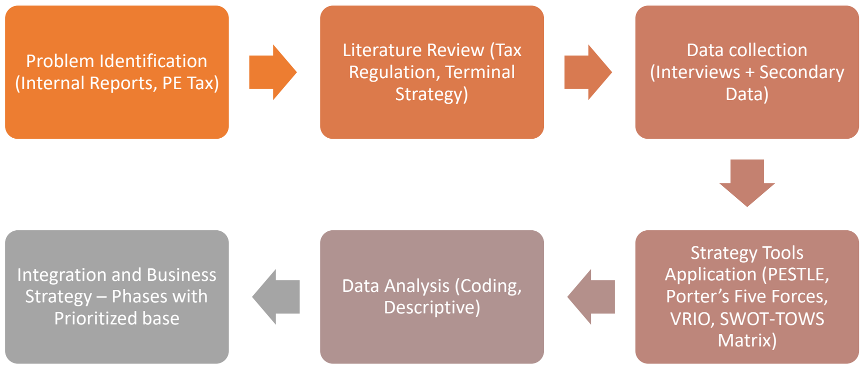

Figure 1. Research Design Process

3. Result and Discussion

Internal Analysis and Resource Assessment

The strategic location of Pulau Sambu Fuel Terminal that being right on the edge of the Singapore Strait provides its own advantages, which is a busy shipping lane between the Indian and Pacific Oceans. Around 100,000 ships pass through this route every year, making it one of the busiest shipping lanes in the world. The terminal is close to Singapore, which is the regional hub, and is located on major shipping routes. This fact can provide a very clear picture of the ease of gaining access to a number of potential customers, such as oil traders or bunker operators, most of whom are currently looking for alternative supply points (outer supply points) due to the overcrowding of terminals in the Singapore area. In addition, the limited land area and plans to implement high carbon-related taxes have caused some major terminal players to cancel their expansion plans. However the terminal's current facilities were primarily designed for domestic use and lack the flexibility, automation, and blending capabilities, that all required to attract high-tier traders and international partners. The VRIO analysis highlighted that Pulau Sambu's location and expansion potential are both valuable and rare but are not fully inimitable or organizationally leveraged due to regulatory barriers and bureaucratic inertia. While being state-owned confers political support and potential access to capital, it also introduces decision-making delays and limits commercial agility. The lack of international brand recognition and absence of PLATTS registration further reduce the terminal's attractiveness to large-scale global buyers.

Resource/Capability	Valuable	Rare	Inimitable	Organized	Competitive Implication
Strategic Malacca location	Yes	Yes	Yes	Partial	Temporary advantage
Bonded zone status	Partial	No	No	No	Competitive parity
Land Availability for Expansion	Yes	Yes	Yes	Partial	Temporary advantage
State-Backed Ownership (Pertamina - PET Integration)	Yes	No	No	No	Competitive parity
Operational Capability for Value-Added Services	Yes	No	No	No	Competitive disadvantage

Table 1. VRIO Table Interpretation

Market Segmentation and Strategic Options

Customer and market feedback gathered through interviews revealed a clear segmentation in demand. Terminal infrastructure design, operational flexibility, regulatory certainty, and meet with international standards are key concerns for major oil traders. The current terminal design and taxation system at Pulau Sambu Fuel Terminal are not considered attractive, due to its impact on pricing.

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Conversely, the terminal can make a steady stream of money by focusing on the low-tier market, such as small and medium-sized oil companies and spesifically national companies (Indonesian legal entity company) that have type “distribution”. This way, it doesn't have to compete directly with larger, higher-capacity companies

Strategic Phasing and Business Model Innovation

The SWOT-TOWS analysis led to the formulation of a phased strategic approach. In the short term, business plan is needed to provide a rescue solution for the Sambu Fuel Terminal. Partnerships with third-tier companies who is act as “Distribution” or newcomers were taken as a strategic step to build a business portfolio in the initial stages, that could create sustain short-term contract. This business strategy is becoming strong way out to address the urgent need for the immediate utilization of Pulau Sambu Fuel Terminal, as there has been no resolution regarding the issue of Permanent Establishment taxation and facing limitations in the existing infrastructure. Meanwhile, intensive approaches to government institutions, especially those related to the taxation and customs sectors, were simultaneously carried out.

The medium-term strategy involves incremental investment in infrastructure upgrades, focusing on bunker facilities to enter the 100 Kt Fuel oil market for bunkering, making it attractive to middle-tier oil traders who require greater operational flexibility but are less demanding than top-tier players.

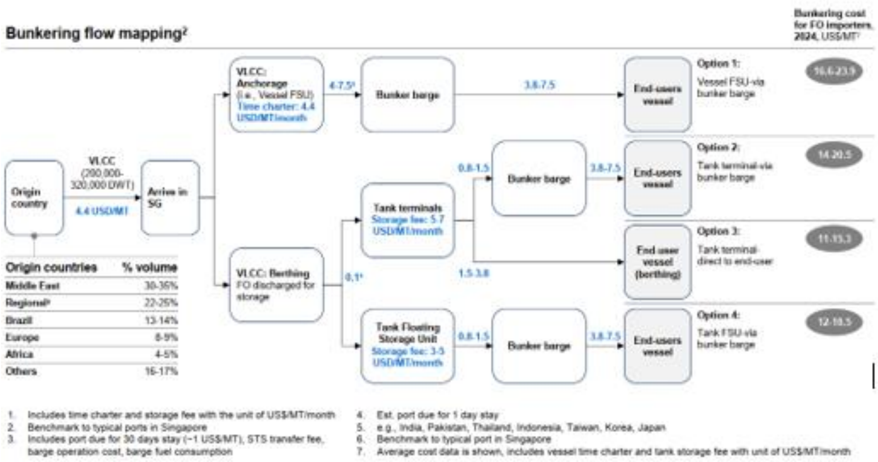

Figure 1. Bunkering Flow Mapping

In the long term, the vision is to establish Pulau Sambu as a regional crude oil storage and bunkering hub, placing Pulau Sambu as one of the major players in the Asian oil and gas market, with the capability to serve oil business players from small to large scale.

Alignment with National Policy and Industry Trends

A recurring theme throughout the research was the critical importance of government alignment. As a critical point, this study underscores the need for alignment of government policies and support with the business climate for the oil & gas storage business, otherwise Pulau Sambu will never be able to compete with other terminals in the region.

4. Conclusion

Pulau Sambu has clear strengths which are, a strategic location less than 2 nautical miles from the Singapore Strait, expansion space, idle tank capacity, and the trust and capital backing of Pertamina. For small-to-medium oil traders and companies with the type of Distribution, the existing infrastructure that Pulau Sambu has including the design is attractive enough, its value flexibility, valuable access to reach the market, and reliable. This will be more attractive, particularly if idle tanks are revamped and basic infrastructure is upgraded. However, for high-tier traders and big international cargo owners, Pulau Sambu's current design fails to meet the expectation. There are wide gaps not only in term of jetty and tank capacity but further in blending capability, and digitalization. The biggest barrier, though, is not physical, it's regulatory: the 11% VAT and 22% PE tax make the terminal uncompetitive against Singapore and Malaysia, especially for global players who see tax predictability as critical.

on marketing strategy and business resilience as the answer what marketing strategy should be used in term of Pulau Sambu Fuel Terminal, to overcome the volatility of oil and gas business including bunker market. As the result the analysis shows that a phased, flexible approach is needed (Singh, 2010). In the short term, Pulau Sambu should focus on the low-tier market and distribution companies. They should use short-term contracts to build trust, use, and cash flow. This "sweetener" segment keeps the terminal running and helps establish a reputation. In the mid-term, after targeted infrastructure investment (blending, tank upgrades, pig able piping, bunker barge setup), Pulau Sambu can move up to serve middle-tier traders, especially those squeezed out of Singapore due to congestion or cost or looking for niche blending options. The last phase that should be taken after this is become full-scale hub for crude oil and bunkering that can serve VLCCs and top-tier traders. To do this, however, the need of huge investments, change the rules (ideally get SEZ status or VAT relief), and set world-class operational standards, should mandatory be carried out.

The conclusion is that Pulau Sambu's design is "fit for purpose" for the lower and middle segments, but not yet compelling for the upper market without further upgrades and regulatory shifts. The right marketing strategy is one that matches these phases build a strong base, move up the value chain, and push for regulatory change as a parallel effort. Success will depend on the ability to gain government support and tax reform, just as it does on technical improvements

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RISK ASSESSMENT OF GOODS SORTING ACTIVITIES IN COLD STORAGE USING JOB SAFETY ANALYSIS (CASE STUDY: LOGISTICS WAREHOUSE, JAPAN)

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Abstract

Goods sorting (shiwake) activities at the Shimohana Logistics warehouse in Atsugi, Japan, constitute the focus of this study, which aims to identify potential hazards, assess risk levels, and evaluate the implementation of occupational health, safety, security, and environmental (HSSE) practices. A qualitative descriptive approach was employed through direct observations, interviews, and documentation review, with risk analysis conducted using the Job Safety Analysis (JSA) method and risk assessment based on likelihood and severity parameters aggregated using the geometric mean. The results identified 11 potential hazards encompassing mechanical, ergonomic, and environmental aspects, with risk levels ranging from low to extreme. The highest risk (RR = 16) was associated with forklift traffic interactions in the sorting area, while other high risks (RR = 9-12) were linked to non-ergonomic postures, repetitive manual handling, and prolonged exposure to cold temperatures. Moderate and low risks were found in manual trolley usage, unstable stacking conditions, and exposure to scanner lighting. The application of JSA integrated with HSSE principles enables a structured and systematic approach to hazard identification and risk control. The findings indicate that, despite efficient warehouse operations, significant risks remain in sorting activities, particularly in worker–equipment interactions and cold environment exposure. Therefore, targeted mitigation strategies, including segregation of forklift and pedestrian pathways, ergonomic improvements, workload regulation, and the use of cold-resistant personal protective equipment, are recommended. These measures are expected to enhance workplace safety, reduce accident risks, and support continuous improvement toward a safer and more sustainable warehouse operation aligned with the zero-accident principle.

Keywords:
Job Safety Analysis, Goods Sorting, Occupational Safety, Risk Assessment, Warehouse Operations

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1. Introduction

In an increasingly integrated era of globalization, the logistics sector plays a vital role in supporting the stability of various industries, ranging from trade to manufacturing. Logistics functions as a strategic link between producers and consumers, ensuring that goods are distributed efficiently, delivered on time, and maintained in optimal condition [1]. In developed countries such as Japan, logistics systems have advanced significantly through the adoption of high technology and stringent operational standards, particularly in cold chain logistics, where consumer demands for food freshness place cold chain management in a highly critical position.

The observed warehouse facility is one of the leading logistics companies in Japan, specializing in third-party logistics (3PL) services with a focus on handling temperature-sensitive food products. The company is supported by advanced cold storage infrastructure to maintain product quality throughout the distribution process and implements high standards of operational efficiency. Key operational activities in cold storage warehouses include inventory management processes such as goods receiving, strict quality inspection, and storage arrangement based on product categories to optimize space utilization and accessibility. In addition, the use of technologies such as handheld terminals and Warehouse Management Systems (WMS) plays a crucial role in improving accuracy and minimizing operational errors.

According to previous studies, forklift-related accidents represent a significant source of occupational injuries and fatalities in warehouse and industrial environments, particularly due to collisions, overturns, and struck-by incidents [2]. Furthermore, warehouse operations are characterized by a high prevalence of slips, trips, and falls, which account for a substantial proportion of non-fatal workplace injuries and are often associated with surface conditions such as wet or uneven floors [3]. In addition, cold storage environments present higher injury rates compared to general industry due to the combined effects of extreme temperatures, condensation hazards, and intensive equipment interaction, emphasizing the need for systematic hazard identification and risk control within operational settings [4,5]. Furthermore, daily risks such as slips, trips, falls, and exposure to extreme working conditions highlight the importance of systematic hazard identification and risk control within operational environments [6–8].

The goods sorting activity (*shiwake*, in Japanese) at a warehouse facility in Atsugi, Kanagawa Prefecture, represents a critical process within the distribution network of a Japanese discount supermarket chain, which operates multiple retail outlets and provides daily consumer goods, particularly food products, at competitive prices. As a retail company serving end customers directly rather than functioning as a wholesaler or distributor, this sorting process plays a vital role in ensuring the accuracy of quantity, product type, and delivery destination before shipment. Errors or disruptions at this stage can affect not only the quality of logistics services but also the occupational health and safety of operational workers [9]. Based on observations conducted during the internship period in the cold storage area, the *shiwake* process is performed in low-temperature environments ranging from below 0°C to 5°C, combined with a high level of physical activity. Workers perform manual sorting tasks across multiple work batches, involving lifting (Figure 1 (a)), bending and arranging (b), and transporting (c) frozen and chilled food products over relatively long periods. These conditions create significant occupational health and safety risks, particularly related to physical fatigue, reduced concentration, and musculoskeletal disorders caused by repetitive manual material handling [10].

(a) (b) (c)

Figure 1. Goods Sorting Activities

In addition to temperature and physical workload factors, risks also arise from the working environment. Cold storage areas typically have damp and slippery floors, increasing the likelihood of slip-and-fall accidents. Furthermore, the operation of material handling equipment, such as forklifts and hand pallets, within the same workspace as workers introduces additional hazards, including collisions and near-miss incidents [11]. The combination of human factors, working environment conditions, and equipment usage makes the *shiwake* activity a high-risk operational process that requires particular attention. To provide a more comprehensive understanding of the complexity of these issues, the relationships among root causes, key phenomena, and resulting impacts in *shiwake* activities within the cold storage area can be visualized through a problem relationship analysis, as illustrated in Figure 2.

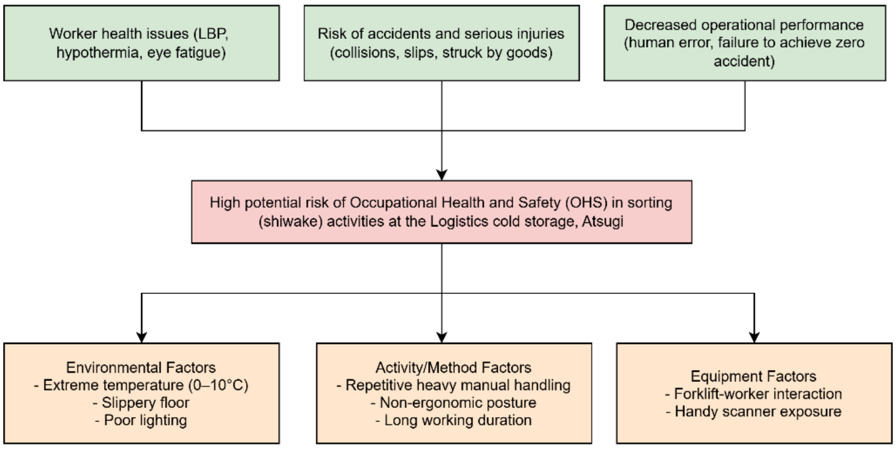

Figure 2. Problem Relationship Diagram

Although this logistics facility has implemented efficient operational systems and advanced warehouse technologies, the high productivity demands in cold storage areas may lead to insufficiently detailed identification of occupational safety aspects at each stage of activity. Without systematic hazard identification and risk control, the likelihood of workplace accidents and occupational diseases may increase, ultimately affecting operational performance, worker well-being, and the overall sustainability of the company's operations.

In addition to the risk factors illustrated in the problem tree, the physical conditions and operational layout of the warehouse in Atsugi also influence the level of occupational safety. Based on the warehouse layout, limited space leads to close interaction between manual workers and the traffic routes of heavy equipment, such as forklifts. The proximity of work areas to internal transportation routes, combined with damp and slippery floor conditions, creates high-risk points that may lead to accidents and disrupt the smooth flow of food logistics distribution. Therefore, a structured occupational safety analysis approach is required to identify potential hazards at each stage of the *shiwake* process. The Job Safety Analysis (JSA) method is considered appropriate, as it enables detailed mapping of work activities, identification of potential hazards, and formulation of effective risk control measures. This analysis is expected to serve as a basis for improving occupational health and safety, particularly in goods sorting activities within this cold storage facility, to support the creation of a safe working environment aligned with the principle of zero accidents [12]. Based on this background, the research questions of this study are as follows:

1. What potential hazards are present at each stage of the sorting (*shiwake*) process in the observed logistics cold storage warehouse?
2. What are the risk levels associated with each of these hazards in relation to worker safety and health?
3. What risk control measures can be proposed using the Job Safety Analysis (JSA) method to minimize workplace accidents and occupational diseases in the *shiwake* area?

2. Method

This study aimed at identifying, analyzing, and evaluating occupational health and safety (HSSE) risks in operational activities within the warehouse under study. The research method employed is Job Safety Analysis (JSA), which breaks down work processes into specific tasks to identify potential hazards, assess risk levels, and determine appropriate control measures to minimize the likelihood of workplace accidents. The object of this study is the goods sorting activity within the warehouse, which consists of several stages, including item picking, checking the quantity and condition of goods, transferring items from pallets to handling equipment, and placing goods into storage or dispatch areas. The subjects of the study are the workers involved in these sorting activities.

Figure 3 illustrates the research flow and scope, which includes the stages of observing the sorting activities, problem identification, literature review, field data collection, data processing using the Job Safety Analysis (JSA) method, results analysis, and conclusion drawing. The study begins with an observation of the research object to understand the conditions and context of the study area and to gather primary information. This is followed by problem identification based on observations, interviews with key informants, and a review of relevant literature.

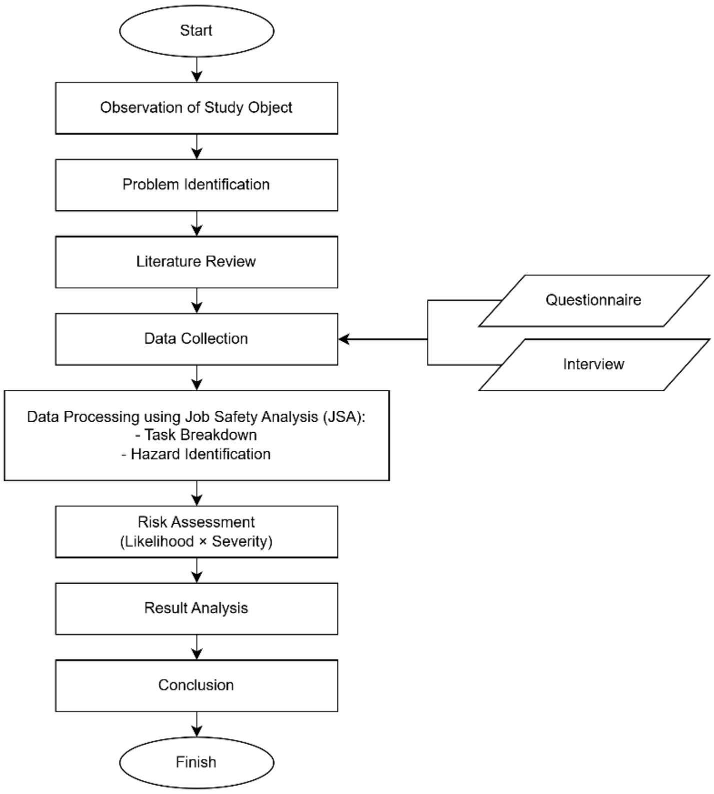

Figure 3. Research Flow Diagram

During the literature review stage, we collect references related to the research problem to establish the study's position and support the analytical process. The subsequent stage involves data collection through interviews, questionnaires, and literature review. The collected data are then processed using the Job Safety Analysis method to determine the risk values associated with each step of the sorting process. These results are further analyzed to assess the level of risk for each work activity, which serves as the basis for drawing conclusions and formulating recommendations. The risk assessment process in this study is conducted by systematically quantifying risk through the multiplication of the likelihood of occurrence and the severity of its potential impact. This approach provides a structured method for evaluating and prioritizing risks based on their overall impact within the work environment.

The data used in this study consists of both primary and secondary data. Primary data were obtained through direct observation in the cold storage warehouse and interviews using a Job Safety Analysis (JSA) questionnaire. Respondents were selected using purposive sampling, focusing on workers directly involved in sorting activities, including floor supervisors (leaders) and operational staff. The selection also considered work experience, with respondents having at least one year of experience, ensuring adequate understanding of work processes, operational procedures, and potential risks at each stage of the activity. Respondents' list, as can be seen in Table 1. The questionnaire used in this study was structured around the Job Safety Analysis (JSA) framework and organized into distinct sections: respondent identity (name, position, and tenure), a breakdown of each work stage in the sorting (*shiwake*) process, an open-ended hazard identification section, and a risk scoring section where respondents rated each identified hazard using two 1-5 scales: likelihood and severity, based on the AS/NZS 4360:2004 standard. A final section captured existing or recommended control measures from the respondent's perspective. Questionnaires were administered through guided, face-to-face sessions combined with semi-structured interviews with all eight respondents (four leaders and four staff), rather than as self-completed forms, to ensure consistent understanding of the risk scale definitions and minimize interpretation bias across participants.

The scoring process followed a sequential approach: researchers first explained each work stage based on prior field observation, respondents then identified hazards relevant to that stage from their own experience, and finally assigned likelihood and severity scores for each hazard. Since these scores are inherently qualitative judgments converted into numerical values, the eight individual ratings for each hazard were aggregated using the Geometric Mean rather than a simple arithmetic average, as this method reduces the influence of extreme or outlier scores arising from subjective variation among respondents, producing a more stable value that better reflects group consensus [13]. This design was further justified by the adoption of the 1-5 scale to maintain consistency with the AS/NZS 4360:2004 standard used in comparable prior studies [14], the use of guided administration over unassisted self-reporting given respondents' varying familiarity with technical risk-management terminology, and the purposive selection of leaders and staff with at least one year of tenure, based on the assumption that meaningful risk assessment requires practical, first-hand understanding of the actual workflow rather than procedural knowledge alone.

Table 1. Respondent Profile

No.	Initials	Job Title	Years of Experience
1	I	Leader	2
2	F	Leader	1
3	S	Leader	1
4	NM	Leader	2
5	HY	Staff	10
6	OU	Staff	6
7	TH	Staff	2
8	G	Staff	2

In addition to primary data, this study also utilizes secondary data obtained through a literature review of company documents and relevant previous studies to establish a strong theoretical foundation. This study adopts the AS/NZS 4360:2004 risk management standard, as referenced by [14], to determine the scales of probability and severity. The use of this international standard aims to ensure consistency and reliability in evaluating various risk scenarios.

Table 2. Likelihood (LK) Scale

Level	Likelihood	Definition
5	Almost Certain	An event that can occur at any time.
4	Likely	May occur periodically or frequently.
3	Possible	Could occur under certain conditions.
2	Unlikely	Rarely occurs during normal operations.
1	Rare	Very unlikely to occur.

Source: AS/NZS 4360:2004 Risk Management Guideline [14]

Table 3. Severity (SV) Scale

Level	Severity	Definition
1	Insignificant	No injury, very minor financial loss
2	Minor	Minor injury requiring first aid, small financial loss
3	Moderate	Moderate injury requiring medical treatment, moderate financial loss.

Level	Severity	Definition
4	Major	Serious injury (one person), loss of body function, major operational disruption
5	Catastrophic	Fatality (>1 person), major financial loss, widespread impact, total shutdown of operations

After the data were collected through questionnaires from respondents, the next stage involved processing the data to determine the values of probability (likelihood) and severity. Considering that risk assessment is qualitative in nature but converted into numerical values, the geometric mean (Geomean) method was used to aggregate the respondents' answers. This method was selected due to its ability to minimize the influence of extreme values (outliers), resulting in a more stable and representative average that reflects group consensus [13]. The calculated geometric mean values were then rounded to the nearest integer to align with the predefined likelihood and severity scales. Once single values for both parameters were obtained, the risk level was evaluated by calculating the Risk Rating (RR) by multiplying LK and SV.

Table 4. Risk Analysis Matrix

Likelihood (LK)	Severity (SV)				
	1	2	3	4	5
5	High	High	Extreme	Extreme	Extreme
4	Medium	High	High	Extreme	Extreme
3	Low	Medium	High	Extreme	Extreme
2	Low	Low	Medium	High	Extreme
1	Low	Low	Medium	High	High

Source: AS/NZS 4360:2004 Risk Management Guideline [14]

Description**:**

- Low Risk = The risk is acceptable. No additional control measures are required.
- Medium Risk = Actions are required to reduce the risk; however, the cost of preventive measures should be carefully evaluated and limited.
- High Risk = The activity must not be carried out until the risk is reduced. Immediate risk management actions are required.
- Extreme Risk = The activity must not be carried out or continued until the risk is reduced. If risk reduction is not feasible, the work must be stopped immediately.

This numerical score serves as an indicator of the urgency of mitigation, where higher values represent more critical risks requiring immediate action, while lower values can be managed through routine monitoring. A complete matrix explaining the risk analysis is shown in Table 4. According to the AS/NZS 4360 standard, risk levels are classified into several categories, namely low, medium, high, and extreme. This classification serves as a basis for determining risk control priorities and allocating resources effectively to maintain occupational health and safety in the warehousing environment.

3. Result and Discussion

The analysis of occupational risks using the Job Safety Analysis (JSA) method in operational activities within the observed logistics warehouse in Atsugi resulted in a comprehensive risk assessment by identifying various potential hazards, their severity, likelihood of occurrence, and corresponding Risk Rating (RR) scores. All RR values in this study were calculated based on observations and evaluations of sorting (*shiwake*) activities carried out in the cold storage environment. The classification of risk levels refers to the AS/NZS 4360:2004 standard matrix to ensure consistency and reliability in the evaluation process. Before conducting hazard identification and risk assessment, a thorough understanding of the operational workflow is essential to accurately map potential risks at each stage. The sorting (*shiwake*) activity in the warehouse involves a series of processes that include interactions between manual labor, the use of scanning technologies, and the movement of material handling equipment. The systematic workflow of these activities in the warehouse (Figure 4), from goods arrival to outbound preparation, is illustrated in the following Figure 5.

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Based on the operational stages that have been visualized, an in-depth analysis was conducted for each work step to map potential hazards arising at every transition of activities. The breakdown of tasks into smaller activity units is essential in the Job Safety Analysis (JSA) method to ensure that all risks, whether mechanical, ergonomic, or environmental, are comprehensively identified. The results of hazard identification, risk level assessment based on likelihood and severity parameters, and the formulation of control measures for sorting activities are presented in detail in the following Table 5.

Results show a total of 11 potential hazards were identified, encompassing mechanical, ergonomic, and environmental aspects. The risk classification indicates a variation in risk levels, ranging from low to extreme. Extreme risks were identified in two main activities: interaction with forklift traffic in the sorting area, which recorded the highest Risk Rating (RR) value of 16, and direct exposure to extreme temperature environments (cold storage), with an RR value of 12. These risks are categorized as extreme due to their potential to cause severe physical injuries, fatalities, and serious health conditions such as hypothermia.

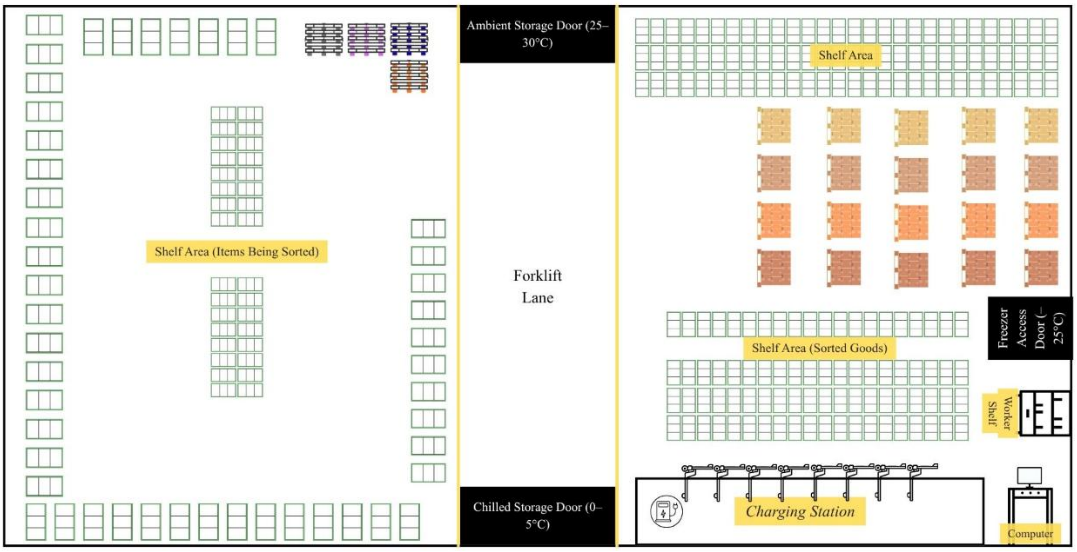

Figure 4. Warehouse Layout

The dominance of forklift traffic as the highest-rated hazard can be attributed to the confined layout of the sorting area, where pedestrian and vehicle pathways are not physically separated, combined with reduced visibility caused by low-temperature condensation forming on protective eyewear and scanner screens. This convergence of spatial constraint and impaired sensory perception elevates both the likelihood and severity of collision events beyond what would typically be observed in ambient-temperature warehouses. Similarly, direct exposure to extreme cold is classified as extreme not only due to the risk of hypothermia itself, but because sustained low-temperature exposure progressively impairs manual dexterity and cognitive alertness. This creates a compounding effect that increases the likelihood of secondary incidents such as dropped loads or delayed reaction to moving equipment rather than acting as an isolated hazard confined to health outcomes alone.

In addition to extreme risks, several activities fall into the high-risk category (RR ≥ 9), including non-ergonomic working postures such as repetitive bending (RR = 12), manual handling of heavy loads (RR = 12), and wet or slippery floor conditions in the cold storage area (RR = 9). Environmental factors, such as prolonged exposure to low temperatures, also present a high level of risk (RR = 9), as they may reduce worker concentration and increase the likelihood of human error. Meanwhile, moderate risks were identified in activities such as the use of manual trolleys (RR = 8) and unstable stacking of goods (RR = 6), while the lowest risk level was associated with exposure to the handheld scanner screen light (RR = 4).

Notably, these four high-risk activities are not independent of one another but are mechanistically linked by the cold storage environment itself. Prolonged cold exposure reduces peripheral blood flow and finger dexterity [15], compelling workers to compensate with awkward gripping and bending postures during manual handling, which in turn elevates the severity of musculoskeletal strain associated with repetitive bending and heavy lifting. At the same time, the temperature differential between the cold storage interior and adjacent areas generates floor condensation, directly contributing to the slip-related risk. This same thermal stress additionally impairs sustained attention, meaning that a worker already fatigued by cold exposure is simultaneously more prone to misjudging floor conditions or lifting technique. In this sense, low temperature functions as a common root cause that amplifies several seemingly separate hazards rather than acting as one hazard among many.

Overall, these findings indicate that although the warehouse technology system operates efficiently, the presence of high and extreme risks in sorting activities requires immediate attention and systematic mitigation measures. Therefore, risk control strategies are prioritized based on the highest Risk Rating values without neglecting other potential hazards. Mitigation efforts primarily focus on high-to extreme-risk activities, particularly forklift traffic interactions in the sorting area (RR = 16), which pose significant risks of collisions or struck-by incidents. Control measures include the separation of forklift and pedestrian pathways, installation of warning signs, clear marking of operational routes, implementation of speed limits, and the use of reflective safety vests to improve worker visibility.

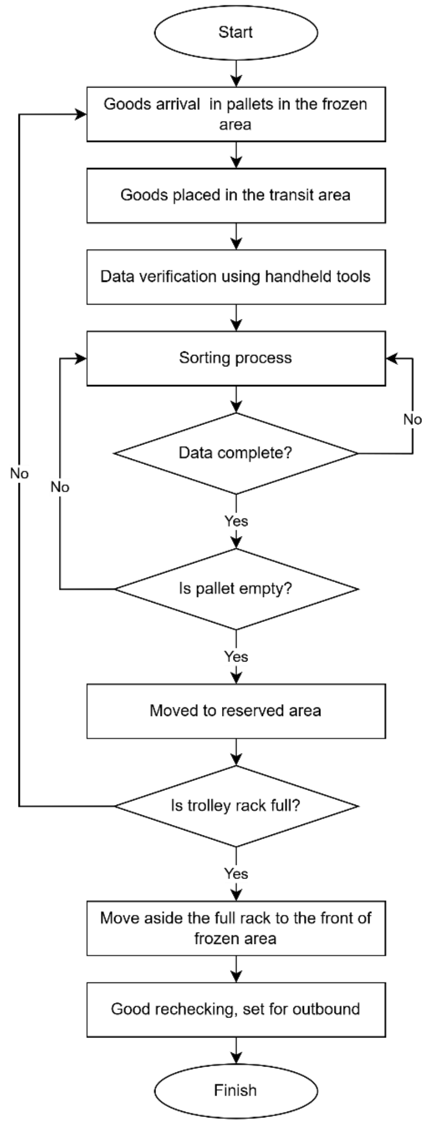

Figure 5. Warehouse Activity Workflow

Ergonomic risks due to repetitive bending postures are addressed through limiting continuous working durations, implementing cycle-based micro-breaks, and job rotation among workers. Training on proper lifting techniques is also essential to reduce musculoskeletal disorders. For manual handling of heavy loads, control measures include limiting lifting weights, utilizing assistive equipment such as trolleys or pallet jacks, and distributing workloads evenly among workers. To mitigate risks associated with extreme cold exposure in cold

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storage areas, control measures include the mandatory use of cold-resistant personal protective equipment (PPE), regulation of working durations, and provision of rest periods in normal temperature areas. These measures aim to prevent health issues such as hypothermia and maintain worker concentration.

In addition to primary mitigation strategies based on Risk Rating, previous studies highlight the effectiveness of administrative and visual controls in cold storage environments. Prolonged exposure to cold temperatures has been shown to reduce concentration and increase physical fatigue [16]. Therefore, job rotation and scheduled micro-breaks are recommended as effective and cost-efficient control measures. Visual management practices, such as floor markings, safety signage, and clear separation between forklift and pedestrian pathways, have also been proven to reduce accident risks due to human error [17]. Furthermore, short practical ergonomic training sessions (toolbox meetings) are recommended to enhance workers' understanding of safe working postures [18]. Additional controls include standardizing pallet stacking and clearly marking transit areas to prevent falling object hazards and maintain workplace organization [11].

Table 5. Risk Analysis Matrix

No.	Activity	Hazard	Risk	LK	SV	RR
1	Sorting process in the warehouse	Forklift traffic in the sorting area	ECollision/struck-by incidents causing serious injury or fatality	4	4	16
2		Movement of trolleys or manual carts	A collision causing bruises or minor injuries to the extremities	4	2	8
3		Wet or slippery floor conditions	Slips/falls causing dislocation or head injury	3	3	9
4		Exposure to the handy scanner screen, light & low lighting	Eye strain and reduced visual acuity	2	2	4
5		Extreme operational temperature (0-10°C)	Reduced motor function and numbness in fingers	3	3	9
6		Non-ergonomic working posture (repetitive bending)	Lower back pain (LBP) or musculoskeletal disorders	4	3	12
7		Prolonged exposure to cold temperatures (environmental factor)	Decreased concentration and increased risk of human error	3	3	9
8		High or unstable stacking of goods/boxes	Falling objects causing head or shoulder injury	3	2	6
9		Repetitive manual handling of heavy loads	Shoulder joint injury or muscle cramps due to excessive workload	4	3	12
10		Manual handling of empty pallets	Hands caught in pallets, causing cuts or finger fractures	3	3	9
11		Extreme cold working environment (Cold Storage)	Hypothermia or frostnip on exposed skin	4	3	12

Overall, these additional mitigation measures are adaptive, practical, and do not require significant technological investment, making them suitable for integration into the existing operational system. Their implementation is also aligned with the principle of continuous improvement in occupational health and safety management within warehouse environments. The feasibility analysis indicates that most recommended controls are administrative and visual in nature, making them relatively easy to implement without disrupting operations. However, potential challenges include operational disruptions during peak hours, worker compliance with administrative policies, and balancing mitigation effectiveness with operational costs.

4. Conclusion

Based on the results of this study using the Job Safety Analysis (JSA) method on sorting (*shiwake*) activities in the observed logistics warehouse in Atsugi, Japan, it can be concluded that working activities in cold storage environments involve varying levels of occupational health and safety risks, ranging from low to extreme. Among the 11 identified hazards, the highest risk was associated with forklift traffic interaction in the sorting area, with a Risk Rating (RR) of 16, categorized as extreme due to its potential to cause severe injury or fatality. In addition, prolonged exposure to cold environments, repetitive manual handling of heavy loads, and non-ergonomic working postures were identified as high-risk factors, with RR values ranging from 9 to 12. These risks may lead to musculoskeletal disorders, decreased concentration, and serious health conditions such as hypothermia. Moderate risks were found in manual trolley use and unstable stacking conditions, while low risks were associated with exposure to handheld scanner screens and lighting conditions.

The likelihood and severity calculations, processed using the geometric mean method, indicate that cold environmental conditions, high physical workload, and interactions between workers and material handling equipment are the primary contributors to occupational risks. Therefore, the proposed mitigation measures include the provision and standardization of appropriate PPE for cold storage environments, regulation of working hours and rest periods, implementation of job rotation, enhancement of ergonomic and manual handling training, clear separation of forklift and pedestrian zones, and maintenance of floor and environmental conditions to prevent slips and falls. The integrated and risk-based implementation of these mitigation strategies is expected to reduce workplace accidents, improve worker comfort and health, and support the creation of a safe, productive working environment aligned with the zero-accident principle.

For future research, it is recommended to expand the risk analysis by combining JSA with other methods such as HIRARC, FMEA, or quantitative ergonomic approaches like RULA or REBA to obtain more comprehensive results. Additionally, future studies may extend the scope beyond sorting activities to include inbound and outbound processes for a more holistic risk assessment. Further research may also evaluate the effectiveness of the proposed mitigation strategies through before-and-after analysis or periodic safety performance assessments.

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ENERGY RESOURCE ASSESSMENT THROUGH HYDRODYNAMIC MODELING OF MARINE CURRENTS IN PULAU PISANG STRAIT, PESISIR BARAT, LAMPUNG

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Abstract
As an archipelagic nation, Indonesia holds tremendous potential for the development of renewable energy, one of which is ocean current energy, recognized for its stability, cleanliness, and sustainability. Pesisir Barat Regency in Lampung Province is a coastal region rich in marine resources, yet it still faces challenges related to dependence on fossil fuels and limited electricity infrastructure, particularly on Pulau Pisang. Despite being a world-class tourism destination, Pulau Pisang remains off-grid and relies solely on diesel generators. This study aims to address these issues by conducting hydrodynamic modeling using Delft3D software across 11 coastal districts and mapping the potential of Ocean Current Power Plants. The simulation results highlight the Pulau Pisang strait, the strait between Pulau Pisang and the mainland, as the most promising location. This area features mixed semidiurnal tidal characteristics, with average current velocities reaching 0.52 m/s and peak velocities up to 5.40 m/s. Based on the hydrodynamic profile and energy conversion efficiency, the Gorlov turbine is identified as the most suitable technology, with an estimated maximum energy output of 94,647.79 kW. The generated energy is intended to supply Pulau Pisang, supporting its transformation into an energy-independent and sustainable tourism zone, and paving the way for a clean energy-driven local economic transition.

Keywords:
Energy; hydrodynamic; modeling; marine Currents; pulau pisang strait; lampung

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1. Introduction

Indonesia's rapid population growth has increased the demand for energy. At the same time, fossil fuels, which remain the primary source of power, are becoming less available. This condition creates a serious challenge for the country's energy security. Indonesia's energy demand keeps increasing, reaching more than 1,200 million BOE in 2024 [1]. BOE stands for Barrel of Oil Equivalent, which is a standard unit to compare different energy sources on the same basis. One BOE equals about 5.8 million BTU, or roughly 1,700 kilowatt-hours of energy.

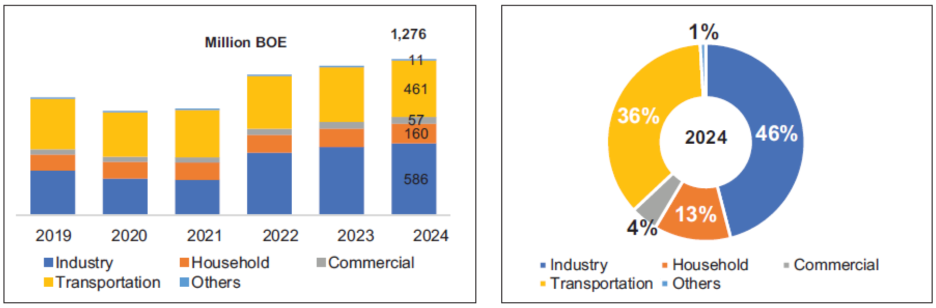

Figure 1. Indonesia Final Energy Consumption [1]

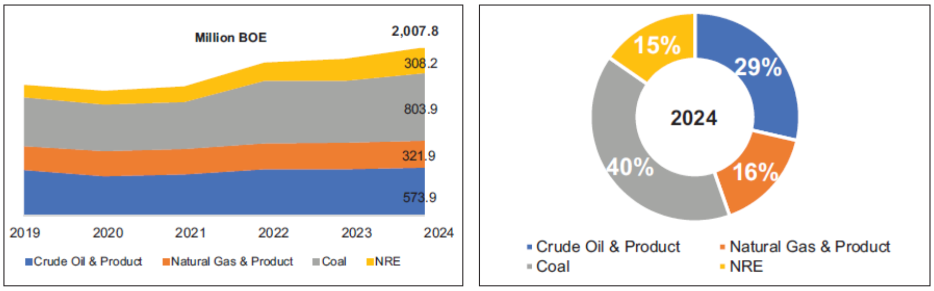

Figure 2. Primary Energy Supply [1]

Aligned with Indonesia's economic growth, the nation's energy supply in 2024 is projected to rise by 7.3% compared to the previous year, reaching 2,007 million BOE its highest level in the past decade. Supplies of fossil energy sources such as crude oil and petroleum products increased by 3.5%, while coal rose by 9.3%. Meanwhile, natural gas grew by 1.5%, and new and renewable energy (NRE) expanded significantly by 17.2%. The primary energy mix remains dominated by coal at 40.37%, followed by petroleum at 28.82%, natural gas at 16.17%, and NRE at 14.65%. By 2025, the share of NRE is targeted to reach 23% [1]. To achieve this target, it is crucial to intensify research and development on renewable energy potential, particularly from Indonesia's marine sector, which holds vast untapped resources.

Indonesia holds significant potential for renewable energy through ocean currents, waves, and tides. In particular, Sumatra Island has several straits that could be developed, including the Pulau Pisang Strait. Straits represent favorable sites for ocean-current energy because their narrow geometry accelerates tidal and residual flows, increasing current velocity and, therefore, the available kinetic power density. This is evidenced by nearby examples in Indonesia: modeled peak tidal streams of ~2–3 m/s in the Sunda Strait with extractable power on the order of ~300 MW, and multi-strait national assessments identifying gigawatt-scale opportunities [2].

Along Sumatra's west coast (exposed to the Indian Ocean), wave-energy flux commonly spans ~10–25 kW/m offshore, with seasonal strengthening during the southeast monsoon indicating a promising complementary resource to tidal streams for hybrid marine energy schemes [3]. Regional hindcasts and multi-dataset ensembles consistently highlight elevated wave power off southern Java–western Sumatra, including waters adjacent to Lampung.

Pulau Pisang, situated on the outermost boundary of Lampung Province, is characterized by its clear waters, white sandy beaches, natural coral reefs, and frequent dolphin sightings along the coast. The island holds high potential for tourism development, appealing to both domestic and international visitors. As of 2024, the area with a population of approximately 1,739 people and 400–600 households remains heavily dependent on diesel generators as its primary electricity source [4]. This reliance has been exacerbated by the failure of the subsea PLN transmission cable, which was damaged by strong waves and currents in 2021 and has not yet been repaired. Consequently, the community's electricity demand continues to be met exclusively by diesel gensets, resulting in high operational costs, unstable supply, and adverse environmental impacts. The central challenge, therefore, is to develop sustainable energy solutions particularly through research and deployment of marine-based renewable energy resources such as currents, waves, or hybrid systems. Therefore, the objectives of this research are to model current patterns in the Pulau Pisang Strait using Delft3D software, estimate the energy potential of ocean currents,

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and conduct a preliminary mapping of areas suitable for Ocean Current Power Plant (PLTAL) development in the waters of the Pulau Pisang Strait.

Figure 3. Research Study Area

2. Method

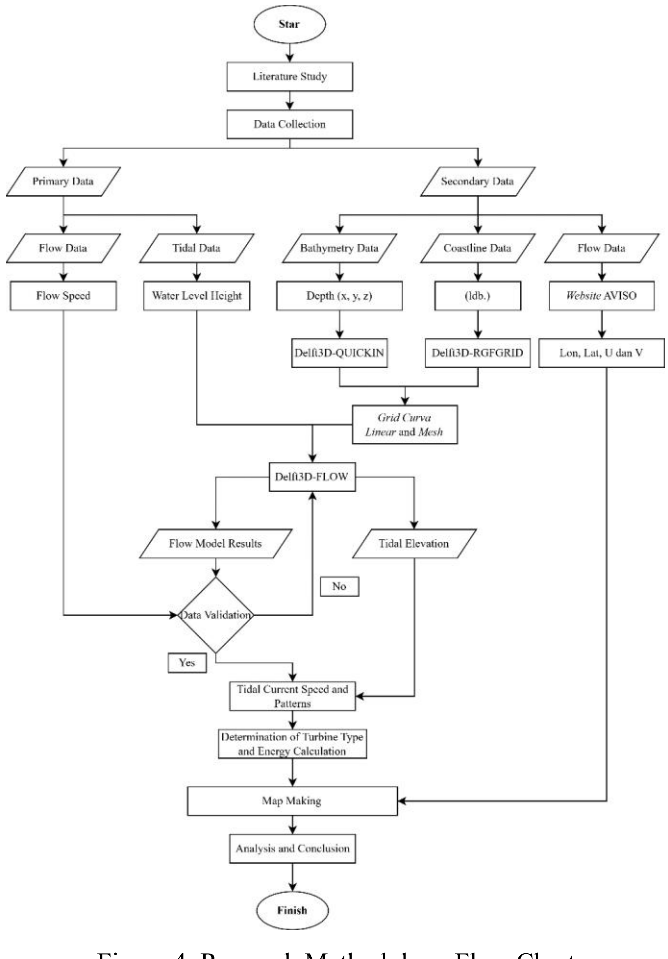

Figure 4. Research Methodology Flow Chart

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2.1 Hydrodynamic Modelling

Delft3D-4, developed by Deltares, is a numerical modeling system designed to represent hydrodynamic processes, sediment transport, morphological evolution, and water quality in riverine, estuarine, and coastal environments. The model solves the nonlinear shallow-water equations, which are derived from the three-dimensional Navier–Stokes equations for incompressible free-surface flows. Its governing equations comprise the continuity equation and the horizontal momentum equations [5]-[8].

$$\frac{\partial \zeta}{\partial t}+\frac{\partial(\zeta+d)u}{\partial x}+\frac{\partial(\zeta+d)v}{\partial y}=0 \quad (1)$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+\frac{w}{(\zeta+d)}\frac{\partial u}{\partial \sigma}=fv-\frac{1}{\rho_0}P_x+F_x+\frac{1}{(\zeta+d)^2}\frac{\partial}{\partial \sigma}\left(\nu_v\frac{\partial u}{\partial \sigma}\right)\&+M_x \quad (2)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+\frac{w}{(\zeta+d)}\frac{\partial v}{\partial \sigma}=-fu-\frac{1}{\rho_0}P_y+F_y+\frac{1}{(\zeta+d)^2}\frac{\partial}{\partial \sigma}\left(\nu_v\frac{\partial v}{\partial \sigma}\right)\&+M_y \quad (3)$$

In this formulation, ζ denotes the water surface elevation relative to mean sea level, while x and y are Cartesian coordinates and u and v represent the horizontal velocity components in the respective directions. The parameter d corresponds to water depth, and σ is the scaled vertical (sigma) coordinate. The Coriolis parameter is expressed as f, and ρ_0 is the reference water density. P_x and P_y indicate the hydrostatic pressure gradients in the x and y directions, whereas F_x and F_y represent the radiation stress gradients. The term ν_v refers to vertical eddy viscosity, while M_x and M_y denote external momentum sinks or sources in the horizontal directions.

2.2 Model Validation Method

The tidal model was validated against field measurements obtained from on-site instrument installations. Model outputs were compared with observed data at the study location to evaluate the degree of agreement between simulations and reality. This verification process was conducted using the Root Mean Square Error (RMSE) method, which quantifies the accuracy of predictions relative to historical measurements. RMSE is particularly advantageous because of its high sensitivity to deviations, making it a reliable indicator of model performance. The formulation of RMSE is presented in Equation 4.

$$\mathrm{RMSE}=\sqrt{\sum_{i}^{n}\frac{(X_{observasi}-X_{model})^2}{n}} \quad (4)$$

Where:

X_{obs} = Field Measurement Data
X_{model} = Result of Model Data
n = Amount of Data

According to research [9] using the RMSE formula, it can be seen that the classification of the error rate based on the RMSE value obtained is shown in Table 1.

Table 1. RMSE Value Classification

RMSE Value	Error rate
0,00 – 0,299	Small
0,30 – 0,599	Medium
0,60 – 0,899	Large
>0.90	Very Large

2.3 Tidal Data Processing

From the analysis of tidal component data, additional information regarding tidal types can be derived. The classification of tidal type is determined using the Formzahl number, as expressed in Equation 5 [10]

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$$F = \frac{(K1 + O1)}{(M2 + S2)} \tag{5}$$

There are four tidal types based on what is shown in Table 2

Table 2. Formzahl Number

Tidal Type	Formzahl Number
Semi-Diurnal	F ≤ 0,25
Mixed Semi-Diurnal	0,25 < F ≤ 1,5
Mixed Diurnal	1,50 < F ≤ 3,0
Diurnal	F > 3,0

A diurnal tide is characterized by one high water and one low water within a 24-hour period, whereas a semi-diurnal tide produces two high waters and two low waters per day, with an average tidal period of approximately 12.4 hours. To estimate water surface elevation caused by tidal oscillations, the amplitude values of the respective tidal constituents are applied.

2.4 Marine current turbine

A marine current turbine is a device designed to harness the kinetic energy of ocean currents and convert it into electrical power. Its working principle is analogous to that of a wind turbine, in which the kinetic energy of moving seawater is captured and transformed into electricity. Specifically, the horizontal flow of water drives the rotation of turbine blades connected to a generator, which subsequently converts mechanical energy into electrical energy [11]. The selection of an appropriate turbine type is crucial to ensure compatibility with local hydrodynamic conditions and to optimize power generation. Considering the flow characteristics of the Sunda Strait, two turbine types have been identified as suitable candidates: the Darrieus turbine and the Gorlov turbine, as illustrated in Figure 5.

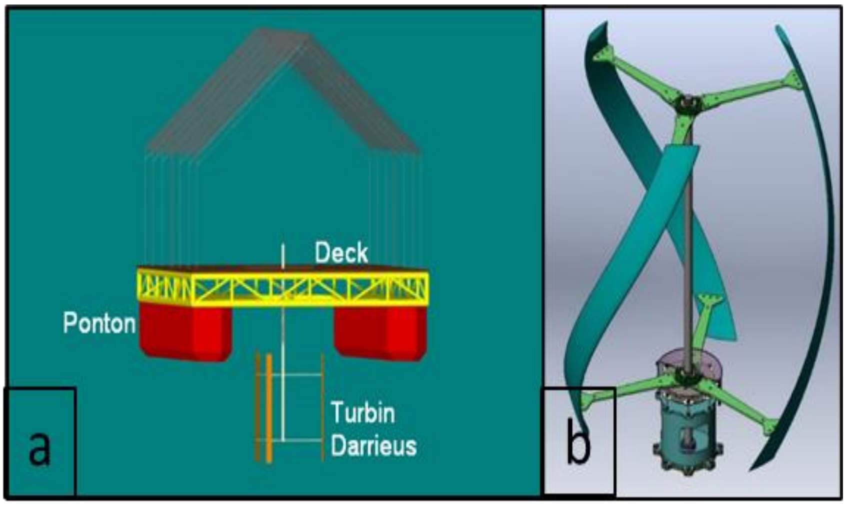

Figure 5. Darrieus turbine (a) ; Gorlov Turbine (b)

The Darrieus turbine. Its symmetrical configuration allows for reduced sensitivity to flow direction, and it is capable of operating under relatively low current velocities. Nonetheless, a key limitation is the tendency to produce significant vibrations at higher flow speeds. With a rotor cross-sectional area of 3 m², the Darrieus turbine has been demonstrated to generate approximately 2 kW of electricity at a current velocity of 1.4 m/s [12][13].

2.5 Energy Calculations

To determine the value of electrical energy from the current speed [14] use Equation 6

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$$P = 0.5 \times \eta \times \rho \times A \times V^3 \quad (6)$$

With:
$P: Electricalenergyproduced(kW)/Power$
$\eta: Turbineefficiency(35$
ρ : Specific gravity of water $= 1025\ \mathrm{kg/m^3}$
A : Cross sectional area (m^2) of the turbine
$V: Currentspeed(m/s)$

3. Result and Discussion

3.1 Hydrodynamic Modelling

The modeling domain adopts a curvilinear grid in spherical coordinates with a spatial resolution of 30 m x 50 m for the finest grid and 120 m x 120 m at the boundary. The bathymetric data used as a reference were obtained from BATNAS. The TPXO database was used to generate the tidal harmonic constituents at open boundaries.

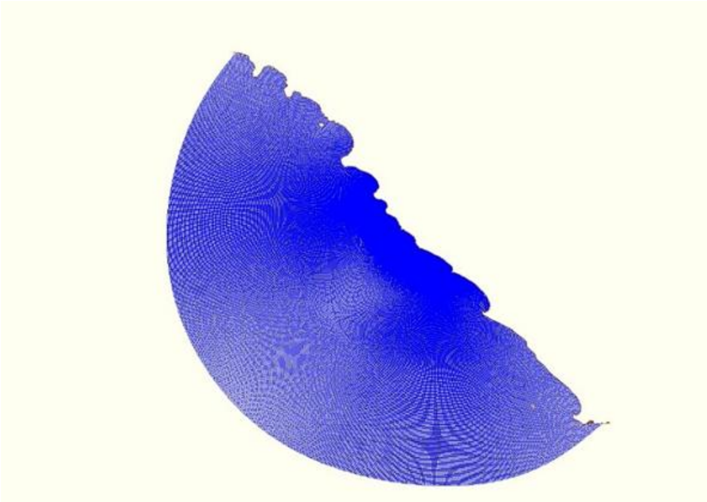

Figure 6. Grid Model

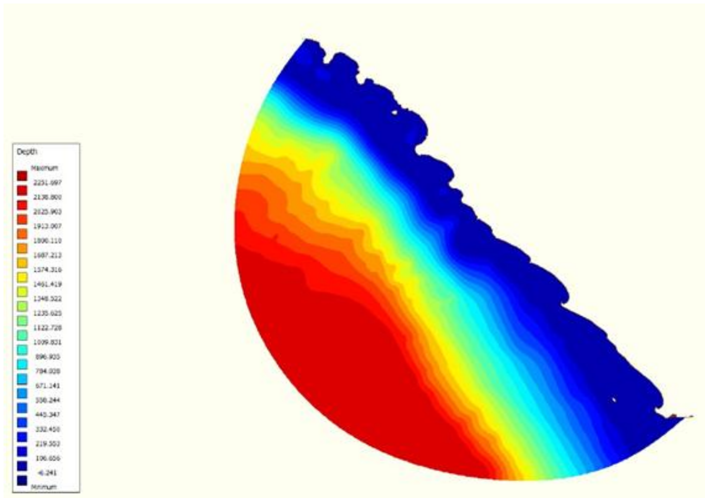

Figure 7. Depth Model

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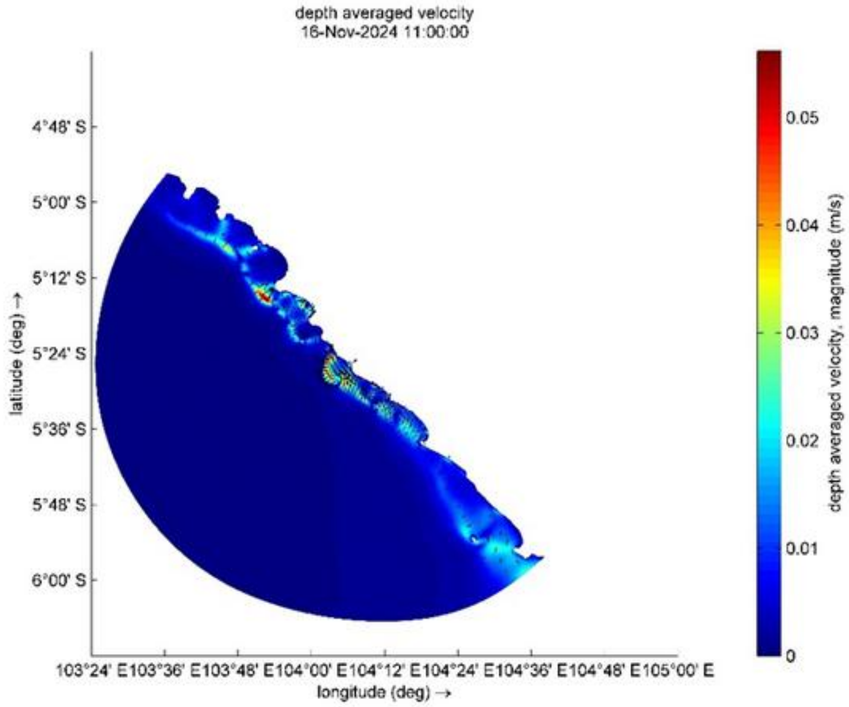

Figure 8. Current Result Model

Current Output

In this study, ocean current modeling was carried out at 11 observation points distributed along the western coastal region of Lampung, specifically in Pesisir Barat Regency. Each location shows different current characteristics in terms of average, maximum, and minimum velocity recorded during the modeling period.

Table 3. Current Speed Result

No	Location	Longitude	Latitude	Avg.Current (m/s)	Max Current (m/s)	Min Current (m/s)
1	Lemong	5°15,12"	103°42'15,85"	0.0015	0.0047	0.0002
2	Pesisir Utara	5°3'59,31"	103°44'35,27"	0.20	0.80	0.003
3	Pulau Pisang	5°7'30,52"	103°49'6,39"	1.67	5.09	0.03
4	KaryaPenggawa	5°8'36,75"	103°52'56,84"	0.25	1.04	0.0004
5	Way Krui	5°9'59,64"	103°54'57,33"	0.17	2.90	0.0021
6	Pesisir Tengah	5°11'11,00"	103°54'9,10"	0.59	5.41	0.010
7	Krui Selatan	5°15'7,11"	103°56'50,22"	0.002	0.009	0.001
8	Pesisir Selatan	5°16'58,49"	103°57'18,50"	0.115	2.11	0.0001
9	Ngambur	5°26'46,82"	104°5'53,85"	0.00097	0.0064	0.0028
10	Ngaras	5°30'47,55"	104°11'34,59"	0.2003	1.70	0.0008
11	Bengkunat	5°36'36,82"	104°18'0,06"	1.25	3.24	0.02

Among these, Pulau Pisang stands out as a site with very strong currents, with an average velocity of 1.67 m/s and a maximum reaching 5.09 m/s. These values indicate that the waters surrounding Pulau Pisang possess significant potential for marine current energy utilization.

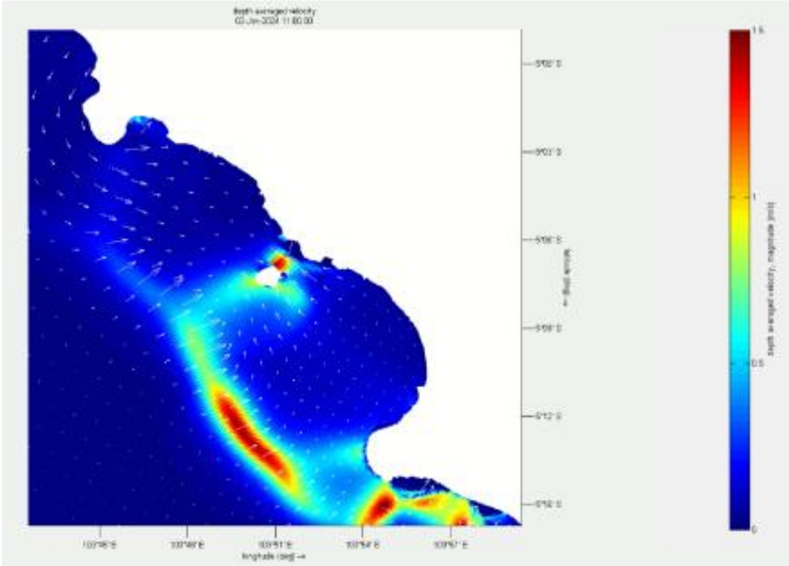

Figure 9. Pulau Pisang currents

Model Validation

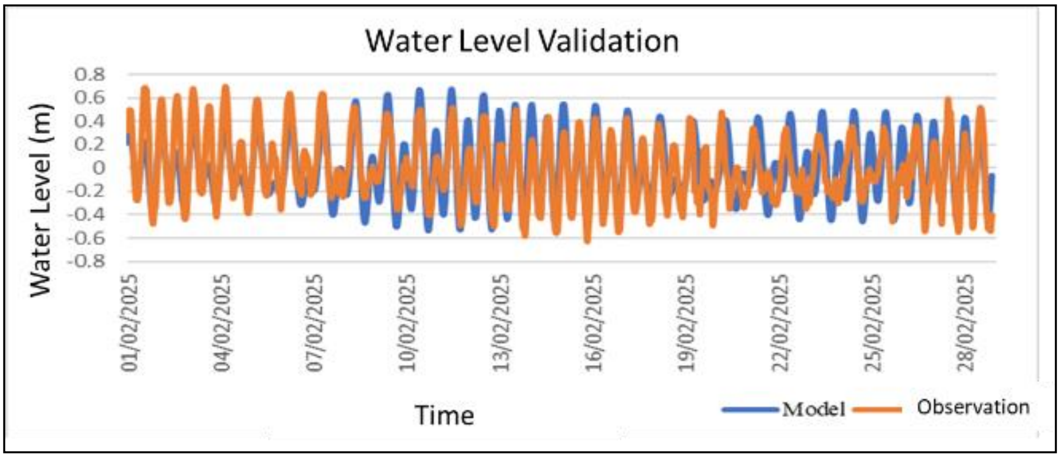

Figure 10. Model Validation

Model validation against tidal field data indicates an error of 0.2, classified as small. This validation of the model's capability in replicating water level trends enhances confidence in its suitability for simulating tidal dynamics within the Pulau Pisang Strait and adjacent coastal regions.

3.2 Estimated Power

Table 4. Estimated Power

Month	Darrieus Turbine (kW)	Gorlov Turbine (kW)
January	3,736.46	7,472.92
February	3,822.80	7,645.59
March	4,406.77	8,813.54
April	4,257.68	8,515.35
May	3,955.36	7,910.71

Month	Darrieus Turbine (kW)	Gorlov Turbine (kW)
June	4,063.90	8,127.80
July	3,836.81	7,673.62
August	4,133.68	8,267.37
September	3,987.44	7,974.89
October	3,960.95	7,921.89
November	3,595.29	7,190.58
December	3,517.21	7,034.43
Total	47,323.89	94,647.79

Darrieus can produce 47,323.89 kW and Gorlov 94,647.79 kW, respectively in one year.

4. Conclusion

A hydrodynamic modeling was conducted to simulate tidal current at Pesisir Barat Regency, Lampung. The model validation, water level suggests that the model can simulate the hydrodynamic condition in the study area with satisfactory accuracy. The results of the modeling indicated potential locations for ocean tidal power plants at Pulau Pisang Strait.

The locations have median current speeds over 1.67 m/s and maximum current speeds exceeding 5.09 m/s. To quantify the potential power, a turbine is tested which features a cross-sectional area of 3 m^2 for Darrieus and 6 m^2 for Gorlov and an efficiency of 0.35 (35%). with a nominal power of 47,323.89 kW and 94,647.79 kW

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DESIGN AND PERFORMANCE ANALYSIS OF AN OFF-GRID PHOTOVOLTAIC SYSTEM FOR AQUACULTURE PONDS IN BORI APPAKAH

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Abstract
The demand for electrical energy in aquaculture, particularly in Pangkep Regency, continues to increase due to the need for nighttime illumination to ensure security and maintain fish activity. However, the geographical location of fish ponds, which are often situated far from the state electricity grid (PLN), creates a significant energy supply challenge. This study aims to design, construct, and analyze the performance of a standalone (off-grid) Photovoltaic (PV) system to supply electrical energy to a 4000 m² fish pond located in Bori Appakah Village. The research methodology includes site assessment, mathematical sizing of system components, system assembly, PVsyst 7.4.8 simulation, and empirical field testing conducted over three days. The total daily energy demand was calculated to be 1,560 Wh/day. The designed system integrates a 400 Wp monocrystalline PV module, a 12 V 300 Ah lead-acid battery bank, a 45 A MPPT solar charge controller, and a 1000 W pure sine wave inverter. Simulation results showed a Performance Ratio (PR) of 66.71% and a Solar Fraction of 93.56%, with an estimated annual energy yield of 554.44 kWh. Field measurements demonstrated that the system was capable of stably supplying power to 13 LED lighting points for 12 hours, with the PV module producing a peak output power of 150 W under fluctuating solar irradiance conditions. The study concludes that the proposed PLTS system is technically feasible and provides a reliable alternative energy solution for remote aquaculture operations.

Keywords:
Photovoltaic System; off-grid; aquaculture ponds;performance; bori appakah

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1. Introduction

Electrical energy has become a fundamental requirement for supporting modern economic activities, including agricultural and aquaculture sectors. The increasing global demand for sustainable and environmentally friendly energy systems has accelerated the transition from fossil-based electricity generation toward renewable energy technologies. In Indonesia, the government has targeted a renewable energy contribution of 23% in the national energy mix by 2025 through the National Energy General Plan (RUEN). Among various renewable energy resources, solar energy has emerged as one of the most promising alternatives due to its abundant availability, environmental sustainability, and continuously decreasing installation costs.

Indonesia is geographically located in the equatorial region and receives relatively high solar irradiation throughout the year. In particular, South Sulawesi Province possesses significant solar energy potential, with average daily solar irradiation ranging from approximately 4.8 to 5.1 kWh/m²/day, making the region highly suitable for photovoltaic (PV)-based power generation systems. Consequently, Solar Power Plants (PLTS) have increasingly been considered an effective solution for rural electrification and isolated areas where conventional grid extension is technically difficult or economically infeasible. Previous studies have demonstrated that off-grid photovoltaic systems can provide reliable electrical energy for remote applications with relatively low operational costs and reduced environmental impact [1, 2].

Recent developments in photovoltaic technologies have also improved system reliability and operational efficiency under tropical environmental conditions. In [3] reported that environmental factors such as temperature and humidity significantly influence photovoltaic degradation and performance. Furthermore, in [4] emphasized the importance of optimal energy management strategies and component sizing to improve the operational reliability of standalone photovoltaic systems. In [5] further demonstrated that PVsyst simulation software can provide accurate performance predictions when validated using real operational data. In addition, optimization techniques and floating photovoltaic systems have been shown to improve overall system efficiency and operational flexibility [6]. Comprehensive reviews on renewable energy technologies also confirmed the growing role of photovoltaic systems in achieving sustainable energy transitions worldwide [7].

The implementation of renewable energy systems in aquaculture and fishery sectors has received considerable attention in recent years. In [8] reported that fishery–photovoltaic integration offers substantial potential for sustainable energy production and climate mitigation. Similarly, In [9] demonstrated the techno-economic feasibility of solar PV systems for shrimp pond aeration applications. In [10] proposed a hybrid solar–wind energy system capable of improving energy sustainability in aquaculture operations. In addition, IoT-integrated photovoltaic systems have increasingly been utilized to improve monitoring capability and operational efficiency in aquaculture environments [11, 12]. Renewable-energy-based aquaculture systems, including aquaponics and fish feed processing applications, have also shown promising results in supporting sustainable fish farming activities [13, 14]. Moreover, hybrid off-grid photovoltaic systems have demonstrated their capability to support recirculating aquaculture systems with improved energy reliability [15].

The aquaculture sector in Bori Appakah Village, Pangkep Regency, represents one of the areas experiencing limited access to reliable electrical infrastructure. The fishpond investigated in this study covers an area of approximately 4000 m² and requires continuous nighttime illumination to support aquaculture operations. Artificial lighting plays a dual role in the pond ecosystem. First, it functions as a phototactic stimulus that helps maintain fish and shrimp activity within safe cultivation zones. Second, the lighting system acts as passive security infrastructure to reduce the risk of theft and predator attacks during nighttime operations. Despite its importance, the pond location is situated approximately 1 km away from the nearest low-voltage utility grid operated by the national electricity company (PLN). Extending the conventional electrical network to the site would require substantial investment costs and may lead to significant voltage drop losses along the distribution line, thereby reducing overall system reliability and economic feasibility.

Although numerous studies have investigated photovoltaic applications for agriculture and aquaculture sectors, most previous works mainly focused on simulation-based analysis or specific subsystem applications such as aeration and water monitoring. Comprehensive studies involving the design, implementation, and real-field validation of off-grid photovoltaic systems for aquaculture pond lighting in remote coastal areas remain limited, particularly under tropical environmental conditions in Indonesia. Therefore, there is still a need for empirical studies evaluating the actual operational performance of standalone PV systems designed for fishpond electrification.

This study proposes the design and implementation of an off-grid solar photovoltaic system for aquaculture pond electrification in Bori Appakah, Pangkep Regency. The proposed system is designed to supply an electrical load demand of 1,560 Wh/day using photovoltaic modules, battery storage, solar charge controllers, and inverter units. System performance is evaluated through both PVsyst simulation and real-field operational measurements to assess the effectiveness and reliability of the proposed design.

The main contributions of this research are threefold. First, the study presents an optimal sizing approach for off-grid PV components suitable for remote aquaculture applications. Second, it provides a comparative analysis between simulation results and real operational performance under tropical environmental conditions. Third, the research evaluates the system feasibility based on key performance indicators, including Performance Ratio (PR) and Solar Fraction, to determine the capability of the system for continuous and sustainable operation. The results of this study are expected to contribute to the development of renewable-energy-based electrification systems for remote aquaculture sectors in Indonesia and other similar tropical regions.

2. Method

A. Research Stages

This study was conducted using a quantitative experimental approach, consisting of literature review, electrical load energy auditing, manual system sizing calculations, software-based simulation, hardware assembly, and field testing.

Figure 1. Location map of the fish pond in Bori Appakah, located approximately 1 km from the PLN utility grid.

A.System Design (Sizing)

The proposed off-grid photovoltaic (PV) system was designed based on the daily electrical energy demand of the fish pond area. The main system specifications are summarized as follows:

- Daily Load Demand: 1,560 Wh/day
- PV Module Capacity: 400 Wp monocrystalline solar panel
- Battery Capacity: 300 Ah (3 × 100 Ah, 12 V batteries connected in parallel)
- Power Conditioning Unit: 45 A MPPT Solar Charge Controller and 1000 W Pure Sine Wave inverter

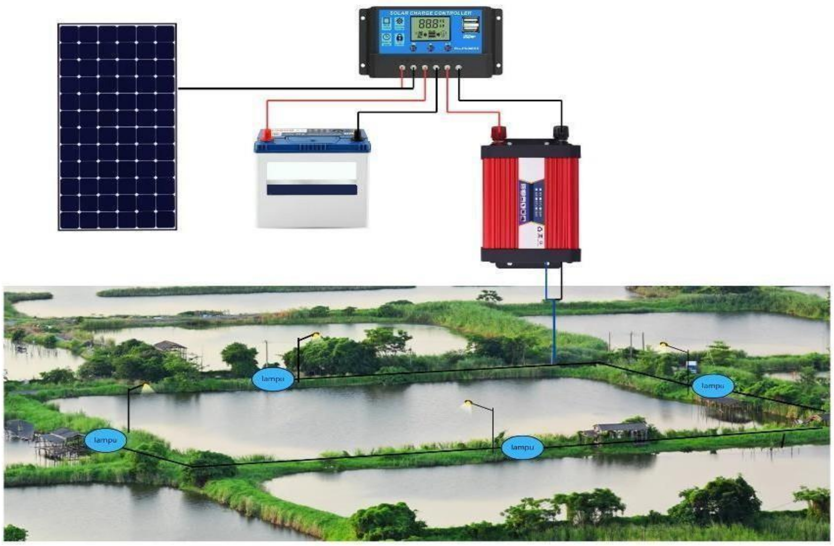


Figure 2. Wiring diagram of the proposed off-grid PV system.

B.Electrical Load Requirement

Table 1. Electrical Load Distribution of the Fish Pond

No	Load Type	Power (W)	Quantity	Operating Time (h/day)	Energy Consumption (Wh/day)
1	Fish Pond Lamps	10	11	12	1,320
2	Terrace Lamp	10	1	12	120
3	Indoor Lamp	10	1	12	120
	Total Daily Energy Demand				**1,560**

To account for system losses, component inefficiencies, and safety factors, the required energy production from the PV system was increased by 25%.
Given:

- Total daily energy demand = 1,560 Wh/day
- System loss/safety factor = 25%

The required PV energy production is calculated as:

- $E_{PV} = E_{total}(1 + 0.25) = 1560 \times 1.25 = 1950 \text{ Wh/day}$

Thus, the PV system must produce approximately 1,950 Wh/day.

1) PV Module Sizing

The number of PV modules was determined based on the required energy production and Peak Sun Hours (PSH).
Given:

- Required PV energy = 1,950 Wh/day
- PV module rating = 400 Wp
- PSH = 5.37 h/day

The daily energy generated by one PV module is:

$$E_{panel} = 0.4 \times 5.37 = 2.148 \text{ kWh/day}$$

The required number of PV modules is:

$$N = \frac{E_{PV}}{E_{panel}} = \frac{1.950}{2.148} = 0.91$$

Therefore, one 400 Wp PV module was selected, resulting in a total installed array capacity of 400 Wp.

2) Solar Charge Controller Sizing

The MPPT Solar Charge Controller rating was determined for a 12 V system with an additional 25% safety margin.
Given:

- Total PV array power = 400 W
- System voltage = 12 V

The base current is calculated as:

$$I_{base} = \frac{P_{PV}}{V_{sys}} = \frac{400}{12} = 33.33 \text{ A}$$

Considering a 25% safety margin:

$$I_{cc} = 33.33 \times 1.25 = 41.67 \text{ A}$$

Therefore, a 45 A MPPT Solar Charge Controller was selected.

3) Battery Capacity Sizing

Battery capacity was calculated by considering inverter efficiency and battery Depth of Discharge (DoD).
Given:

- Total load energy = 1,560 Wh
- Inverter efficiency = 90%

The required battery energy is:

$$E_{bat} = \frac{1560}{0.9} = 1733.33 \text{ Wh}$$

For a lead-acid battery with 50% DoD:

$$C = \frac{1733.33}{0.5} = 3466.67 \text{ Wh}$$

For a 12 V battery system:

$$Ah = \frac{3466.67}{12} = 288.89 \text{ Ah}$$

Thus, a 300 Ah battery bank at 12 V was selected.

4) Inverter Sizing

The inverter capacity was determined based on the total simultaneous AC load with a safety factor to accommodate surge current.

Given:

- Total AC load = 130 W
- Safety factor = 2–3

With a safety factor of 2:

$$P_{inv} = 130 \times 2 = 260 \text{ W}$$

With a safety factor of 3:

$$P_{inv} = 130 \times 3 = 390 \text{ W}$$

Therefore, a minimum 300 W pure sine wave inverter is required. However, a 500 W inverter is recommended to provide better surge handling capability and future load expansion flexibility.

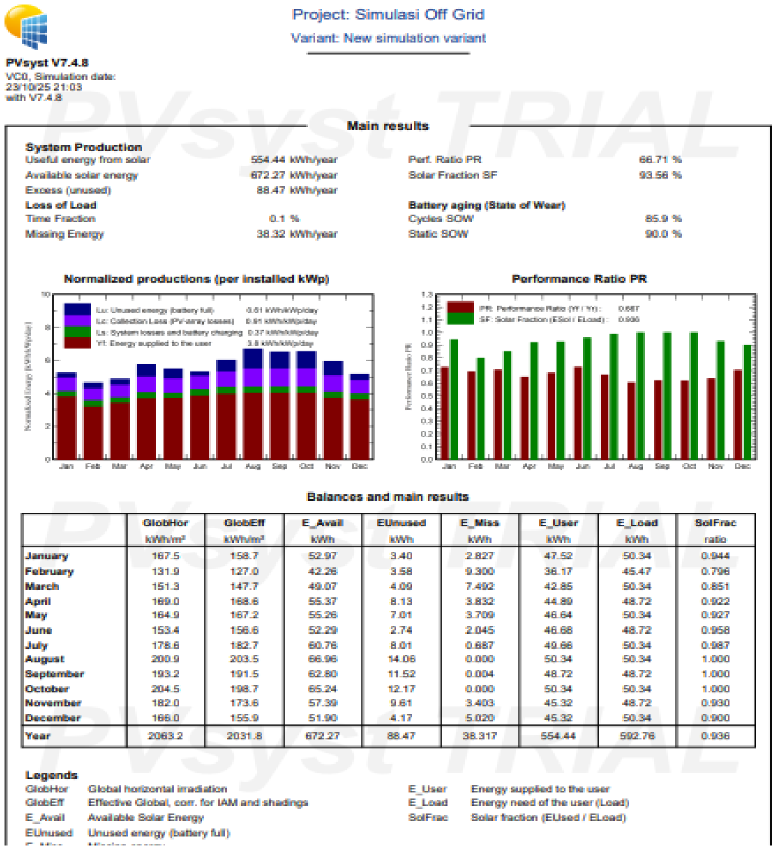
3. Result and Discussion

A. PVSyst Simulation Results

Based on Figure 3, the PVsyst simulation results indicate that the proposed off-grid photovoltaic system is capable of supplying electrical energy reliably for aquaculture pond operations. The system produced an annual useful energy output (E_User) of 554.44 kWh/year, while the total electrical load demand reached 592.76 kWh/year. The simulation also showed that the available solar energy generated by the PV array was 672.27 kWh/year, indicating sufficient solar resource potential to support the operational load requirements.

The average annual Performance Ratio (PR) obtained from the simulation was 66.71%, which reflects satisfactory system performance considering the influence of temperature losses, battery charging–discharging losses, inverter losses, and tropical environmental conditions. In addition, the Solar Fraction (SF) value reached 93.56%, indicating that approximately 93% of the total load demand could be supplied directly by the photovoltaic system. This result demonstrates that the proposed PLTS configuration is capable of operating with a high degree of energy independence and only requires minimal external energy support.

The simulation results also reveal that the unused energy reached 88.47 kWh/year, mainly occurring during periods of full battery charge conditions, whereas the missing energy was recorded at 38.32 kWh/year with a Loss of Load probability of only 0.1%. These findings indicate that the designed system possesses relatively good operational reliability and is suitable for continuous nighttime lighting applications in remote aquaculture ponds. Furthermore, monthly performance analysis shows that the system achieved optimal solar fraction values close to 1.0 during periods of high solar irradiation, particularly from July to October, confirming the strong correlation between solar availability and system energy performance..



Project: Simulasi Off Grid
Variant: New simulation variant

PVsyst V7.4.8
VC0, Simulation date:
23/10/25 21:03
with V7.4.8

Main results

System Production

Useful energy from solar	554.44 kWh/year	Perf. Ratio PR	66.71 %
Available solar energy	672.27 kWh/year	Solar Fraction SF	93.56 %
Excess (unused)	88.47 kWh/year		

Loss of Load

Time Fraction	0.1 %	Cycles SOW	85.9 %
Missing Energy	38.32 kWh/year	Static SOW	90.0 %

Battery aging (State of Wear)

Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_Miss kWh	E_User kWh	E_Load kWh	SolFrac ratio
January	167.5	158.7	52.97	3.40	2.827	47.52	50.34	0.944
February	131.9	127.0	42.26	3.58	9.300	36.17	45.47	0.796
March	151.3	147.7	49.07	4.09	7.492	42.85	50.34	0.851
April	169.0	168.6	55.37	8.13	3.832	44.89	48.72	0.922
May	164.9	167.2	55.26	7.01	3.709	46.64	50.34	0.927
June	153.4	156.6	52.29	2.74	2.045	46.68	48.72	0.958
July	178.6	182.7	60.76	8.01	0.687	49.66	50.34	0.987
August	200.9	203.5	66.96	14.06	0.000	50.34	50.34	1.000
September	193.2	191.5	62.80	11.52	0.004	48.72	48.72	1.000
October	204.5	198.7	65.24	12.17	0.000	50.34	50.34	1.000
November	182.0	173.6	57.39	9.61	3.403	45.32	48.72	0.930
December	166.0	155.9	51.90	4.17	5.020	45.32	50.34	0.900
Year	2063.2	2031.8	672.27	88.47	38.317	554.44	592.76	0.936

Legends

GlobHor Global horizontal irradiation
GlobEff Effective Global, corr. for IAM and shadings
E_Avail Available Solar Energy
EUnused Unused energy (battery full)
E_User Energy supplied to the user
E_Load Energy need of the user (Load)
SolFrac Solar fraction (EUsed / ELoad)

Gambar 3. Simulasi *Off-Grid*

B. Implementation Results

1) Solar PV Testing

Based on Figure 4, the testing results show that the current and output power of the solar panel increased gradually from 07:00 to approximately 10:00 as the intensity of solar radiation increased. During the period between 10:00 and 11:30, the current and power values reached near-maximum conditions, indicating that the photovoltaic modules operated under optimal irradiation conditions. However, several minor fluctuations were observed in the graph due to changes in weather conditions, such as passing clouds and variations in ambient temperature during the testing process.

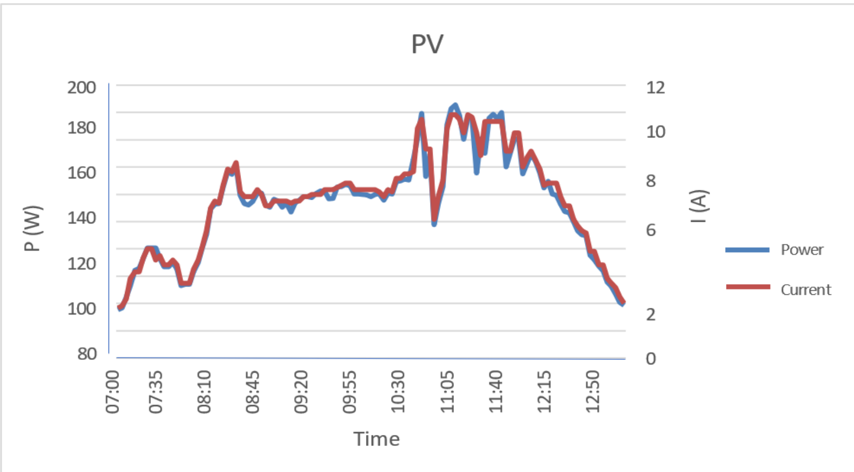


Figure 4. Graph of the relationship between current (A) and power (W) in solar PV

After 11:40 until 12:50, the PV current and output power gradually decreased. This condition was mainly caused by the increase in panel surface temperature, which reduced the efficiency of electrical energy conversion. Overall, the testing results indicate that the performance of the PV modules was strongly influenced by solar irradiation intensity and surrounding environmental conditions. Therefore, the designed photovoltaic system was able to generate power optimally under clear weather conditions while maintaining stable operating characteristics throughout the field testing process.

2) Battery Testing

Based on Figure 5, the graph illustrating the relationship between current and power in the battery system shows relatively stable characteristics throughout the testing period. During the morning period from 07:00 to 09:00, the current and power values remained at moderate levels with very small fluctuations, indicating that the initial battery charging process operated normally. This condition demonstrates that the energy generated by the solar panels was successfully transferred to the energy storage system.

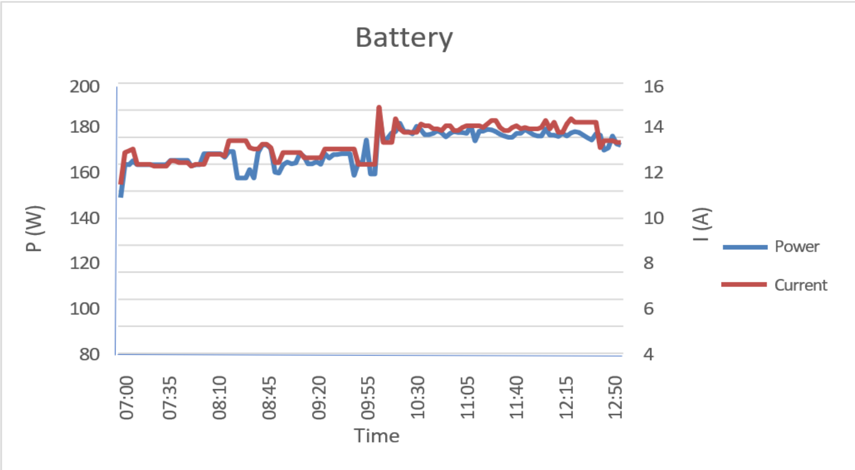


Figure 5. Graph of the relationship between current (W) and power (W) in a battery

Between 09:00 and 11:00, a slight increase in current and power was observed while the system remained stable. This indicates that the battery continuously received energy from the photovoltaic modules as solar irradiation increased. Furthermore, from 11:00 to 12:50, the current and power values returned to stable conditions, indicating that the battery entered a near fully charged state. Overall, the testing results confirm that the battery system operated stably and that the charging system effectively maintained controlled current and power during operation.

3) Inverter Testing

Based on Figure 6, the inverter testing results indicate that the inverter output current and power remained relatively stable throughout the observation period. At the beginning of the testing period, from 07:00 to 09:00, the current and power values were relatively constant without significant changes. This condition indicates that the inverter operated properly in supplying stable electrical power to the load.

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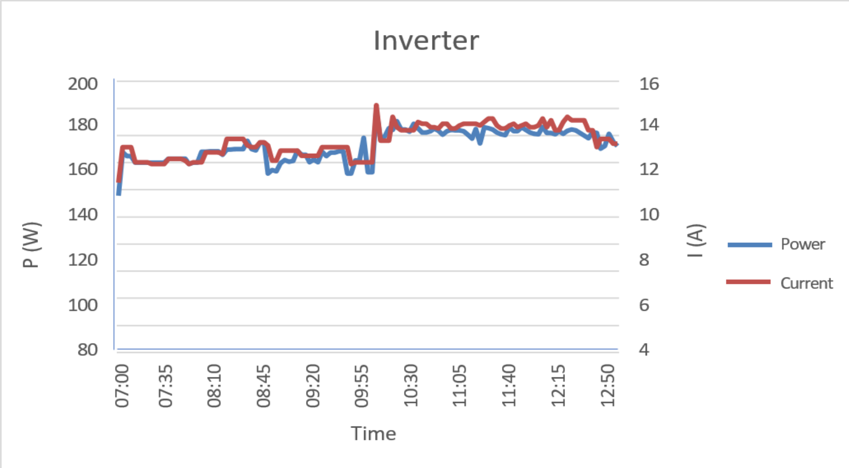

Figure 6. Graph of the relationship between current (A) and power (Watts) on the inverter

At approximately 09:30, a slight increase in current and output power was observed. This condition was likely caused by temporary load changes or the inverter response to increased energy supply from the battery and photovoltaic system. After this period, the current and power values returned to stable conditions until 12:50, indicating that the inverter had good output regulation capability. Overall, the testing results demonstrate that the inverter was capable of converting DC energy into AC power steadily without significant fluctuations, allowing the system to operate reliably during the field testing process.

4) Load Testing

Based on Figure 7, the graph illustrating the relationship between power and current on the load side shows that the system power consumption ranged between 110 W and 140 W during the testing period. The relatively stable power consumption indicates the presence of a constant base load throughout system operation. In addition, the load current remained stable at approximately 0.6 A from morning until afternoon, indicating that the inverter was capable of continuously supplying the required electrical demand.

However, between approximately 14:35 and 16:20, repeated current fluctuations between 0.6 A and 0.7 A were observed. This condition indicates the presence of additional cyclic loads operating periodically, resulting in temporary fluctuations in current demand. Despite these minor fluctuations during the afternoon period, the system was still able to maintain stable power delivery without significant operational disturbances. Overall, the results demonstrate that the designed off-grid photovoltaic system possesses good capability in supplying electrical energy to the load continuously and reliably during field testing.

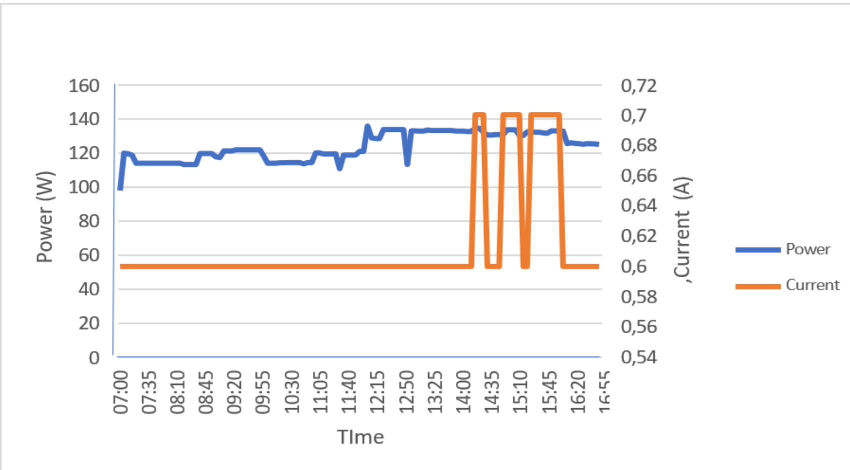

Figure 7. Graph of the relationship between current (A) and power (Watts) under load

4. Conclusion

1) The proposed off-grid photovoltaic system, consisting of a 400 Wp solar panel, 300 Ah 12 V battery, and 45 A MPPT solar charge controller, was successfully designed to supply an electrical load demand of 1,560 Wh/day for aquaculture pond lighting applications.
2) The PVsyst simulation results demonstrated that the system achieved a Performance Ratio (PR) of 66.71% and a Solar Fraction (SF) of 93.56%, indicating satisfactory operational performance and a high level of energy independence under tropical environmental conditions.
3) Field testing results confirmed that the designed photovoltaic system was capable of operating reliably and continuously for approximately 12 hours during nighttime operation. The system also exhibited stable performance in the photovoltaic modules, battery charging process, inverter output, and load supply throughout the testing period.
4) Overall, the proposed PLTS off-grid system is technically feasible and suitable for implementation in remote aquaculture areas lacking access to conventional electrical infrastructure. The study demonstrates the potential of solar energy utilization as a sustainable and environmentally friendly solution for supporting energy needs in coastal aquaculture sectors.

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