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TECHNICAL STUDY ON THE COMPARATIVE PLANNING OF A WASTE COLLECTION VESSEL PROPULSION SYSTEM: CONVENTIONAL ENGINE AND SOLAR PANELS

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ABSTRACT

Conventional diesel engines, also known as mechanical direct injection systems, represent a traditional approach to fuel delivery in engines. In contrast, solar panels convert sunlight into electrical energy using the photovoltaic effect. This research aims to conduct a technical comparative study on the planning of a waste collection vessel propulsion system using both conventional diesel engines and solar panels. The vessel system design requires 3.78 hp. The battery capacity calculated for this system is 84.24 Ah, with an operational duration of 6.4 hours for the diesel engine. The waste capacity is 0.371 m^3/ton, with a power requirement of 3.75 hp, and the chosen engine for this setup is the Yamaha 5CHMS. For the solar panel system, the potential calculation is 5.47 hours of sunlight, with a similar vessel system design of 3.78 hp. The battery usage duration is 6 hours, with the same waste capacity and power requirement. The selected solar panel is the Hangkai DNYSJYSJ. Based on technical calculations, it can be concluded that a waste collection vessel with a conventional diesel engine is more efficient due to its consistent technical performance requirements.

Keywords: Diesel, propulsion, solar panels, technical comparative analysis, waste collection vessel.

Introduction

Environmental issues have become increasingly critical in recent years, with aquatic pollution being one of the major concerns [1]. Rivers and oceans worldwide are plagued with floating debris and waste, severely impacting marine ecosystems and human health. Tackling this problem requires innovative and effective solutions to maintain clean waterways and preserve aquatic life [2].

One straightforward yet impactful approach to mitigate water pollution is the deployment of waste collection vessels [3]. These vessels play a vital role in cleaning up floating debris, thereby reducing pollution levels and preventing the spread of contaminants [4]. However, the efficiency and sustainability of these vessels depend significantly on their propulsion systems. This study aims to compare the technical aspects of two propulsion systems: conventional engines and solar panels [5].

Conventional engines, known for their mechanical direct injection systems, have been the traditional choice for marine propulsion [6]. They are renowned for their reliability and performance. However, the environmental impact of diesel engines, including greenhouse gas emissions and fuel consumption, has raised concerns about their long-term viability [7]. As a result, there is a growing interest in exploring alternative, more sustainable propulsion methods [8].

Solar panels, which convert sunlight into electrical energy through the photovoltaic effect, offer a promising alternative [9]. Solar-powered vessels produce zero emissions during operation,

Figure 1. Vessel Hull Shape

making them an environmentally friendly option [10]. The ability to harness renewable energy from the sun presents an opportunity to reduce the carbon footprint of marine operations significantly [11]. However, the practicality and efficiency of solar panels in marine applications require thorough investigation.

This research will conduct a technical comparative analysis of waste collection vessel propulsion systems powered by conventional engines and solar panels. By evaluating key performance indicators such as power output, operational duration, energy efficiency, and environmental impact, this study aims to provide valuable insights into which system offers a more viable solution for future applications. The findings will help guide the design and implementation of more sustainable marine vessels, contributing to cleaner waterways and a healthier planet.

In conclusion, this study not only addresses the pressing issue of aquatic pollution but also explores innovative solutions to enhance the sustainability of waste collection vessels. By comparing diesel and solar-powered systems, we seek to identify the most effective propulsion method, paving the way for cleaner and more efficient marine operations. The results of this research will be instrumental in shaping the future of marine environmental conservation efforts.

Methodology

a. Vessel Specification

The first step in the methodology involves specifying the waste collection vessel used in this study. The chosen vessel is a small 4-meter waste collection boat, as shown in Figure 1. This boat is designed for efficiency in navigating narrow waterways and collecting floating debris, making it an ideal candidate for waste collection in various aquatic environments [12]. The vessel's main dimensions, weight, and waste capacity are detailed in Table 1, providing a clear overview of its specifications.

This particular vessel model was selected based on its proven performance in previous research and practical applications. Its compact size allows it to operate effectively in confined spaces, such as canals and rivers, where larger vessels would struggle. Additionally, the design and construction of the vessel have been optimized for stability and maneuverability, ensuring it can handle the demands of waste collection without compromising safety or efficiency.

The specifications outlined in Table 1 include key parameters such as the vessel's length, width, depth, weight, and maximum waste capacity. These parameters are critical for understanding the operational limits and capabilities of the vessel, which in turn influence the propulsion system requirements. By providing a detailed specification, this study ensures that all subsequent analyses and comparisons between the conventional diesel engine and solar panel systems are grounded in a realistic and practical context.

Furthermore, the vessel's waste capacity is a crucial factor in this study. The capacity determines how much debris the vessel can collect before needing to return for unloading, directly impacting the efficiency and effectiveness of the waste collection process. By selecting a vessel with a known and tested waste capacity, this study builds on a foundation of reliable data, enhancing the validity of the comparative analysis.

Table 1. Vessel Specification

Specification	**Value**
Length of Overall (LOA)	4,000 m
Length of Waterline (LWL)	3,858 m
Breath (B)	1,200 m
Height (H)	0,600 m
Draft (T)	0,300 m
Volume Displacement	0,36 m^3

In summary, the specification of the waste collection vessel is a foundational step in this methodology. It establishes the baseline parameters for the vessel's performance and ensures that the study is rooted in practical, real-world conditions. This careful selection and detailed documentation of the vessel's specifications enable a robust comparison of the propulsion systems under consideration, providing valuable insights into their respective efficiencies and operational characteristics.

b. Vessel Power Selection

The power selection process is critical for ensuring the vessel's operational efficiency. For this study, two power systems are compared: a conventional diesel engine and a solar panel system. The conventional diesel engine, specifically the Yamaha 5CHMS, was chosen for its proven reliability and compact design, making it suitable for small vessels. This engine is known for its robust performance, ease of maintenance, and availability, making it a practical choice for waste collection operations.

In contrast, the solar panel system was selected for its capability to provide a sustainable and environmentally friendly power source. The chosen solar panel, the Hangkai DNYSJYSJ, is designed to harness solar energy efficiently and convert it into electrical power. This system offers the advantage of reducing fuel consumption and emissions, aligning with modern environmental standards and sustainability goals [13].

The vessel's power requirements were meticulously calculated to ensure both systems can meet the operational demands. These calculations consider factors such as the vessel's speed, operational duration, and the power needed to drive the propulsion system and auxiliary equipment. By ensuring that both power systems can deliver the required performance, this study provides a fair basis for comparing their efficiency and suitability for waste collection applications.

c. Engine Performance Calculation

A series of performance calculations were conducted to evaluate the diesel engine's suitability [14]. These include determining the effective horsepower (EHP), shaft horsepower (SHP), brake horsepower (BHP), and delivered horsepower (DHP). The calculations are based on standard engineering principles, taking into account factors such as fuel efficiency, mechanical losses, and engine load conditions. These performance metrics are essential for understanding the engine's operational efficiency and reliability.

- Effective Horsepower (EHP): This metric measures the actual power delivered to the propeller, considering the losses in the drivetrain.
- Shaft Horsepower (SHP): This represents the power available at the engine shaft before any losses due to the propeller or other mechanical components.
- Brake Horsepower (BHP): This measures the engine's power output before losses due to friction and other mechanical inefficiencies.
- Delivered Horsepower (DHP): This final metric represents the power that effectively reaches the water to propel the vessel.

These calculations are based on standard engineering principles and take into account factors such as fuel efficiency, mechanical losses, and engine load conditions. By evaluating these performance metrics, the study provides a comprehensive understanding of the diesel engine's operational efficiency and reliability.

d. Solar Panel System Calculation

The solar panel system's feasibility was assessed by calculating its energy production capabilities and storage requirements [15]. This involves evaluating the potential sunlight exposure, typically measured in peak sunlight hours per day, and determining the solar panel's ability to generate the necessary power. The solar panels' placement and orientation on the vessel were optimized to maximize energy capture, ensuring that the system can operate effectively even in varying sunlight conditions.

Additionally, the battery storage capacity was calculated to ensure the vessel can operate continuously, even during periods of low sunlight. This includes considerations for battery type, storage efficiency, and overall system integration to meet the operational power requirements. The chosen battery type, capacity, and expected performance metrics are detailed to provide a clear understanding of the solar power system's capabilities and limitations.

By conducting these detailed calculations, the study ensures that the solar panel system is not only theoretically viable but also practical for real-world application. The combination of optimized solar energy capture and adequate battery storage ensures that the vessel can maintain its operational efficiency and reliability, making the solar panel system a viable alternative to the conventional diesel engine.

Result and Discussion

a. Technical Calculation of Ship Powering Using Conventional Engine

In the calculation of the main engine power for this vessel, Break Horse Power (BHP) was considered. The initial calculation involved determining the service speed used. To calculate the service speed, the formula used was Vp plus 1, multiplied by 0.5144. The result of this calculation was 4.629 knots.

$$Vp = (Vd + 1) \times 0.5144$$
$$= (18 + 1) \times 0.5144$$
$$= 4.629 \text{ knots}$$

In addition, the vessel's resistance was calculated based on the ship's speed. The resistance calculation had already been performed, yielding a result of 28.056 N. This hull resistance value was then used to calculate the Effective Horsepower (EHP). To calculate EHP, the ship's resistance (Wo) was multiplied by the service speed (Vp) and then divided by 75, resulting in 1.731 hp.

$$EHP = \frac{Wo\ x\ VP}{75} = \frac{28.056\ x\ 4.629}{75} = 1.73 \text{ hp}$$

Wake Friction is assessed by comparing the ship's speed with the propeller's rotational speed. To calculate W, 0.5 was multiplied by Cb, which was 0.8, and then 0.05 was subtracted. Hence, the calculated result for wake friction was 0.35.

$$W = (0.5 \text{ x } 0.8) - 0.05 = (0.5 \text{ x } 0.228) - 0.05 = 0.35$$

The Thrust Deduction Factor, which signifies the loss of thrust in the propulsion system, was calculated. It was determined by multiplying 0.6 by W. Consequently, the thrust deduction factor was found to be 0.21.

$$t = 0.6 \text{ x } W$$
$$t = 0.6 \text{ x } 0.35 = 0.21$$

From the calculations of wake friction and thrust deduction factor, the hull efficiency was determined. To calculate the hull efficiency (ηh), the thrust deduction factor (t) was subtracted from 1 and then divided by 1 minus the wake fraction (w). The result of this calculation was 1.21.

$$\eta h = \frac{1-t}{1-w} = \frac{1-0.21}{1-0.35} = 1.21$$

From these calculations, the coefficient of propulsion (Pc) can be determined to find the Delivered Horse Power (DHP). Pc is calculated by multiplying the propulsion efficiency ηp by the hull efficiency ηh and then by the relative rotational efficiency ηrr. Here, the propulsion efficiency is taken as 0.419, and the relative rotational efficiency as 1.03. Thus, the coefficient of propulsion Pc is determined to be 0.523.

$$Pc = \eta p\ x\ \ \eta h\ x\ \eta rr$$
$$= 0.419 \text{ x } 1.21 \text{ x } 1.03 = 0.523$$

Following this, the propeller shaft power is calculated based on the ratio of Effective Horsepower (EHP) to the coefficient of propulsion (Pc). From this calculation, the Delivered Horsepower (DHP) is determined to be 3,309 hp.

$$DHP = \frac{EHP}{Pc} = \frac{1.731}{0.523} = 3.309 \text{ hp}$$

Following that, the Thrust Horsepower (THP) was calculated, which represents the power delivered by the driving engine (shaft power). THP was calculated by dividing DHP by 0.98, resulting in 3.376 hp.

$$THP = \frac{DHP}{0.98} = \frac{3.309}{0.98} = 3.376 \text{ hp}$$

Table 2. Comparison of Conventional Engine Options

Specification	**Option 1**	**Option 2**	**Option 3**
Engine	Maritime 10DO1	Yamaha 5CMHS	Outboard MOB-803G
Fuel	Diesel	Gasoline	Gasoline
Engine Type	Inline 1	1 Cylinder – 2 Stroke	2 - Stroke
Power (hp)	10	5	3
Engine Speed (rpm)	3600 – 4000	4500 – 5500	6500
Displacement (cc)	406 cc	103 cc	52 cc
Transmission	Forward – Neutral - Backward	Forward – Neutral - Backward	Forward
Weight (kg)	60	21	10
Physical Figure			

To calculate Shaft Horse Power (SHP), DHP increased by 3% and is multiplied by DHP. The result is 3.408 hp.

SHP = DHP + (3% x DHP)
= 3.309 + (3% x 3,309) = 3.408 hp

In this system, the vessel does not use a reduction transmission system, so the calculated BHP_{scr} is equal to SHP, which is 3.408 hp.

BHP_{scr} = SHP = 3.408 hp

BHP_{mcr} is the output power of the propulsion motor sought for the main engine of the ship. To calculate BHP_{scr} BHP_scr is divided by 0.85, resulting in a value of 4.26 hp.

$BHP_{mcr} = BHP_{scr}/0.85$ = 4.26 hp

From the results obtained, it is known that the power required for the conventional engine to be used on this ship is 4.26 hp. This power is categorized as relatively small compared to larger vessels. After researching several engines within this power range, three engines were found that fit this requirement for the ship. Table 2 presents a comparison of several conventional engines found within this power range.

It was found that the Yamaha 5CMHS engine closely matches the required power. This gasoline-powered engine has a maximum power output of 5 hp. The other two engines, Maritime 10DO1 and Outboard MOB-803G, are still significantly outside the required power range. Several other options are displayed in Table 2.

Engines that are too large or too small can be disadvantageous for their use on the ship, affecting both capital expenditure and operational costs. Additionally, oversized engines increase the weight of the ship, potentially reducing payload capacity [16]. Engines with insufficient power cannot effectively meet the operational needs of the ship, aligning with the intended purpose of the vessel construction [17].

b. Technical Calculation of Ship Powering Using Solar Panel Battery Selection

Battery Selection

Batteries store electrical energy received from solar panels and distribute it to loads. They also provide power to loads when there is no sunlight. There are specific specifications to evaluate solar battery options, such as how long the solar battery will last and how much power it can supply [18]. For this study, the IDrive2 magnetic motor battery has been chosen, as shown in Figure 2 with detailed specifications in Table 3.

The data provided outlines the specifications for a battery system intended for use in the waste collection vessel's solar panel power setup. The battery dimensions are 522 mm in length, 239 mm in width, and 221 mm in height, making it compact enough to fit within the vessel's designated space for energy storage components. This compact size ensures that the battery can be easily integrated without compromising the vessel's design or functionality. With a weight of 25 kg, the battery is also relatively lightweight, minimizing the impact on the vessel's overall weight and stability.

Figure 2. Visual Construction of IDrive2 Battery

The battery operates with a nominal voltage of 24 V and a nominal capacity of 100 Ah. This capacity indicates that the battery can store a substantial amount of energy, essential for ensuring the vessel can operate for extended periods, even during cloudy days or when sunlight is limited. The charge voltage is specified at 57.6 V, with a standard charge current of 15 A, providing a clear guideline for the charging infrastructure required to maintain optimal battery performance. These specifications are critical for designing the solar panel system and ensuring that the energy storage is efficient and reliable.

Moreover, the battery's depth of discharge (DoD) is 80%, which means that 80% of the battery's total capacity can be used before recharging is necessary. This higher DoD allows for more efficient use of the stored energy, ensuring that the vessel can make the most out of each charging cycle. The balance between nominal capacity and DoD is crucial for maintaining battery health and longevity, making this battery a robust choice for the vessel's energy needs. These specifications collectively contribute to the effectiveness and sustainability of the solar-powered propulsion system.

Vessel Power Requirement

To calculate the solar panel requirements, data on power needs and the potential solar energy output specific to the location where the ship will operate, in Surabaya, Indonesia, are necessary. Table 4 presents the required data for this calculation.

Table 3. Battery Specification

Specification	Value
Dimension (mm)	522 x 239 x 221
weight (kg)	25
Charge Voltage (V)	57,6
Charge Current Standard (A)	15
Nominal Voltage (V)	24
Nominal Capacity (Ah)	100 Ah
Depth of Discharge (%)	80

Table 4. The Primary Data for Calculating Solar Panel Requirements

Basic Consideration	Value	Unit
Pload	1850	Watt
PSI	1000	Watt/m^2
Gav	5473	Wh/m^2 per day
ΔT	7	^{o}C
PSH	5.473	Hour

With this data, the efficiency of solar panels at each capacity can be determined by calculating ηpv. In this study, selections were made for several solar panel capacities: 200 Wp, 300 Wp, and 450 Wp, using the following method. The calculated ηpv for a 200 Wp solar panel is 15.27%, for a 300 Wp solar panel is 18.45%, and for a 450 Wp solar panel is 21.65%. From these results, it was found that the 450 Wp solar panel exhibits the highest efficiency.

ηpv = (Pmax)/(PSI x A)(100%)

Pmax = 200 wp

PSI = 1000 watt/m^2
A = 1,309 m^2

ηpv = $(\frac{200}{1000\ x\ 1{,}309})$x100%
= 15,27 %

Pmax = 300 wp

PSI = 1000 watt/m^2
A = 1,626 m^2

Hpv = $(\frac{300}{1000\ x\ 1{,}626})$x100%
= 18,45 %

Pmax = 450 wp

PSI = 1000 watt/m^2
A = 2,078 m^2

NPv = $(\frac{450}{1000\ x\ 2{,}078})$x100%
= 21,65 %

After obtaining the efficiency values for each solar panel capacity, the power generated by each capacity can be determined to identify which solar panel can meet the power requirements of the electric conveyor motor. The power required (Pwp) is calculated as the product of peak solar irradiation (PSI), which is 1000 Watt/m^2, multiplied by the effective solar energy absorption time (PSH), the area of the solar panel (A), and the solar panel efficiency. The PSH value is derived from the global horizontal irradiance (GHI), which is 5478, divided by 1000, resulting in an energy absorption time of 5.478 hours.

Pwp = PSI x A x ηpv x PSH

PSH = $(\frac{GHI}{PSI})$
PSH = $\frac{5478}{1000}$
PSH = 5,478 hour

From the calculation of PSH, the power generated by each solar panel can be determined. The solar panel with a capacity of 200 Wp generates a power output of 1094 Wp, while the 300 Wp solar panel generates 1643 Wp, and the 450 Wp solar panel generates 2464 Wp.

Pwp solar panel 200 wp

PSI = 1000 watt/m^2
A = 1,309 m^2
Npv = 15,27 %
PSH = 5,478 jam

Pwp 200 wp = 1000 x 1,309 x (15,27%) x 5,478
= 1094 wp

Pwp solar panel 300 wp

PSI = 1000 watt/m^2
A = 1,626 m^2
Npv = 18,45 %
PSH = 5,478 jam

Pwp 300 wp = 1000 x 1,626 x (18,45%) x 5,478
= 1643 wp

Pwp solar panel 450 wp

Pmax = 450 watt
PSI = 1000 watt/m^2
A = 2,078 m^2
PSH = 5,478 jam
Npv = 21,65 %

Pwp 300 wp = 1000 x 2,078 x (21,65%) x 5,478
= 2464 wp

The calculations from the equation above show the power generated by solar panels during their effective operating time in Surabaya. According to the Solar Global Atlas website, the effective solar energy absorption time in Surabaya is approximately 5.47 hours, occurring between 09:00 and 14:47, which is the optimal period for energy absorption.

The power generated by solar panels is influenced by the location's temperature

If the location where the solar panels are used exceeds 25°C, the panels will experience a power loss of 0.5%. In this study, the solar panels are deployed in the sea near Surabaya, with daily temperatures averaging 28.1°C according to the data in the image. Thus, the difference between the standard panel temperature and the sea temperature in Surabaya is 7°C.

To determine the total power (Pmpp) generated by each solar panel capacity after accounting for the temperature difference, it can be calculated as follows: Pwp multiplied by (1 - 0.005) multiplied by the temperature difference.

Pmpp = Pwp - (0.5% x Pwp x ΔT)

Pmpp solar panel 200 wp

Pwp =1000 wp
ΔT = 3°C

Pmpp = 1094 – (0,5% x 1094 x 3)
= 1055 wp

Pmpp solar panel 300 wp

Pwp = 1077 wp
ΔT = 3°C

Pmpp = 1643 – (0,5% x 1643 x 3)
= 1618.4 wp

Pmpp solar panel 450 wp

Pwp = 2250 wp
ΔT = 3°C

Pmpp = 2464 – (0,5% x 2250 x 3)
= 2430.25 wp

After obtaining the total power generated, the temperature correction factor (TCF) can be calculated using the following equation.

$$TCF = \frac{Pmpp}{Pwattpeak}$$

TCF of 200 wp

$TCF = \frac{1055}{1094}$
= 0.96 %

TCF of 300 wp

$TCF = \frac{1618,4}{1643}$
= 0.98%

TCF of 450 wp

$TCF = \frac{2430,5}{2464}$
= 0.98%

From the calculations, it is found that the temperature correction factors are similar, at 0.96% and 0.98%. Next, based on several previous calculation results, the number of solar panels needed for the ship's power requirements is determined based on the area of the solar panels [19]. Based on the power to be generated (Wpeak) with an assumed inverter efficiency of 0.9, the required number of solar panels (Npv) can be calculated as follows: Npv is equal to the total required power divided by the total power generated by a solar panel (EL).

EL = Pv area x GSI x ηpv x TCF x ηout

The number of 200 Wp solar panels needed can be calculated using the formula

EL = 1.309 m^2 x 5478 x (15.27%) x 0.96 x 0.9
EL = 946 wattpeak

$Npv = \frac{1850}{946}$
Npv = 1.95 pieces

Thus, the result of the calculation shows that 2 units of 200 Wp solar panels are needed.

The number of 300 Wp solar panels needed can be calculated using the formula

EL = 1.676 m^2 x 5478 x (18.45%) x 0.98 x 0.9
EL = 1494.03 wattpeak

$Npv = \frac{1850}{1494,03}$
Npv = 1.2 pieces

Thus, the result of the calculation shows that 2 units of 300 Wp solar panels are needed.

The number of 450 Wp solar panels needed can be calculated using the formula

EL = 2.16 m^2 x 5478 x (18.45%) x 0.98 x 0.9
EL = 1925 wattpeak

$Npv = \frac{1850}{1925}$
Npv = 0.96 pieces

Thus, the result of the calculation shows that 1 unit of 450 Wp solar panels is needed.

In this study, the available area for solar panels on the waste collection vessel is 2.76 m^2. Therefore, it is determined that the solar panel suitable for use

Table 5. Solar Panel Specification

Specification	Value	Unit
Maximum Power	450	wp
Maximum Power Voltage	41.40	V
Maximum Power Current	10.87	A
Operating Temperature	-40 – 85	$°C$
Dimension	2108 x 1048 x 35	mm
Weight	24,50	Kg
Open Circuit Voltage	50	V
Short circuit current	11,36	A

on the waste collection vessel is a 450 Wp solar panel. This is because a 450 Wp solar panel can adequately cover the available area for solar panel installation, which is sufficient for one solar panel.

Battery Capacity Requirement

To meet the electric motor's power requirements using solar energy, the next step is to determine the energy storage device, namely batteries. The suitable battery type for the solar photovoltaic system (PLTS) is a Deep Cycle Battery VRLA, such as VRLA Absorbent Glass Mat (AGM) or VRLA Gel, due to their long charge and discharge cycles, leak-free, and maintenance-free characteristics. To calculate the required battery capacity based on the load to be supplied, the following considerations are made: the autonomy day is one day, with a battery voltage of 24 V and a depth of discharge (DOD) of 0.9.

$$AH = \left(\frac{(\text{Pload x } Autonomy\ day)}{(Vbattery\ x\ Depth\ of\ Discharge)}\right)$$

$$AH = \frac{(1850\ x\ 1)}{(24\ x\ 0.9)} = 84.24 \text{ Ah}$$

The calculated battery capacity required is 84.24 Ah.

It has been determined that to meet the load requirements, a battery capacity of 84 Ah is necessary. However, batteries commonly available in the market are rated at capacities of 50 Ah, 100 Ah, and 150 Ah. Therefore, a 100 Ah battery capacity is selected. The electric conveyor motor operates at 230 V, hence 10 pieces of 100 Ah batteries are connected in series. This series configuration is chosen to increase the voltage output while keeping the current constant.

Subsequently, calculations are performed using the selected battery data from the previous calculation to determine the duration the conveyor power requirements can be met. This calculation yields the following result.

$$\text{Tbattery} = \left(\frac{(\text{Ah battery x V battery x PSH})}{\text{Pload}}\right)$$

$$\text{Tbattery} = \frac{(100\ \ x\ 24\ x\ 5\ )}{1850} = 6{,}4 \text{ (calculated as 6 hours)}$$

Thus, the calculated battery runtime required is 6.4 hours (rounded to 6 hours).

In this study, a 450 Wp solar panel is used, as shown in Figure 3. To determine the Voc (Open Circuit Voltage) and Isc (Short Circuit Current) values of the solar panel, refer to the panel's specifications in Table 5.

$Vmaxin$ > 1,25 × 50 = 62,5 V

$Imaxin$ > 1,25 × 11,36 = 14 ,2 A

Figure 3. Solar Panel with 450 Wp Monocrystalline (m.icasolar.com)

Based on the above calculations, the electric conveyor requires a minimum current of 14.2 A and a minimum voltage of 62.5 V. In this study, an SCC (Solar Charge Controller) with a maximum input current of 20 A is used, as SCCs commonly available in the market are sold in multiples of 10 A.

Apart from the conveyor, another electric motor is required for driving purposes in this study, which operates independently from the conveyor. Even if used together, it does not require power exceeding that of the conveyor, as specified in Table 6.

Table 6. Electric Motor Specification

Specification	**Value**
Type	Hangkai DNYSYSJ
Material	Aluminium
Operation	Electric
Model	DD-48V-1000W
Voltage	48V
Ampere	18A
Motor Speed	3000 rpm

c. Comparison of Diesel Engine and Solar Panel

From the calculation above about the power selection, it should be considered that for small vessels, such as a 4-meter waste collection boat, the comparison between conventional combustion engines and solar power becomes distinctively nuanced. Conventional small vessels powered by combustion engines, typically running on gasoline or diesel, offer reliable and powerful performance crucial for consistent operation, especially in areas with fluctuating waste collection needs. These engines are compact and can be easily maintained, but they require a supply of fuel, which adds to the operational costs and environmental impact due to emissions [20]. In contrast, small solar-powered vessels harness solar panels' energy, providing an environmentally friendly and sustainable power source. However, the power output from solar panels can be variable and dependent on sunlight availability, which might not be sufficient for consistent daily operations, especially in areas with limited sunlight.

From an investment and operational cost perspective, small conventional combustion engine vessels are generally less expensive to purchase initially due to the lower cost of small engines and the minimal infrastructure required [21]. However, the ongoing fuel and engine maintenance costs can accumulate over time, making them potentially more expensive in the long run. Solar-powered vessels require a higher initial investment due to the cost of solar panels and battery storage systems [22]. Nonetheless, they benefit from minimal operational costs as they do not require fuel and have lower maintenance needs, primarily focused on the upkeep of solar panels and battery systems. The long-term cost savings from reduced fuel expenses can be significant, especially for small vessels with regular use.

Space utilization is also a critical consideration for small vessels. Conventional engines require space for the engine itself and fuel storage, which can be substantial even on a small vessel, reducing the available space for waste collection. Solar panels, on the other hand, can be mounted on the vessel's roof or deck without taking up significant interior space, preserving more room for waste collection. However, battery storage systems for solar power can occupy space within the vessel, although advancements in battery technology are making these systems more compact and efficient [23]. Overall, for a small 4-meter waste collection vessel, solar power offers a promising alternative with environmental benefits and potential long-term cost savings, but it is limited by power availability and storage capacity compared to conventional combustion engines.

Conclusion

In conclusion, for small waste collection vessels, there is a trade-off between the reliability of conventional combustion engines and the sustainability of solar power. Conventional engines, such as the Yamaha 5CHMS, provide dependable performance but incur higher long-term costs and environmental impacts, requiring 3.78 hp and a battery capacity of 84.24 Ah for 6.4 hours of operation. Solar-powered vessels, using systems like the Hangkai DNYSJYSJ, offer an environmentally friendly and cost-effective alternative with better space utilization, needing 3.78 hp and providing 6 hours of operation from solar energy. However, their effectiveness depends on sunlight and advancements in battery technology. This research highlights the importance of continued innovation in solar technology to improve its feasibility for small marine vessels.

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