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Design and Analysis of Solar Power Generation for a Hybrid Airship as Cargo Transportation

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Keywords

Solar Power Plant, hybrid airship, cargo transportation, greenhouse gas emissions, energy efficiency.

Abstract

This study aims to design and analyze a solar power system for hybrid airships used as cargo transportation, with a focus on evaluating the potential of solar energy as the primary power source to support airship operations. The goal is to reduce dependence on fossil fuels and mitigate greenhouse gas (GHG) emissions. Simulations and analyses were conducted using PVsyst and Inventor software to design a solar power system that meets the energy needs of the airship. The research involves simulations across various geographic routes, including Yogyakarta, Salatiga, Semarang, and the Java Sea towards Karimunjawa.

Simulation results indicate annual energy production of 30,161 kWh in Yogyakarta (PR 75.82%), 29,651 kWh in Salatiga (PR 75.35%), 29,773 kWh in Semarang (PR 72.33%), and 29,802 kWh over the Java Sea towards Karimunjawa (PR 71.13%). Despite this, a diesel generator is still required as a backup to ensure energy availability throughout the journey. Implementing solar power systems on airships can reduce GHG emissions by up to 53.66%, representing a significant step towards greener aviation technology. This study demonstrates the feasibility of utilizing the airship's surface area for optimal solar panel installation.

1 Introduction

To connect islands, Indonesia relies on air and sea transportation. However, land transportation, which includes highways and railways, remains the primary choice for transporting passengers and goods. The increasing demand for mobility directly contributes to higher energy consumption and greenhouse gas (GHG) emissions. Since 2012, the transportation sector has been the largest final energy user after the industrial sector, accounting for 45% of total final energy consumption in 2018. Approximately 95% of transportation energy needs are met by petroleum, while around 5% comes from biofuels, and less than 1% from natural gas and electricity (KESDM, 2018). Energy consumption in the transportation sector grew at a Compound Annual Growth Rate (CAGR) of 5.9% from 2000 to 2018 (KESDM, 2018). It is projected to grow by 5.2% per year until 2040 under the Business As Usual (BAU) policy (Kimura & Phoumin, 2016), which will lead to an increase in GHG emissions.

As oil production continues to decline, energy security in Indonesia is becoming an increasing concern, while oil field exploration lags behind the rate of depletion. At the current consumption rate, oil reserves are projected to be exhausted by 2037. Currently, imported fuel accounts for 53.5% of the energy consumed by the transportation industry (IESR, 2023). Globally, CO2 emissions from the transportation sector increased by more than 250 million tons in 2022, reaching nearly 8 billion tons of CO2, 3% higher than in 2021. This was largely driven by aviation, which continues to recover from the pandemic downturn, reaching around 70% of 2019 levels (IEA, 2024).

The National Energy General Plan (RUEN) projects that greenhouse gas (GHG) emissions from the transportation sector will increase from 143 MtCO2e in 2015 to 218 MtCO2e in 2030 and reach 394 MtCO2e by 2050. According to the latest data from the Ministry of Environment and Forestry (KLHK), transportation sector emissions in 2017 reached 147 MtCO2e, accounting for 26% of the total GHG emissions from the energy sector. Of this total, land transportation contributed 90.8%, air transportation 9.1%, and sea transportation only 0.1%. Emissions from the rail transport sector were considered insignificant (Ministry of Environment and Forestry, 2019).

With technological advancements and the passage of time, transportation has evolved with facilities and systems that play a significant role in shaping human life. In addition to influencing individual development, transportation also affects society as a whole. One of the factors that can impact urban air quality is transportation activity. The increasing volume of vehicles on the roads contributes to a surge in air pollution emissions, which can negatively affect human health and harm the environment. In Indonesia, the growth of the transportation system has led to increased emissions and energy consumption, ultimately contributing to climate change (Hendratmoko & Dewantoro, 2018).

To address environmental issues, renewable energy sources such as solar energy have emerged as promising alternative solutions. Solar panel technology has made significant progress in terms of energy efficiency and weight reduction, making it a viable option to support the transportation sector. However, the application of solar panels in air transportation, particularly on airships, still faces various technical and operational challenges. Current crystalline silicon-based solar panel technology has an average efficiency rate of 15% to 22% in converting sunlight into electricity (Green, et al., 2021). Nevertheless, installing solar panels on airships requires special consideration of the available surface area and the efficiency of the energy produced. For instance, solar-powered aircraft like the Solar Impulse 2 can travel long distances, but only at low speeds and without carrying large cargo (Noth, 2008). For airships designed to transport large amounts of cargo, a larger surface area is required to accommodate solar panels that generate sufficient power.

The power requirements for airship operations are heavily influenced by cargo weight and desired travel distance. According to a study by the International Air Transport Association (IATA), airships designed to transport large cargo loads require approximately 500 kW to 1 MW of power to operate (International Air Transport Association, 2020). Assuming solar panels operate at 20% efficiency, a surface area of around 5000 square meters is needed to install solar panels capable of generating 1 MW of electricity under optimal lighting conditions. This challenge necessitates design modifications to ensure the airship has enough space to accommodate the solar panels.

Additionally, the installation of solar panels on airships presents challenges related to increased weight. Although modern solar panel technology is becoming lighter, the added load still affects flight efficiency and cargo capacity. To address this, the use of lightweight yet strong materials in the airship's structure is essential. Materials such as carbon fiber or nanomaterial-based composites are considered ideal because they reduce weight without compromising structural integrity. Carbon fiber is known for its high strength-to-weight ratio and is widely used in the aviation and aerospace industries to lower total mass without sacrificing strength (Gibson, 2010). Moreover, composite materials offer advantages in impact resistance and design flexibility, which are crucial for maintaining optimal airship aerodynamics (Abrate, 1998).

The performance of solar panels heavily depends on weather conditions and the intensity of sunlight available. Poor weather or nighttime flights can reduce the effectiveness of the energy produced. Therefore, an energy storage system, such as high-capacity batteries, is necessary to ensure the airship can continue operating when sunlight is insufficient. Although the presence of these batteries is crucial, adding such components also increases the overall weight and potentially reduces cargo capacity (Chen et al., 2008). In a study conducted by Manikandan et al. in 2021 on the design and analysis of a multi-lobed hybrid airship for cargo transportation, the hybrid propulsion system combined conventional and renewable energy sources, such as fuel cells and solar panels. They found that using a hybrid propulsion system could reduce fuel weight by up to 350 kg, indicating a significant improvement in e-mobility efficiency.

Currently, regulations regarding airships in Indonesia still refer to general aviation laws, as there are no specific regulations governing airship operations separately. According to Law Number 1 of 2009 on Aviation, all air vehicles, including airships, must comply with operational and safety standards applicable in Indonesia (Ministry of Law and Human Rights, Republic of Indonesia, 2009). Additionally, the use of airspace is regulated under Minister of Transportation Regulation Number PM 80 of 2017, which requires any party wishing to use airspace for aviation, including airships, to obtain authorization from the relevant authorities (Ministry of Transportation, Republic of Indonesia, 2017). Indonesia's civil aviation safety regulations also follow international standards set by the International Civil Aviation Organization (ICAO), which provides safety guidelines for all types of aircraft, including airships, in global aviation (International Civil Aviation Organization (ICAO), 2021). Hence, although there are no specific airship regulations, these vehicles must still adhere to existing aviation rules, covering safety, airspace use, and environmental protection (Ministry of Energy and Mineral Resources, 2017).

To address these issues, new innovations in electric vehicle transport infrastructure are needed, as the sector still heavily relies on fossil fuels, particularly petroleum, as its primary energy source. These innovations aim to transition to new and renewable energy sources. In this research, the focus is on designing and analyzing a Solar Power Plant (PLTS) system for airships as cargo transport, capable of carrying large quantities of goods through aerial routes while reducing dependency on petroleum-based energy. Solar energy positively impacts the environment because its use does not produce emissions resulting from fossil fuel combustion. The generated electricity can effectively and sustainably support airship operations.

2 Materials and Methods

This research employs a quantitative method with a simulation approach to analyze the performance of the solar power plant system on an airship designed for cargo transportation. The quantitative approach is chosen because this study involves the collection and analysis of numerical data from various technical parameters that influence the energy system's performance. Simulations are conducted using PVsyst software to model the solar power plant system and predict energy performance based on meteorological data and predefined technical specifications.

A. Simulation Scenario for Solar Power Plant Design on Airship

The simulation scenario for designing the Solar Power Plant (PLTS) on the airship is developed as part of a hybrid system that integrates two main energy sources: a diesel generator and photovoltaic (PV) panels. This integration aims to enhance energy efficiency and resilience during airship operations, particularly in responding to fluctuating electricity demands and varying weather conditions. In this simulation, the solar power plant is directly connected to the electrical distribution network that supports various operational loads of the airship. The system is also backed by a diesel generator as a backup source to ensure continuous power supply when energy production from the solar power plant is insufficient. The simulation utilizes solar panels, inverters, and batteries. The solar power plant is designed with a standalone configuration using a Fixed Tilted Plane with a tilt of 0° and azimuth of 0°. The PV modules used have a capacity of 144 Wp, consisting of 147 units arranged in 21 strings, with each string comprising 7 modules connected in series. Additionally, two inverters are used in the system.

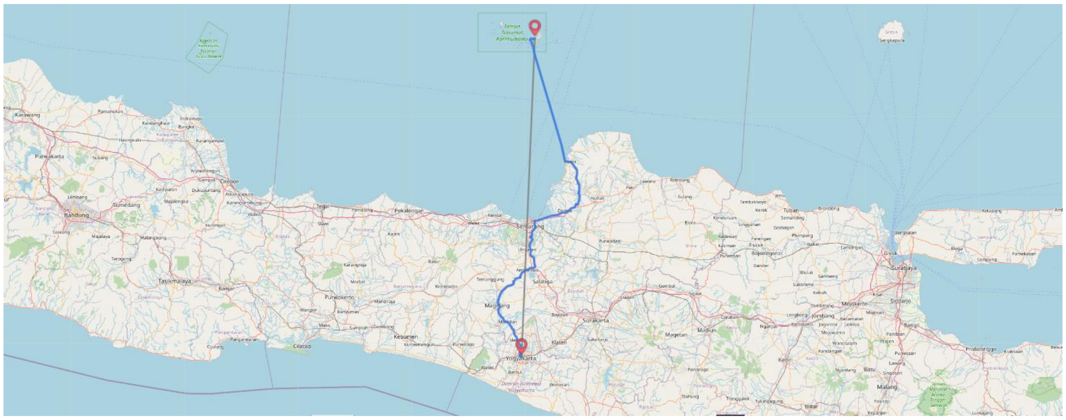

Figure 1. Rute Airship
Source: id.2markers.com

Figure 1 shows the travel route to be taken by the airship, starting from Yogyakarta to Salatiga, continuing to Semarang, and proceeding to a midpoint in the Java Sea located between Semarang and Karimunjawa. The route ends in Karimunjawa with a total operational time of 7 hours. The journey from Yogyakarta to Salatiga takes 1.5 hours, the same as the duration from Salatiga to Semarang. Subsequently, the trip from Semarang to the midpoint in the Java Sea requires 2 hours, followed by a 2-hour journey to Karimunjawa. This route follows a straight line as illustrated in Figure 1, assuming the airship's speed is 30 km/h.

To enhance system reliability, the design scenario is equipped with batteries for energy storage. The batteries function to store excess energy generated by the solar power plant (PLTS) during the day when solar radiation is at its peak. This stored energy is then used to meet electricity needs at night or during unfavourable weather conditions that prevent maximum electricity production from the solar panels. The addition of batteries in the hybrid system offers significant technical benefits. When the solar power plant does not operate optimally, the energy stored in the batteries can be distributed to meet the load, thereby reducing reliance on the diesel generator. This not only improves fuel efficiency but also supports the reduction of carbon emissions produced during airship operations.

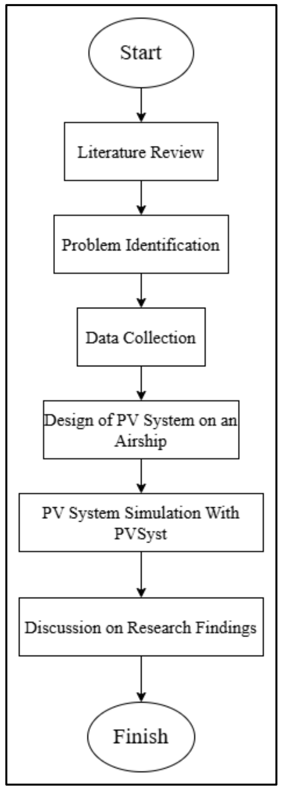

Figure 2. Research Process Flowchart

Figure 3 below will illustrate the configuration of the solar power plant (PLTS) system and the diesel generator, as well as the integration of batteries as energy storage in this design scenario.

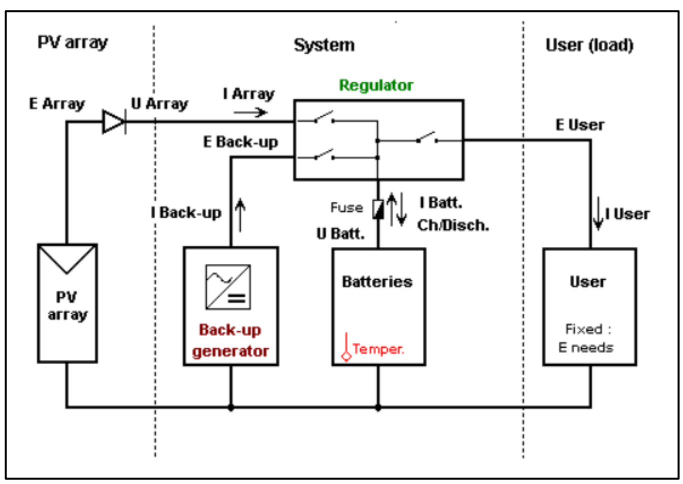

Figure 3. Solar Power System Configuration

B. Simulation Data

The simulation for meeting the electricity needs of the airship was conducted using PVsyst software, which estimates the capacity required to fulfill electricity demands through solar panels. Meteorological data, such as solar radiation intensity, ambient temperature, and wind speed, are integrated into the simulation to provide more accurate predictions. Additionally, technical data of the solar panels, including module efficiency, inverter capacity, and panel orientation, are taken into account to determine the overall system performance. The total capacity of the solar power system is designed based on the daily energy requirements of the airship, factoring in power losses and panel degradation over time. This simulation also includes an analysis of battery durability as part of the energy storage system, ensuring continuous electricity supply when solar radiation is insufficient. Table 1 below presents the tabulation of solar radiation data used in this study.

Table 1. Solar Radiation Data

Month	Yogyakarta	Salatiga	Semarang	Laut Jawa ke Karimunjawa
January	4.30	4.03	4.13	4.29
February	4.68	4.34	4.31	4.49
March	4.59	4.37	3.72	5.11
April	4.95	4.85	5.07	5.30
May	4.92	4.89	4.92	4.88
June	4.89	4.94	4.87	4.73
July	5.13	5.16	5.09	5.04
August	5.42	5.45	5.40	5.35
September	5.66	5.68	5.56	5.52
October	5.47	5.46	5.47	5.43
November	4.70	4.71	4.87	4.99
December	4.80	4.63	4.64	4.61

Table 2 below presents monthly temperature data from various locations within the research area. The temperature variations across these locations are analyzed to evaluate the potential and performance of renewable energy in each region.

Table 2. Temperature Data

Month	Yogyakarta	Salatiga	Semarang	Laut Jawa ke Karimunjawa
January	24.9	24.9	24.8	24.7
February	24.7	24.7	24.6	24.5
March	25.1	25.2	25.2	25.0
April	25.2	25.3	25.3	25.2
May	25.7	26.0	26.0	25.8
June	24.9	25.2	25.3	25.2
July	24.5	24.9	25.0	25.1
August	24.5	25.1	25.2	25.2
September	24.7	25.4	25.5	25.5
October	25.6	26.2	26.3	26.2
November	25.1	25.5	25.5	25.4
December	25.0	25.2	25.1	25.0

Table 3 below presents the electrical load profile of the airship based on the specifications of the components and systems used. The load profile is compiled from the datasheets of each device, which include technical information on power consumption, the number of devices, and the types of components used in the system.

Table 3. Electrical Load Profile on Airship

System	Type	Power (W)	Quantity
Lighting System	LED	10	10
Avionics System	Garmin GNS 430	16	1
	Garmin GTX 330	27	1
	Kannan 406 AF- Kompak	5	1
	Raja Bendix KR 87	12	1
	Raja Bendix KN 64	35	1
Control System	Bendix/King KAP 140	50	1
Electric Motor	Emrax 208	86,000	1
Pump Hidrogen	Welch Vacuum 2154B-01	373	1
Load (W)		**86246**	

3 Results and Discussions

A. Design of Photovoltaic Hybrid Airship

The design of the Solar Power Plant (PLTS) on the airship aims to utilize solar energy as the primary source to support the operation of various systems within the airship. Solar panels are installed on the surface of the airship and are designed to capture solar radiation and optimally convert it into electrical energy. This solar power plant system is designed to provide sufficient power to meet the energy needs of the lighting, avionics, and control systems. In the design process, factors such as panel capacity, energy conversion efficiency, and panel placement aligned with the airship structure are key considerations.

The airship has a surface area of 3,216.36 m², with 10% of the total surface area, equivalent to 321.536 m², allocated for solar panel installation. The placement of the panels is adjusted to fit the shape of the airship, with a tilt of 0° and an azimuth of 0°. This design aims to reduce reliance on external energy sources, minimize conventional fuel consumption, and contribute to lowering carbon emissions.

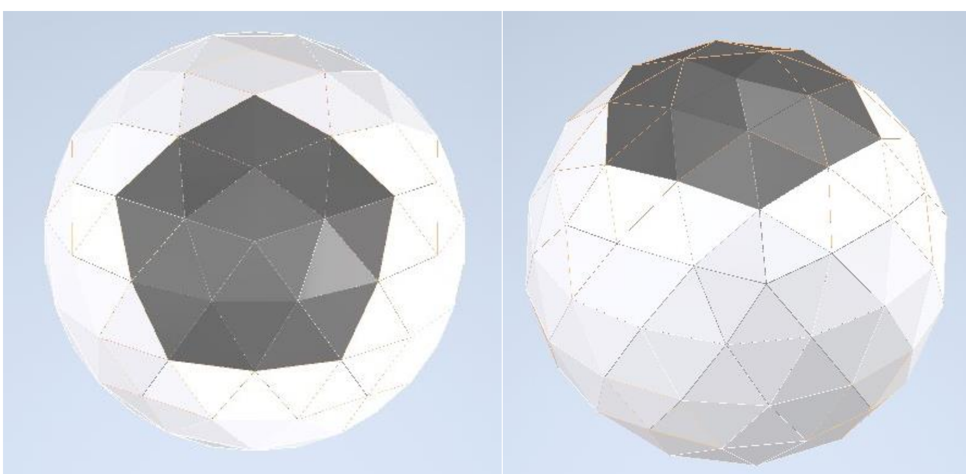

Figure 4. Top and Side Views of Solar Panel Installation on Airship

B. Simulation Result of Electrical Energy Supply on Airship

1. Yogyakarta's Geographical Area

In the simulation of Yogyakarta's geographical area, the Solar Power Plant (PLTS) and diesel systems are utilized as the primary energy sources to supply power to the airship. The simulation involves the use of solar panels, inverters, and batteries, with PV modules having a capacity of 144 Wp. A total of 147 solar panels are arranged into 21 strings, with each string consisting of 7 panels connected in series. The system is equipped with 2 inverter units to convert the generated power.

As part of the operational simulation, the solar panels were tested for 1.5 hours, matching the travel time to Salatiga. In this simulation, a specific load profile was applied, where the airship uses a hydrogen pump as the main component in its operational system during the flight. The hydrogen pump supports the energy supply to maintain the airship's performance, optimizing the power generated by the solar power plant and diesel systems. The simulation results for the Yogyakarta geographical area are presented in the table 4 below.

Table 4. Simulation Results of Yogyakarta's Geographical Area

Parameter	Simulation Result
Array Nominal Energy PV	36,801 kWh/Tahun
Specific Energy Produced	1.372 kWh/kWp/Tahun
Performance Ratio (PR)	75,82 %
Solar Fraction (SF)	63,60 %
Power Used for Load	47.423 kWh/Tahun
Diesel Power	17.262 kWh/Tahun
Solar Power	30.161 kWh/Tahun

Table 4 above shows that the simulation results in Yogyakarta indicate a Performance Ratio (PR) of 75.82%, signifying high efficiency in solar energy conversion. The Solar Fraction (SF) reaches 63.60%, meaning that a significant portion of the energy demand is met by solar power. Out of the total annual energy demand of 47,423 kWh, solar power supplies 30,161 kWh, while the remaining 17,262 kWh is provided by the diesel generator. This figure highlights the substantial contribution of solar energy to the power generation system.

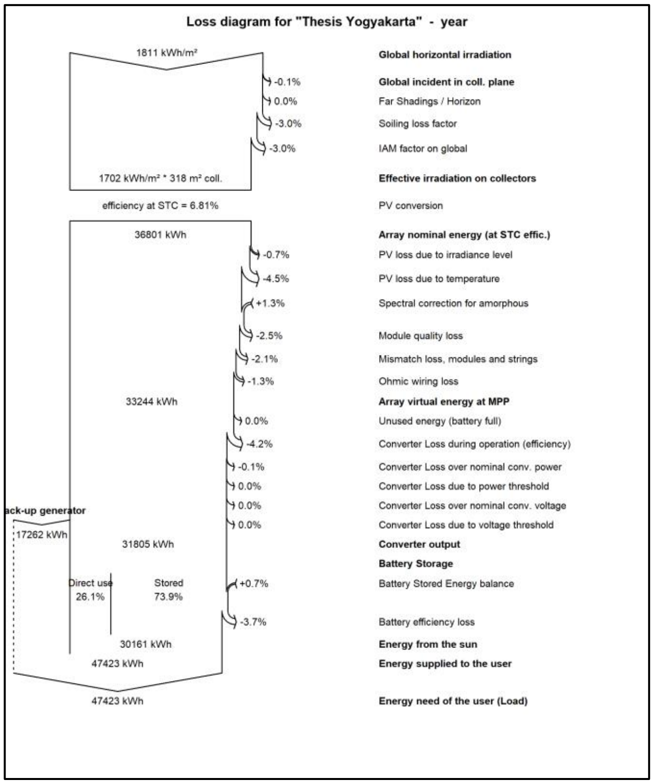

Figure 5. Loss Diagram Yogyakarta's Geographical Area

Figure 5 above illustrates the flow of solar energy from global irradiation to the energy supplied to users, including losses at each stage. Total global horizontal irradiation reaches 1,811 kWh/m²/year, but experiences a 6.1% reduction due to soiling loss (3%) and IAM (3%), resulting in effective irradiation at the collector of 1,702 kWh/m²/year. During the photovoltaic conversion stage, a nominal energy of 36,801 kWh is generated with an efficiency of 6.81%. However, losses from irradiance (-0.7%), panel temperature (-4.5%), module quality (-2.5%), module mismatch (-2.1%), and cables (-1.3%) reduce the energy at the MPP (Maximum Power Point) to 33,244 kWh. Inverter losses of -4.2% result in 31,805 kWh, which is further reduced by battery efficiency loss (-3.7%), leaving a net energy output of 30,161 kWh. This energy is used directly (26.1%) and stored (73.9%), while user demand reaches 47,423 kWh. The shortfall is met by a backup generator supplying 17,262 kWh. This diagram illustrates the various factors affecting the efficiency of the solar power system.

2. Salatiga's Geographical Area

The Salatiga region has a mid-altitude geographic condition with relatively stable solar radiation. The simulation was conducted by considering greater temperature fluctuations compared to Yogyakarta. The geographic simulation for the Salatiga area models the solar power plant and diesel as the primary energy sources supplying energy for the airship.

Table 5. Simulation Results of Salatiga's Geographical Area

Parameter	Simulation Result
Array Nominal Energy PV	36,212 kWh/Tahun
Specific Energy Produced	1.341 kWh/kWp/Tahun
Performance Ratio (PR)	75,35 %
Solar Fraction (SF)	62,80 %
Power Used for Load	47.218 kWh/Tahun
Diesel Power	17.567 kWh/Tahun

Parameter	Simulation Result
Solar Power	29.651 kWh/Tahun

Table 5 above shows that the simulation results in Salatiga indicate a Performance Ratio (PR) of 75.35%, reflecting good solar energy conversion efficiency. The Solar Fraction (SF) is recorded at 62.80%, signifying that the majority of energy needs are met by solar power. Out of the total annual energy demand of 47,218 kWh, solar power contributes 29,651 kWh, while 17,567 kWh is supplied by the diesel generator. This highlights the importance of solar power in meeting energy needs in Salatiga.

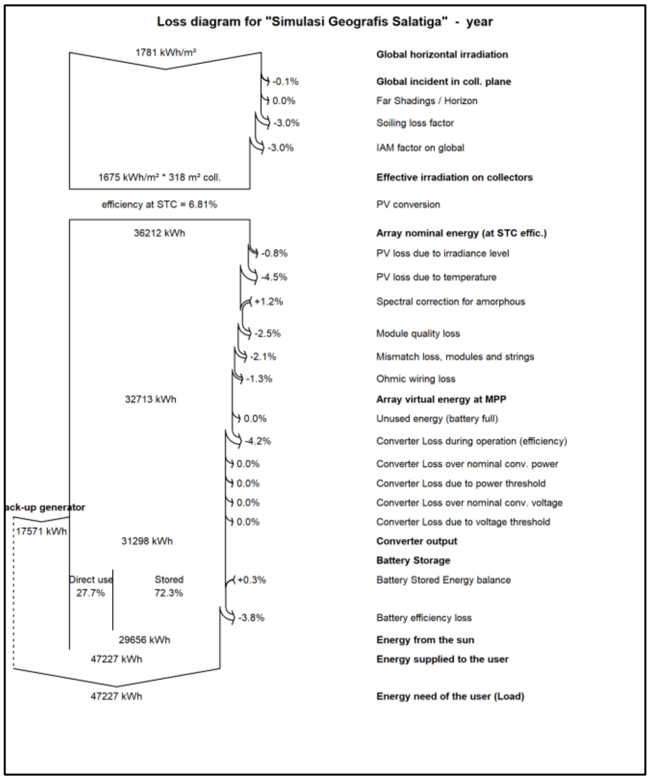

Figure 6. Loss Diagram Salatiga's Geographical Area

Figure 6 above shows the flow of solar energy from global irradiation to the energy received by users, highlighting the largest losses at each stage. From a global horizontal irradiation of 1,781 kWh/m^2/year, a 6.1% reduction occurs due to soiling loss and IAM. During photovoltaic conversion, the largest losses are caused by temperature loss (-4.5%) and module quality loss (-2.5%), reducing energy to 32,713 kWh at the MPP (Maximum Power Point). The inverter experiences a converter loss of -4.2%, resulting in 31,298 kWh. Battery losses of -3.8% further reduce net energy to 29,656 kWh. Out of the total energy demand of 47,227 kWh, the backup generator supplies 17,571 kWh. This diagram highlights the key losses affecting the efficiency of the solar power plant.

3. Semarang's Geographical Area

As a coastal area, Semarang presents challenges in the form of higher temperatures and potential humidity, which can affect the performance of solar panels. The geographic simulation for the Semarang area models solar power plant and diesel as the primary energy sources supplying energy for the airship.

Table 6. Simulation Results of Semarang's Geographical Area

Parameter	Simulation Result
Array Nominal Energy PV	36,541 kWh/Tahun
Specific Energy Produced	1.299 kWh/kWp/Tahun
Performance Ratio (PR)	72,33 %
Solar Fraction (SF)	47,29%
Power Used for Load	62.957 kWh/Tahun
Diesel Power	32.184 kWh/Tahun
Solar Power	29.773 kWh/Tahun

The simulation results in Semarang indicate a Performance Ratio (PR) of 72.33%, reflecting good solar energy conversion efficiency. However, the Solar Fraction (SF) is recorded at 47.29%, meaning that less than half of the energy demand is met by solar power. Out of the total annual energy demand of 62,957 kWh, solar power supplies 29,774 kWh, while 32,183 kWh is provided by the diesel generator. These results highlight a relatively high dependence on backup generators in the Semarang area.

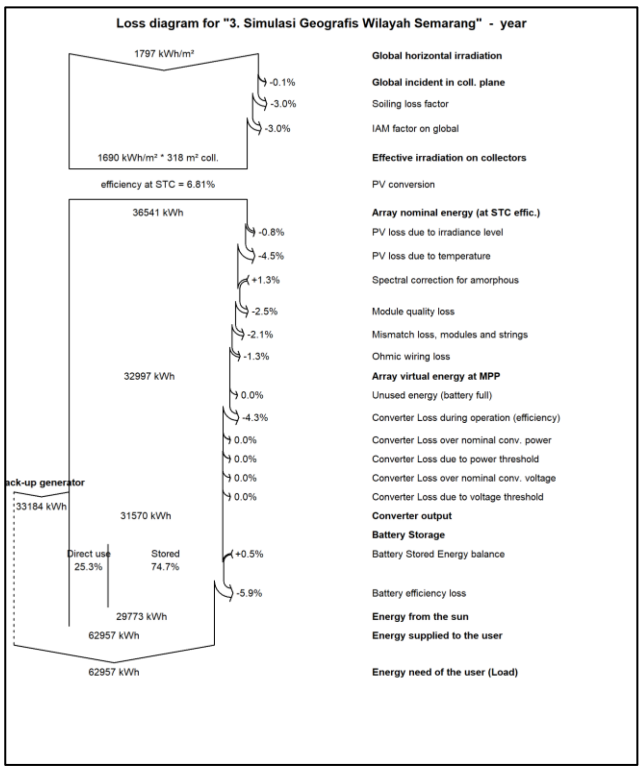

Figure 7. Loss Diagram Semarang's Geographical Area

Figure 7 above shows the flow of solar energy from global irradiation to the energy received by users, highlighting the largest losses at each stage. From a global horizontal irradiation of 1,797 kWh/m^2/year, a 6.1% reduction occurs due to soiling loss and IAM, resulting in effective irradiation of 1,690 kWh/m^2/year. Photovoltaic conversion produces a nominal energy of 36,541 kWh; however, the largest losses are caused by temperature loss (-4.5%) and module quality loss (-2.5%), reducing energy to 32,997 kWh at the MPP (Maximum Power Point). The inverter experiences a converter loss of -4.3%, resulting in 31,570 kWh. Battery losses of -5.9% further reduce net energy to 29,773 kWh. Out of the total energy demand of 62,957 kWh, the backup generator supplies 33,184 kWh, indicating a high reliance on the generator to meet energy needs. This diagram highlights the key factors affecting the efficiency of the solar power plant.

4. Geographical Area of the Java Sea Towards Karimunjawa

The waters of the Java Sea connecting Semarang and Karimunjawa represent a critical route facing challenges in energy supply, particularly for transportation and maritime infrastructure. One proposed solution is to utilize Solar Power Plants (PLTS) as the primary energy source, with diesel generators serving as backup support. This simulation aims to evaluate the performance of the solar power system in addressing the unique geographical and climatic conditions of the Java Sea region. By taking into account solar radiation intensity and potential weather changes in the area, this simulation assesses the effectiveness of solar power plant in supplying energy during the journey to Karimunjawa.

Table 7. Simulation Results of Geographical Area of the Java Sea Towards Karimunjawa

Parameter	Simulation Result
Array Nominal Energy PV	36,986 kWh/Tahun
Specific Energy Produced	1.292 kWh/kWp/Tahun
Performance Ratio (PR)	71,11 %
Solar Fraction (SF)	47,34 %
Power Used for Load	62.958 kWh/year
Diesel Power	33.156 kWh/year
Solar Power	29.802 kWh/year

The simulation results for the Java Sea waters leading to Karimunjawa indicate a Performance Ratio (PR) of 71.15%, signifying good solar energy conversion efficiency. The Solar Fraction (SF) is recorded at 47.34%, meaning that nearly half of the energy demand is met by solar power. Out of the total annual energy demand of 65,957 kWh, the solar power plant supplies 31,922 kWh, while 33,155 kWh is provided by the diesel generator. These results show that although the contribution of solar power is significant, the diesel generator still plays a major role in meeting the energy needs of this region.

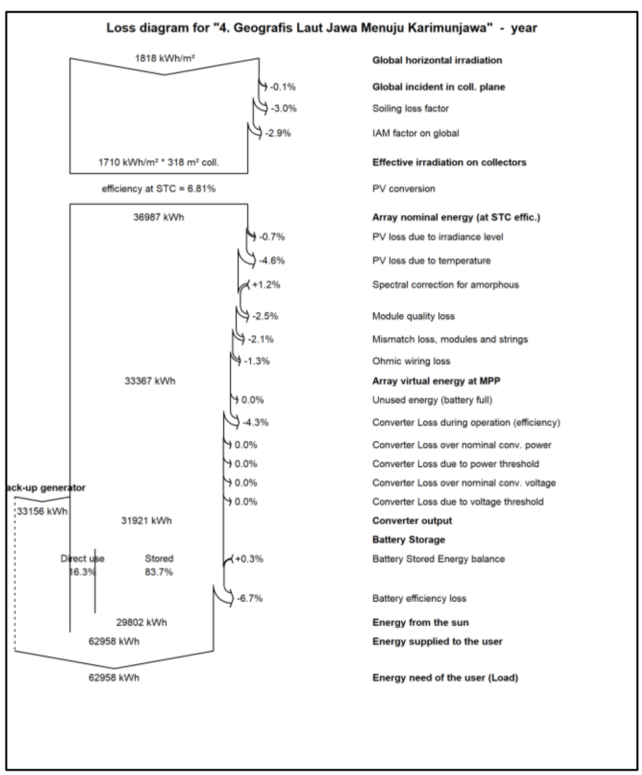

Figure 8. Loss Diagram Geographical Area of the Java Sea Towards Karimunjawa

The loss diagram illustrates the flow of solar energy from global horizontal irradiation to the energy ultimately supplied to the user, detailing losses at each stage. The process begins with a global horizontal irradiation of 1,818 kWh/m²/year. This energy decreases by 6% due to a combination of soiling loss (3%), IAM (Incidence Angle Modifier) factor (2.9%), and a minor global incident loss of 0.1%, resulting in an effective irradiation of 1,710 kWh/m²/year. The photovoltaic (PV) conversion process generates a nominal energy output of 36,987 kWh. However, significant losses occur due to temperature (-4.6%), module quality (-2.5%), and mismatch loss (-2.1%), reducing the energy at the Maximum Power Point (MPP) to 33,367 kWh.

Converter losses during operation further reduce the available energy by 4.3%, resulting in 31,921 kWh. A backup generator contributes an additional 33,156 kWh to meet energy demands. After storage losses of 6.7%, the net energy available for use stands at 29,802 kWh. Direct use accounts for 16.3% of the total energy, while 83.7% is stored in batteries. The total energy supplied, including contributions from both the solar power system and the diesel generator, meets the total user energy demand of 62,958 kWh. This diagram emphasizes the importance of backup generators in ensuring energy reliability and highlights the various factors affecting the efficiency of the solar power system.

For further discussion, we will analyze the journey from Yogyakarta to Karimunjawa, which takes 7 hours. The total energy generated by the photovoltaic (PV) system and the diesel generator during the airship's journey from Yogyakarta to Karimunjawa amounts to 327.0877 kWh from PV and 277.1753 kWh from the diesel generator. This totals 604.26 kWh, which is very close to the total airship load during the 7-hour journey, amounting to 604.275 kWh. From this calculation, it is evident that the combination of energy from PV and the diesel generator is almost entirely capable of meeting the airship's energy needs throughout the route. The minimal difference indicates that the designed energy supply system operates effectively, with significant contributions from PV and the generator serving as a backup to ensure smooth operations.

C. Projection of GHG Emission Reduction

Emissions refer to the release of certain substances into the environment, particularly into the air. These substances can include gases, particles, or chemicals that have the potential to degrade air quality, harm the environment, and affect human health. Emission sources can vary, such as from industrial sectors, transportation, power generation, agriculture, and other human activities (Seinfeld & Pandis, 2016). The use of Solar Power Plants (PLTS) in a hybrid system on airships aims not only to enhance energy efficiency but also to make a significant contribution to reducing greenhouse gas (GHG) emissions. In this context, an analysis is conducted to evaluate the impact of using the solar power system on projected GHG emissions produced by the airship. This analysis includes operational scenarios without solar power plant and scenarios with solar power plant integration into the system.

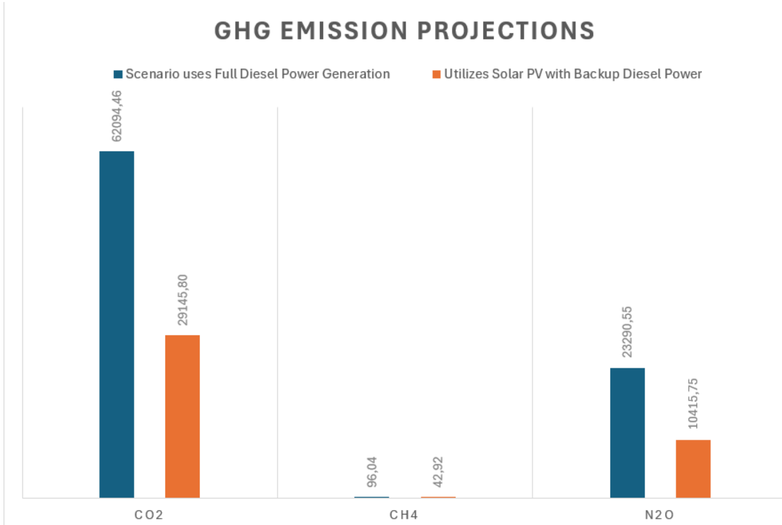

Figure 9. GHG Emission for hybrid airship

Figure 9 above shows a comparison of greenhouse gas (GHG) emissions between the full diesel power generation scenario and the solar power plant integration scenario with diesel backup. It is evident that the implementation of solar powe significantly reduces carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions. The reduction in CO_2 emissions reaches nearly 50%, highlighting the substantial contribution of solar energy in decreasing reliance on fossil fuels.

Based on the simulation results, total emissions for the full diesel power generation scenario amounted to 85,481.05 MtCO2e, whereas the scenario with solar power plant integration and diesel backup resulted in emissions of 39,604.47 MtCO2e. This reflects a 53.66% reduction in emissions in the solar power scenario. Additionally, the reduction in N2O emissions recorded in the solar power plant scenario positively impacts climate change mitigation, given that N2O has a much higher global warming potential compared to CO_2.

Thus, integrating solar power not only enhances energy efficiency but also contributes to achieving decarbonization targets in the air transport sector. The implementation of this hybrid system represents a strategic step in supporting sustainable energy policies and reducing the carbon footprint in the transportation sector. The analysis demonstrates that, although the initial investment for solar power installation is relatively high, the long-term impact of emission reduction and fuel savings can provide significant economic and environmental benefits.

4 Conclusion

The research results show that the implementation of solar power plant as the primary energy source on hybrid airships can improve energy efficiency and reduce dependence on fossil fuels. Simulations conducted across various regions indicate that solar energy contributes up to 63.6% of the total energy demand, although the diesel generator still plays a role in meeting electricity supply shortages. The use of solar power plant has also been proven to significantly reduce GHG emissions, supporting decarbonization policies in the air transport sector. Therefore, integrating solar power plant into airships serves as a strategic solution to promote environmentally friendly and sustainable cargo transportation.

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