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Contribution of Solar Energy at Ship Power System in Reducing Emission and Fuel Consumption

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Abstract: International Maritime Organization has entered into force several regulations to lessen the carbon footprint of maritime transport. Energy Efficiency Existing Ship Index (EEXI) is utilized to sustain continuously increased energy efficiency and CII (Carbon Intensity Indicator) is utilized to measure carbon emissions and rating boundary of ships. Every ship must have strategies to reduce fossil fuel consumption to meet the minimum required carbon emissions. Solar energy can be a viable solution for reducing emissions and fuel consumption in ship power systems. Solar panels can be installed on the ship's deck or other suitable areas to generate electricity. This electricity can be used for auxiliary systems such as lighting, ventilation, and onboard equipment, reducing the reliance on conventional fuel-powered generators. Solar energy can also be integrated into hybrid power systems, combining it with traditional fuel-powered engines or other renewable energy sources like wind power. This hybridization can optimize energy generation and reduce the consumption of fossil fuels. This paper will review several studies and applications of solar energy as part of ship power system, and analyze the contributions in supporting reduction of carbon emissions.

Keyword: Solar Energy, Ship Power System, Carbon Emission, Fuel Consumption, CII.

INTRODUCTION

International shipping carries around 80 per cent of global trade by volume and over 70 per cent by value (Shi, 2016). Nevertheless, marine transportation is still considered as the most efficient mode of transport which consumed energy only about 12% of total transportation consumption and around 2.2% of world energy consumption (Ang et al., 2017)

CO2 emissions from maritime transport represent around 3% of total annual anthropogenic greenhouse gas (GHG) emissions. These emissions are assumed to increase by 150–250% in 2050 in business-as-usual scenarios with a tripling of world trade. On the other hand achieving a 1.5–2°C climate target requires net zero GHG emissions across all economic sectors. Consequentially, the maritime sector is facing the challenge to significantly reduce its GHG emissions as contribution to the international ambition to limit the effects of climate change (Bouman et al., 2017). IMO through its Marine Environment Protection Committee are grappling with this issue, and GHG emissions from international shipping have been partially regulated by amendments to Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) in 2011 and 2014. These amendments aim to reduce GHG emissions from international shipping by means of technical and operational measures (Shi, 2016).

Carbon emissions could be significantly reduced if operational efficiency on ships is improved, so the International Maritime Organization (IMO) has enacted a series of regulations that will increase the energy efficiency of ships themselves and reduce their environmental impact as much as possible. One of the adopted provisions is the International Energy Efficiency Certificate (IEEC). For a new ship to obtain this certificate (contract placed on or after 1 January 2013), it must meet the Energy Efficiency Design Index (EEDI) and must also have a Ship Energy Efficiency Management Plan (SEEMP). Older ships must have a SEEMP, an operational measure to improve the energy efficiency of ships and applies to all ships of 400 GT or more on international voyages (Krmek et al., n.d., 2021).

The maritime sector has been searching for efficient solutions to change energy consumptions patterns of ports and ships to ensure sustainable operation and to reduce CO2 emissions to support sustainable transport in line with International Maritime Organization (IMO) policy guidelines. Therefore, pursuing smart strategies by utilizing renewable energy sources, clean fuels, smart grid, as well as measures of efficient-energy use are beneficial towards attaining the core goals of the IMO, specifically CO2 emission reduction in the future(Hoang et al., 2022). A hybrid power system comprised of various types of energy, such as conventional fossil fuels, renewables, hydrogens, fuel cells and batteries, can ensure a continuous and reliable power source for ships by using different types of energy for various operating conditions. This has become an emerging solution for greener ships(Yuan et al., 2020).

The extensive electrification of ship power systems has become a very appealing option for the development of more efficient and environmentally friendly ships. Renewable energy sources and energy storage systems will have a key role in such systems as they can lead to fuel consumption reduction and increase of ship efficiency (Tsekouras et al., 2015). The integration of new energy sources into traditional ship power systems has enormous potential to bring the shipping industry in line with international regulatory requirements and is set to become a key focus of ship-related researches in the immediate future (Pan et al., 2021).

Solar ship, which integrates the solar photovoltaic (PV) system into its own ship power system, is becoming one kind of most promising and fastest developing green ship. For the solar PV system that integrated in ship power system, two different kinds of operation mode are implemented, including off-grid and grid connected mode. In order to optimize energy managements of photovoltaic-ship power system (PSPS), control strategies of multiple inverter equipment under grid-connected mode are operated (Qiu et al., 2015).

METHOD

In this section we will discuss the implementation of solar energy in the ship power system, then analyze the on-board fuel savings.

Solar Energy on Marine Passenger Ship

A Research conducted by Md. Abdullah Al Mahbub where a solar panel system is made in the shape of a sunflower, which can move according to the position of the sun's rays. Solar energy implemented on marine passenger ship, using “tower rounded flower-shaped solar PV” system of PV panel arrangement, designed in such a way that they may be freely rotated on their vertical axes and that the tilt angles of their solar panels can be adjusted from 0° to 50° on their horizontal axes freely.

This system is combined with a storage system and diesel generator. Energy Output per PV tower (Epvt) is obtained from the equation Epvt = Im × At × ηmax, where Im is the realistic average daily solar insolation by month (kWh/m2/day), At is the area of tower, and ηmax is the module efficiency of 22.6 %. From monthly data measurement, average is obtained about 4386.083 kwh/m2/day. Area of tower is about 37.107 m2. So daily energy output obtained in average is 36,792 kwh/day for 1 tower (consist of 21 modules. A total of 17 ships were selected for the energy calculation and the total area calculated of all passenger vessels' roof is 6864 m2 . A total of 3432 m2 of ship's roof is being examined for the installation of solar panels, or about 50% of the total area. This will create 1240 MWh of power yearly and save around 325.56 tons of CO2 from being released into the environment(Abdullah-Al-Mahbub et al., 2023).

Hybrid PV in Oil Tanker Ship Power System

Photovoltaic (PV) generation system, diesel generator and energy storage system in a stand-alone ship power system are combined to minimizes the investment cost, fuel cost and the CO2 emissions. The Focus of Research by Hai Lan is to optimize the size of a hybrid PV/diesel/ESS (Energy Storage System) in an Oil Tanker Ship power system. The detailed parameters of the oil tanker are that the length, width, and height are 332.95 m, 60 m and 30.5 m, respectively. The total area for PV array installation is 2000 m2, the deadweight is 100,000 tons. Hybrid ship power system scheme where PV combined with diesel generator and energy storage system supply electrical power which controlled by a control strategy.

From the table it can be found that the total diesel output power is reduced with the application of solar energy and battery, and the emissions are reduced from 22,192,000 kg (without PV) to 5,005,990 kg (optimized hybrid power) or 77.44%. Without PV system, the total load demand is supplied by diesel generators only so that the fuel cost is high and the problem of emissions is serious. Even though the ship's power system includes PV generation, without ESS, it associated with the highest total system cost. The LiFePO4 battery and MOPSO algorithm are used, the system cost and the total fuel cost are the lowest in optimized hybrid power case, being $1,200,828 and $1,126,600, respectively. By considering the total output 3,822,100 kW h of diesel generator in one year, the total fuel cost in the hybrid ship system is reduced dramatically which is 28.5% reduction with respect to that in without PV case(Lan et al., 2015).

Solar energy as Part of Power System of Container Vessel

Solar energy for instance, is proposed by A. Aijjou, as a method to improve the ship efficiency. Ships can get the benefits from solar energy since most of their upper decks are always exposed to the Sun, especially in tropical regions. This section presents an example of practical application of energy saving by fitting the solar panels on container vessel. The Container vessel has Length /Beam 123 / 121 m, Gross Tonnage 6479, Propulsion Engine 5400 KW, Diesel generators 2 sets: 640 KW each; Shaft generator 990 KW, and Emergency generator 340 KW. The size of PV modules depends on load demand, available solar radiation, battery efficiency, inverter efficiency, module performance etc. Estimation of electric power required is 24 kW, so total load energy per day is 576 kWH. For supply such energy, it need to install 740 modules of SPV panels. Each one has 1.9 × 0.9 $m2$ surface. Minimum area is approx. 1300 m2. The available deck area in this sample vessel is max. 700 m2 which will cover only the half of the power approx. 12 Kw which cover emergency lighting, navigation and radio equipment and alarm system. 12 KW represents 0.2 - 0.3% of total power required for supplying all ship electric equipment. Considering 300 days of solar radiation per year, economy in fuel oil may reach 17 tons of fuel oil and 172 tons of CO2(Aijjou et al., 2019).

Hybrid Container Ship Power System Design

There are several combinations in the Hybrid system, for example Gas Turbines and Solar Panels, this combination is very important to reduce exhaust emissions produced by conventional ships listed in Annex Marpol where in 2016 the maximum sulfur emission limit is 0.5%. Research conducted by Aldyn Clinton, investigating the application of hybrid energy on container ships with specifications Length Over All (LOA): 160 m, Draft (T): 9,75 m, and Breath (B) : 25,60 m. This dimension capable of accommodating 640 panels on the top surface of the container on the empty deck of the container ship, which has an average absorption capacity of 712.467 kWh/day.

In this study, it was determined that the amount of panel power that can cover the gas turbine to meet all the electricity needs on ships is 44438.669 kWh or with a percentage of 2.760% of the total electricity demand. For 556,600 miles trip, the amount of CO2 emissions from the fuel emitted by the gas turbine on this Hybrid ship is 0.891 tons of the required 14.893 tons fuel consumption with an emission factor of 0.05988. The result of reducing the weight of CO2 emissions released by LNG fuel with panel power input for hybrid ships is 4.152 %. Fuel consumption before solar panel application is 14893 kg and after solar panel application is 14482 kg, fuel consumption reduction is 411 kg or 2.76%(Clinton et al., n.d.).

Hybrid Energy Using Fuzzy Logic Energy Management

Yupeng Yuan investigated application of Fuzzy Logic as energy management strategy to distribute the ship power generation, solar energy, and battery output power according to the ship's electrical load demand. The target ship is an ocean-going auto ro-ro ship with a main engine of 14,520 kW. Three diesel generators are installed to provide electricity for all electrical loads on the ship. Based on the original power system, the ship is modified by installing a new photovoltaic system. The total capacity of the energy storage system can reach 652.8 kWh. Each group of batteries is equipped with a battery management system (BMS), and the battery packs are balanced by smart real-time control. The ship has three diesel generators of which two are 1020 kW 6N21AL-GV diesel generators and one is 960 kW 6N21AL-UV diesel generator. Upon ship arrival or departure, two 1020 kW generators are used to provide ship power; while, during normal sailing conditions, only one 1020 kW diesel generator is operated. The ship load demand is between 200 and 700 kW. According to the design of the hybrid power system, the solar power is between 0 and 143 kW.

During normal navigation, the electrical load of the ship is around 600 kW. When the solar hybrid system that is designed in this paper is not used, the fuel consumption and CO_2 emission of the diesel generators in one year are 1208.00t and 3829.98t respectively. Assuming that the effective sunlight is six hours per day, in an ideal case, the ship can save fuel consumption and reduce CO_2 emission as 38.9 t and 123.33t yearly respectively(Yuan, Zhang, et al., 2018).

RESULTS AND DISCUSSION

Solar Energy Aplication on Ship Power System

Solar energy which harnessed for ship power, offering several benefits such as reduced fuel consumption, lower emissions, and increased energy efficiency. While solar power alone may not be sufficient to power a ship entirely, it can supplement traditional propulsion systems and onboard electrical systems. Here are examples of solar energy applications for ship power:

1. *Solar Panels for Auxiliary Power*

The system includes a solar energy generation unit, a battery storage system, a diesel generating set, controlled inverters, a battery management system (BMS) and an energy management system. According to an analysis of the experimental data, it can be concluded that the use of solar energy hybrid power, in theory, can reduce fuel consumption by 4.02% and carbon dioxide (CO_2) emissions by 8.55% a year (Yuan, Wang, et al., 2018). Solar panels can be installed on the ship's deck or superstructure to generate electricity for auxiliary power needs. This electricity can be used to power lighting, communication systems, navigation equipment, pumps, and other onboard systems. By utilizing solar energy for auxiliary power, ships can reduce their reliance on fossil fuel generators, resulting in fuel savings and decreased emissions. On the basis of the existing power system, a unified grid-tied or stand-alone solar system is designed with a built-in battery energy storage system.

2. *Solar-Powered Ventilation and Cooling*

Solar-powered ventilation systems integrated into the ship's design can help improve indoor air quality and reduce the need for traditional air conditioning. Solar-powered fans and ventilation units can be used to circulate air, providing cooling and improving comfort for passengers and crew. This reduces the energy consumption associated with traditional cooling systems and contributes to energy efficiency. Air conditioning is essential for maintaining thermal comfort in indoor environments, particularly for hot and humid climates. During the summer, the demand for electricity greatly increases because of the extensive use of air-conditioning systems. On the other hand, vapour compression air conditioning systems have impacts on stratospheric ozone depletion because of the chlorofluorocarbons (CFC) and the hydro fluorocarbon (HCFC) refrigerants. The use of solar energy to drive cooling cycles is attractive since the cooling load is roughly in phase with solar energy availability. To cool with solar thermal energy, one solution is to use an absorption chillier using water and lithium bromide solution. Solar air conditioning systems help to minimize fossil fuel energy use (Gugulothu et al., 2015).

3. *Solar-Powered Water Desalination*

Ships at sea require a significant amount of freshwater for various purposes. Solar energy can be utilized to power onboard desalination systems that convert seawater into freshwater through processes like reverse osmosis. Solar-powered desalination reduces the reliance on traditional energy sources, making the ship more self-sufficient and environmentally friendly. The layout involves the integration of several membrane distillation modules into a multistage MD (membrane distillation) system in order to minimize the specific energy consumption. Technical simplicity, long maintenance-free operation periods and high-quality fresh water output are the most important aims which will enable successful application of the systems that are based on MD. The heat source will proceed from an advanced compound parabolic solar concentrator, developed for the specific concentration ratio to achieve the specific needed range of temperatures, and the seawater heater will include the development of advanced non-fouling surface coatings to avoid scaling (Blanco Gálvez et al., 2009).

4. *Solar-Powered Charging Stations*

Solar-powered charging stations enable clean and renewable energy for onboard transportation, reducing emissions and dependence on fossil fuels. Energy storage systems in recent days are witnessing an increased trajectory of hybridization to decrease the burden on the single energy storage systems in renewable energy sources. The hybridization of energy storage imposes the need for an efficient power-sharing strategy. The hybrid energy storage system consists of a battery and supercapacitor with solar power generation as a primary source. The battery supports the slow varying power and the supercapacitor supports the fast-varying power (C et al., 2021). Solar-powered charging stations can be installed on ships to charge electric vehicles (EVs) or battery-powered equipment onboard. This is particularly useful for cruise ships or hybrid vessels that have electric or hybrid electric propulsion systems.

5. *Solar-Assisted Propulsion*

While solar energy alone may not provide sufficient power for propulsion, it can be used to supplement the ship's main propulsion systems. Solar panels can be integrated into the ship's structure or installed on deck areas to generate electricity, which can be used to power electric propulsion systems or assist the main engines. This solar-assisted propulsion approach reduces fuel consumption and emissions, particularly during low-power or standby operations. The renewable energy capture for a ship's propulsion system was optimised for a combination of wind sail and solar power using two models. The first model optimised the rigid wind sail angle under varying wind conditions, while the second model optimised the available deck area of the ship assigned to wind and solar systems to maximise total power production. The optimum power obtained from the results was used in the Energy Efficiency Design Index calculation to evaluate the carbon dioxide emission reduction per unit transport work. The results showed that sailing at optimal sail angle and optimising the available deck area with combined installation of solar and wind system allowed maximising the renewable power to contribute 36% reduction of carbon dioxide emissions compared to the same ship without innovative technologies (Nyanya et al., 2021).

6. *Energy Storage Systems*

Solar energy generated during the day can be stored in onboard energy storage systems such as batteries. The stored energy can then be used during periods of low solar availability or high energy demand. Energy storage systems improve the reliability and stability of solar power usage onboard, ensuring a continuous power supply and optimizing energy management. All-electric ship power system generally employs energy storage (ESS) to improve operation efficiency, redundancy, and flexibility while reducing environmental impacts (Hein et al., 2021).

It's important to note that the feasibility and effectiveness of solar energy for ship power depend on factors such as ship size, energy demand, available deck space, and geographical location. The integration of solar energy systems into ship designs requires careful planning, including considerations for weight, stability, and structural integrity. However, as solar technology continues to advance and costs decrease, the adoption of solar power for ships is expected to increase, contributing to more sustainable maritime operations.

Challenges for Implementing Solar Energy on Ships

There are several challenges and limitations to implementing solar energy on ships. Some of the key challenges include:

1. *Limited Space*

Ships, especially commercial vessels, have limited deck space available for installing solar panels. The space constraint can limit the amount of solar energy that can be harnessed, potentially restricting the power output and the extent to which solar energy can be integrated into the ship's systems. On container ships, for example, the limited space for installing PV panels is due to the fact that container vessels are loading containers on the deck(Aijjou et al., 2019).

2. *Weight and Stability*

Solar panels add weight to the ship, which can impact stability and maneuverability. Ships must carefully consider the structural integrity and weight distribution when installing solar panels to ensure safe operation. Additionally, the added weight may require modifications to the ship's design, potentially resulting in increased costs. The number of PV module and battery determine the PV system weight while the PV system weight will affect to the propulsion power, and the power itself will affect to the number of PV module and battery. Therefore, the balance condition where the effect of PV system weight is not influence to the propulsion power anymore has to be fulfilled. This is an iteration process where the process will be stop after the balance condition is reached (Nasirudin et al., 2017).

3. *Variable Weather Conditions*

   Solar energy generation is influenced by weather conditions, including cloud cover, shading, and the angle of sunlight. Ships often travel across different regions and encounter varying weather patterns, which can affect solar panel efficiency and output. In areas with frequent cloud cover or low sunlight intensity, the solar energy generation may be compromised. As the energy source of the ship is solar energy, harvesting of adequate amount of energy for the propulsion of motor under the varying weather conditions is a primary concern. The weather conditions in which monitored data for that specific case showed relatively low irradiation, caused by clouds and rain. The battery capacity needs to be improved for facilitating the working under the varying weather conditions(Rodrigues & Chandran, n.d.).

4. *Energy Storage*

   Ships often require power during periods of low solar availability, such as at night or in areas with limited sunlight. Implementing effective energy storage systems, such as batteries, is essential to ensure a continuous power supply. Energy storage technologies can add complexity, weight, and cost to the overall solar energy system. The objective of PV system optimization is to find the number of PV module and battery with minimum cost. The effect of PV system weight to the propulsion power should be taken into consideration. Minimum freeboard, ship stability, minimum battery, and the maximum number of PV module because of the space limitation are taken as constraint. The linear optimization programming by simplex method can be chosen as optimization algorithm in this PV system optimization(Nasirudin et al., 2017)

5. *Cost Considerations*

   While the cost of solar panels has decreased over the years, they still represent a significant upfront investment. The initial cost of purchasing and installing solar panels on a ship can be substantial, which may deter some ship operators from adopting solar energy solutions. However, it's worth noting that the long-term operational cost savings from reduced fuel consumption can offset the initial investment. Another issue in the designing of solar powered boat is regarding to PV system cost, with the appropriate determination of PV system size then the minimum cost can be reached(Nasirudin et al., 2017).

6. *Efficiency and Performance*

   The efficiency of solar panels can vary depending on the technology used, the angle of sunlight, and other factors. Achieving optimal efficiency and performance from solar panels on a moving ship can be challenging due to factors like vibrations, tilting, and the need to maintain the panels' cleanliness in a marine environment. Important factor in increasing efficiency in the implementation of solar power is determining the optimal size of the photovoltaic (PV) generation system, the diesel generator and the energy storage system in a stand-alone ship power system that minimizes the investment cost, fuel cost and the $CO2$ emissions. The power generation from PV modules on a ship relies on the date, local time, time zone, longitude and latitude along a navigation route and is different from the conditions of power systems on land(Lan et al., 2015).

Despite these challenges, advancements in solar technology, including more efficient solar panels and energy storage systems, along with improved ship design and integration techniques, are continuously addressing these limitations. The integration of solar energy in ships is expected to increase as technology progresses and the industry seeks more sustainable power solutions.

Solar Energy Implementation Steps

Implementing solar energy on a ship's power system can help reduce fuel consumption and greenhouse gas emissions. Here are the steps involced in implementing solar energy on a shop.

1. *Assess Feasibility*

   Conduct a feasibility study to determine if solar energy is a viable option for ship. Consider factors such as the ship's energy requirements, available space, sailing routes, and solar exposure. These factors are compared with some of the limitations of the implementation on board, such as limited space, costs, battery weight, and potential of fuel saving, so that the best design can be decided for combining solar energy and energy sources that are already on board.
2. *Energy Calculation*

   Perform an energy calculation to understand the ship's energy consumption patterns. This will help determine the size and capacity of the solar energy system required. If a ship use electrical propulsion, total energy demand consists of energy required by propulsion power and energy required by electrical equipment for service purpose. The propulsion power energy is function of propulsion power and ship cruising duration, while the service energy is product of electrical equipments power and the usage duration of each equipment(Nasirudin et al., 2017).
3. *Design Solar Energy System*

   Work with a marine engineer or a specialized solar energy consultant to design an appropriate solar energy system for your ship. Consider factors such as solar panel placement, mounting options, electrical connections, and battery storage capacity. The aim of ship design optimization is to find an optimum size of a certain ship design with minimum power(Nasirudin et al., 2017).
4. *Select Solar Panels*

   Choose high-quality solar panels suitable for marine environments. Look for panels that are durable, corrosion-resistant, and capable of withstanding the harsh conditions at sea. In order to select the appropriate solar panels it is necessary to know the solar radiation by month to appropriate area(Krčum et al., n.d.).
5. *Install Solar Panels*

   Install the solar panels on suitable locations on the ship, such as the deck or superstructure, where they can receive maximum sunlight exposure. Ensure secure mounting and proper sealing to prevent water ingress. Larger the number of solar panels that can be installed, the more sunlight they can collect and, consequently, the faster the solar energy is converted into electricity that can be stored in batteries. Large deck area is also important in other situations, such as cloud cover, or low-angled and low-intensity light in winter. The charging time can vary from 4 to16 hours of sunlight for one battery, depending on the surface area and light conditions (Salem & Seddiek, 2016)
6. *Electrical System Integration*

   Connect the solar panels to the ship's electrical system. This may involve installing a solar charge controller, inverters, and batteries for energy storage. Ensure compliance with marine electrical standards. A grid-connected PV solar power system consists mainly of solar panels, inverter, battery bank, and other necessary electric devices. A simple model of a grid-connected PV system can be installed on board a ship(Salem & Seddiek, 2016).

7. *Monitoring and Control*

   Set up a monitoring and control system to track the performance of the solar energy system. Monitor energy production, battery status, and other relevant parameters to optimize efficiency and troubleshoot issues. The energy system is used to power the propulsion system and electrical accessories. Conversion from classical techniques to RES (Renewable Energy Source)-based electrical transportation system requires strategic approach and control algorithms(Manickavasagam et al., 2019).
8. *Safety and Regulatory Compliance*

   Ensure the solar energy system on the ship meets safety and regulatory requirements. Comply with maritime regulations, electrical codes, and safety standards for marine installations. The analysis of the stability of the vessel performed numerically with reference to the IMO regulations requiring minimum value stability arm at certain angles. IMO regulations already require the amount of arms that must be owned vessel stability so that safety and passenger comfort can be assured (Budi Purwanto et al., 2017).
9. *Continuous Improvement*

   Monitor the system's performance over time and identify opportunities for improvement. Consider upgrading with newer, more efficient technologies as they become available. For example, design improvements are required for housing more panels. During the design process it turned out that the area for the solar panels should be bigger so that the engine can run with maximum power. Light and inexpensive materials were selected to manufacture. Wood and fiber glass were selected due to their relative low price and weight. The weather conditions in which data monitored for specific case low irradiation, caused by clouds and rain. The battery capacity needs to be improved for facilitating the working under the varying weather conditions. The implementation of interleaved boost converter improved the energy conversion efficiency (Edwina G. Rodrigues, 2016).

Implementing solar energy on a ship requires collaboration with experts, including marine and electrical engineers, solar energy specialists, and compliance professionals. Consulting with professionals in the field will help ensure a successful implementation.

Discussion

After discussing several implementations of solar power as part of the electrical energy source on ships, below we will review the extent of fuel savings and reduction in CO_2 emissions. The following is a data table on the use of solar energy which was discussed previously.

Table 1. Solar Energy Applications Recap

Case no	Type of Ship	Special specification	Solar PV Capacity	Electrical capacity	Fuel reduction	CO2 reduction
1	Passenger Ship	Rounded flower shaped solar PV	4386 kwh/m2/day, 3432m2 solar PV	1240MWh yearly	Not mentioned	325.56 ton yearly
2	Oil Tanker	Multi-objective optimization PV/ESS/DG	298 kW and 113 kWH ESS capasity	3882.1 MWh yearly	Fuel: $ 449100 (28.5%) Total cost: $374872 (23.8%) yearly	17186 ton yearly (77.44%)
3	Container	-	12 kW	576 kWH per day	17 tons ($10,200) yearly	172 ton yearly
4	Container	-	640 panels	712.467 kWh/day	0.411 ton (2,76%)	0.037 ton (4,152%)

5	Ro-ro	Fuzzy Logic Energy management	143 kW	38.9 t (3.22%)	123.33t (3,22%)

Table 1 displays a recap of the implementation of solar energy on ships, with 5 examples that were discussed in the previous section.

Number 1 is the implementation of solar panels on a passenger ship, which produces 1240 MWh yearly. The advantage of this application is reduces the release of CO_2 by 325.56 tons per year, unfortunately the source does not mention the reduction in fuel produced.

Number 2 is an oil tanker equipped with solar panels with power management called Multi-objective Optimization which produces 3882.1 MWh of energy per year. The reduction in fuel consumption is converted into dollars, where if we look at it from fuel, we get a saving of 28.5%, while if we look at it from overall operational costs we get a saving of 23.8%. The reduction in CO_2 emissions is claimed to be quite high, namely 17,186 tons or 77.44% yearly compared to a full supply of electricity from a diesel generator.

In the third case, it is a container ship equipped with 12 kW solar panels. This application resulted in fuel savings of 17 tons or $10,200, as well as a reduction in emissions of 172 tons. Unfortunately, the source does not mention fuel and emissions data before the application of solar panels, so the reduction percentage cannot be obtained.

The fourth case is still a container ship, where the solar panels installed produce 712,467 kWh/day, resulting in savings of 0.411 tons for 1 trip of 428 miles, as well as reducing CO2 emissions by 0.037 tons.

The 5th ship is a ro-ro ship, which is equipped with solar panels to produce up to 143 kW of electrical energy using fuzzy logic for energy management. In 1 year, fuel savings of 38.9 tons are generated and CO2 emissions are reduced by 123.33 tons.

From the five cases it can be concluded that although fuel savings and carbon emission reductions are still relatively small, they can still be developed by using energy management or optimization as was done in the case of ship number 2, resulting in more significant fuel savings and emission reductions.

CONCLUSION

1. Although solar energy still has limitations in terms of efficiency, space limitations, energy storage and cost, it is a one of promising renewable energy source in the shipping sector which can still be developed.
2. Currently, solar energy is not yet fully capable of being a source of electrical energy on ships and must still be combined with conventional energy sources such as diesel generators or other energy sources.
3. The implementation of solar energy on ships as part of the electrical energy source has been proven in saving fuel consumption and reduce CO_2 emissions compared to that come purely from diesel generators.
4. Optimization and good power management can increase the efficiency of solar energy applications and further can increase fuel savings and reduction in CO_2 emissions.

REFERENCE

Abdullah-Al-Mahbub, M., Towfiqul Islam, A. R. Md., Alam, E., & Asha, M. R. (2023). Sustainable solar energy potential on marine passenger ships of Bay of Bengal: A way of reducing carbon dioxide emissions and disaster risk reduction. *Energy Exploration & Exploitation*, *41*(5), 1697–1723. https://doi.org/10.1177/01445987231173097

Aijjou, A., Bahatti, L., & Raihani, A. (2019). Influence of Solar Energy on Ship Energy Efficiency: Feeder Container Vessel as Example. *International Journal of Electrical*

Energy, *7*(1), 21–25. https://doi.org/10.18178/ijoee.7.1.21-25

Ang, J. H., Goh, C., Saldivar, A. A. F., & Li, Y. (2017). Energy-efficient through-life smart design, manufacturing and operation of ships in an industry 4.0 environment. In *Energies* (Vol. 10, Issue 5). MDPI AG. https://doi.org/10.3390/en10050610

Blanco Gálvez, J., García-Rodríguez, L., & Martín-Mateos, I. (2009). Seawater desalination by an innovative solar-powered membrane distillation system: the MEDESOL project. *Desalination*, *246*(1–3), 567–576. https://doi.org/10.1016/j.desal.2008.12.005

Bouman, E. A., Lindstad, E., Rialland, A. I., & Strømman, A. H. (2017). State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping – A review. *Transportation Research Part D: Transport and Environment*, *52*, 408–421. https://doi.org/10.1016/j.trd.2017.03.022

Budi Purwanto, D., Sulisetyono, A., & Putranto, T. (2017). Stability Analysis of Catamaran Passenger Vessel with Solar Cell Energy in Calm Water. *IPTEK The Journal for Technology and Science*, *28*(3). https://doi.org/10.12962/j20882033.v28i3.3222

C, B., CK, S., NS, S., Sharma, J., & Guerrero, J. M. (2021). Interval Type2 Fuzzy Logic-Based Power Sharing Strategy for Hybrid Energy Storage System in Solar Powered Charging Station. *IEEE Transactions on Vehicular Technology*, *70*(12), 12450–12461. https://doi.org/10.1109/TVT.2021.3122251

Clinton, A., Muslim, M., Buwono, A., Danil Arifin, M., & Budi, A. (n.d.). *Design Of Utilization Of Solar Panel and Gas Turbine On The Hybrid Container Ship From Tanjung Priok Jakarta to Tanjung Perak Surabaya*.

Gugulothu, R., Somanchi, N. S., Banoth, H. B., & Banothu, K. (2015). A Review on Solar Powered Air Conditioning System. *Procedia Earth and Planetary Science*, *11*, 361–367. https://doi.org/10.1016/j.proeps.2015.06.073

Hein, K., Xu, Y., Wilson, G., & Gupta, A. K. (2021). Coordinated Optimal Voyage Planning and Energy Management of All-Electric Ship With Hybrid Energy Storage System. *IEEE Transactions on Power Systems*, *36*(3), 2355–2365. https://doi.org/10.1109/TPWRS.2020.3029331

Hoang, A. T., Foley, A. M., Nižetić, S., Huang, Z., Ong, H. C., Ölçer, A. I., Pham, V. V., & Nguyen, X. P. (2022). Energy-related approach for reduction of CO2 emissions: A critical strategy on the port-to-ship pathway. *Journal of Cleaner Production*, *355*, 131772. https://doi.org/10.1016/j.jclepro.2022.131772

Krčum, M., Gudelj, A., & Krčum, P. (n.d.). *THE RENUEWIBLE ENERGY ON SHIP: SIMULATION AND OPTIMIZATION*. http://www.ecomarinepower.com

Krmek, I., Biočić, T., Vujičić, S., & Hasanspahić, N. (n.d.). *SWOT ANALYSIS OF SHIP ENERGY EFFICIENCY MANAGEMENT PLAN (SEEMP)*.

Lan, H., Wen, S., Hong, Y.-Y., Yu, D. C., & Zhang, L. (2015). Optimal sizing of hybrid PV/diesel/battery in ship power system. *Applied Energy*, *158*, 26–34. https://doi.org/10.1016/j.apenergy.2015.08.031

Manickavasagam, K., Thotakanama, N. K., & Puttaraj, V. (2019). Intelligent energy management system for renewable energy driven ship. *IET Electrical Systems in Transportation*, *9*(1), 24–34. https://doi.org/10.1049/iet-est.2018.5022

Nasirudin, A., Chao, R.-M., & Utama, I. K. A. P. (2017). Solar Powered Boat Design Optimization. *Procedia Engineering*, *194*, 260–267. https://doi.org/10.1016/j.proeng.2017.08.144

Nyanya, M. N., Vu, H. B., Schönborn, A., & Ölçer, A. I. (2021). Wind and solar assisted ship propulsion optimisation and its application to a bulk carrier. *Sustainable Energy Technologies and Assessments*, *47*, 101397. https://doi.org/10.1016/j.seta.2021.101397

Pan, P., Sun, Y., Yuan, C., Yan, X., & Tang, X. (2021). Research progress on ship power systems integrated with new energy sources: A review. *Renewable and Sustainable*

Energy Reviews, *144*, 111048. https://doi.org/10.1016/j.rser.2021.111048

Qiu, Y., Yuan, C., & Sun, Y. (2015). Review on the application and research progress of photovoltaics-ship power system. *2015 International Conference on Transportation Information and Safety (ICTIS)*, 523–527. https://doi.org/10.1109/ICTIS.2015.7232167

Rodrigues, B. S. J., & Chandran, V. (n.d.). Design and Fabrication of Solar Boat. *International Journal of Electrical Engineering & Technology (IJEET)*, *7*(6), 1–10. http://www.iaeme.com/IJEET/issues.asp?JType=IJEET&VType=7&IType=6www.jifactor.comhttp://www.iaeme.com/IJEET/issues.asp?JType=IJEET&VType=7&IType=6

Salem, A. A., & Seddiek, I. S. (2016). Techno-Economic Approach to Solar Energy Systems Onboard Marine Vehicles. *Polish Maritime Research*, *23*(3), 64–71. https://doi.org/10.1515/pomr-2016-0033

Shi, Y. (2016). Reducing greenhouse gas emissions from international shipping: Is it time to consider market-based measures? *Marine Policy*, *64*, 123–134. https://doi.org/10.1016/j.marpol.2015.11.013

Tsekouras, G. J., Kanellos, F. D., & Prousalidis, J. (2015). Simplified method for the assessment of ship electric power systems operation cost reduction from energy storage and renewable energy sources integration. *IET Electrical Systems in Transportation*, *5*(2), 61–69. https://doi.org/10.1049/iet-est.2013.0011

Yuan, Y., Wang, J., Yan, X., Li, Q., & Long, T. (2018). A design and experimental investigation of a large-scale solar energy/diesel generator powered hybrid ship. *Energy*, *165*, 965–978. https://doi.org/10.1016/j.energy.2018.09.085

Yuan, Y., Wang, J., Yan, X., Shen, B., & Long, T. (2020). A review of multi-energy hybrid power system for ships. *Renewable and Sustainable Energy Reviews*, *132*, 110081. https://doi.org/10.1016/j.rser.2020.110081

Yuan, Y., Zhang, T., Shen, B., Yan, X., & Long, T. (2018). A Fuzzy Logic Energy Management Strategy for a Photovoltaic/Diesel/Battery Hybrid Ship Based on Experimental Database. *Energies*, *11*(9), 2211. https://doi.org/10.3390/en11092211.