

Integrated Design Optimization of Marine Solar PV Systems for Reducing Fuel Consumption and Maximizing Efficiency in Container ships

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ABSTRACT

Fuel saving and emission reduction has become major issue due to strategic and political concerns like oil prices. Moreover, the fuel oil extraction became costly process. So, renewable energy became the proper solution to decrease the dependency of fossil fuels. This paper studied the optimization of the PV panel type which is more efficient in container ships (SDARI SEALION 4300 TEU) through an experimental investigation. Mono-crystalline and poly-crystalline PV panels were tested. Several PV panels were installed on the useful area on the deck to cover part of HVAC load. Mono-crystalline PV was more efficient where it produced 19.5% of HVAC load while polycrystalline produced 11.6%. Both panels (A) and (B) saved 84 and 51 tons/month respectively. The saving cost was more in panels (A), which reached 66,000 \$ per month while panel (B) reached 40,000 \$ per month

Keywords: Mono-crystalline and poly-crystalline Photovoltaic, marine vessel, HVAC in marine vessel, fuel saving, emission reduction.

Date of Submission: 07-05-2026

Date of acceptance: 18-05-2026

I. Introduction

The world energy demand increased by 30% since 2010. Consequently, the emission increased by 18% in addition to the global warming problem that cause increasing the global temperature by 3°C. So, the world must tend to renewable energy where the fossil fuels become not enough. It is expected in 2050, emissions may grow twice or more that produced from marine vessels as a result of expanding in world trade. Recent agreements and legislative regulations have become more restricted with greenhouse gases emission like CO₂, Nox, and SO_x. Renewable energy are one of the best energy alternative in addition to its cleanness. Solar energy one of the most common renewable energy source. It uses the radiation and heat from sun. PV panels are used to produce electric power while solar heaters are used to produce heating energy from the sun load. The most common application of the PV solar panels that are used in street lighting. Using the photovoltaic solar cells has cost benefits for the container vessels and ships. High cost of diesel fuel and harmful emission are the major factors that force the researchers to study the

possibility of PV usage to save diesel fuel. Several advantages are obtained from PV usage in marine vessels like:

- Produce energy without fossil fuels.
- Less emission produced from energy production
- Low maintenance cost.
- Long lifetime
- Easy to be installed

Any PV solar panel has four components; Solar panels, controller, battery and inverter as shown in figure 1.2. Generally, increasing the cell temperature due to sunlight exposure causes electrons excitation on the semiconductor material that existed in the cell (Silicon). The battery stores the excess energy produced during the daylight by the controller. The inverter is used to convert the DC current and 12V into 220v and AC current.

Generally, there are three common types of PV solar panels in respect of materials and technology. Monocrystalline Silicon (Mono-Si) is made from a single crystal of silicon. It has high efficiency, long lifespan, takes less space but it is

relatively expensive. The second type is Polycrystalline Silicon (Poly-Si or Multi-Si), made from multiple silicon crystals. It is cheaper than mono-crystalline, and it has lower efficiency. The third type is thin film solar panels which made by placing thin layers of photovoltaic material on a substrate. It has lower efficiency, but it has lightweight. Both of mono-crystalline and polycrystalline PV was selected to be studied in this paper.



Figure I-1 Solar system components

II. Literature Review

Many experimental and academic studies were carried out to investigate the how it is useful to use solar energy in marine vessels and ships.

Y. Fugii et al. [2] studied the PV effect on the fuel consumption in diesel engine. It was found that the amount of diesel fuel decreased by 20%, Nox and Sox reduction by 15% and 17% respectively. Farias et al. [3] investigated the optimum design of an electric catamaran for tourists. Hydrogen fuel cells, batteries, and PV array were used to produce energy for two electric motors. It was concluded that the PV system is the most effective in tourist ship specially in the summer season. Shin et al. [4] tested the hybrid system (PV + diesel engine) that was connected to the grid. The main goal is to propose the green ship. PV system with 3.2 KW was used. Economical study was conducted for commercial purposes. Emmanuel et al. [5] proposed different types of solar cells and PV arrays. it was concluded that PV was very useful in marine applications however, several factors were affected on the PV power like wind, dust accumulation, humidity, deck useful area clouds, and corrosion occurrence.

This paper studies the optimum design and the possibility of fitting different types of photovoltaic solar panels onboard a container ship (SDARI SEALION 4300 TEU) as a practical investigation to reduce dependability on fossil fuel. The electric demand of HVAC on the ship was considered and the power produced by different panels were calculated as well. Comparison between two different types of solar panels was conducted to determine the best behavior and fuel cost savings.

III. Methodology

3.1.Selected Container ship

PV panels shall be selected after calculation of the available are and the power demand. Generally, the PV produced power are not quite enough to save power for the main propeller instead of diesel engine. However, PV panels can produce power for part of the auxiliary loads. The selected container ship in the investigation is SDARI SEALION 4300 TEU. TEU is unit tending to twenty-foot equivalent unit which is a measure of volume in units of twenty-foot long containers. Its specifications and dimensions are listed in table 3.1.

Table III-1 Container ship SDARI SEALION 4300 TEU specifications

Overall Length (LOA)	220 m
Length between perpendiculars	215.8m
Beam (Width)	37.5m
Depth	19.6m
Draft	11.5m
Speed	22 ~ 25 Knots
Dead Weight	55000 Ton
Capacity	4300 TEU
Deck area	9450 m ²

3.2. Calculated auxiliary loads

Generally, PV panels cannot produce power in megawatts on the marine vessels due to its lower

efficiency and large area requirements. However, it can supply auxiliary loads in marine vessels like:

- Lighting (~10% of the auxiliary load)
- HVAC (~45% of the auxiliary load)
- Water and Oil Pumps (~10% of the auxiliary load)
- Air compressors (~10% of the auxiliary load)
- Navigation systems (5% of the auxiliary load)

For SDARI SEALION 4300 TEU, the machine load (diesel engine) has the following specifications:

- Main engine type: MAN 6G70ME-C10.5
- Specific maximum continuous rating (SMCR):16,500 KW
- Bow thruster 1500KW
- Aux generator: 4x2000 KW

So, the selected PV shall cover part or all HVAC load which near or equal to 3600 KW required.

3.3. Selected suitable numbers of PV panels

From table 3.1, the recommended useful area to install the PV panels represents 35% to 40% of the total deck area. Then, the designed area for the PV is 3300 to 3400 m².

Table 3.2. Mono-crystalline panel (A) and Polycrystalline panel (B) specifications

Parameter	Panel (A) Mono crystalline	Panel (B) Polycrystal line
Model No	VDS-S132/M12H 650	DT235-24
Power Warranty	12 years	5 years
Max power tolerance	1%	1
Max power Pmax (watt)	650	235
Volt at max power (Vmpp)	37.6	30.4
Current at max power (Impp)	127.29	7.73
Open circuit voltage (Voc)	44.9	37.4
Short circuit (Isc)	18.27	8.5

Panel efficiency	20.9	17.5
Operating temperature range	-40 to 85°C	-40 to 85°C
Panel dimensions	2348 x 1303 x 35 mm	1640 x 992 x 50 mm
Cell number	132	60
Glass type	Anti reflection coating	Tempered
Glass thickness	3.2 mm	3.2 mm
Frame type	Anodized Aluminum	----
Protection class	IP68	IP65

From table 3.2 shown below, both panels (A: mono-crystalline) and panel (B: poly-crystalline) were selected and installed on two similar container ship (SDARI SEALION 4300 TEU) on the deck. The selected PV panels specifications are as shown in table 3.2.

3.4. Experimental protocol:

Power, efficiency, and fuel consumption were measured and calculated. So, the following protocol was as follows:

- Continuous data logging (irradiance, current, and voltage) for one month.
- Daily manual cleaning was performed to keep the panel efficiency and decrease dust loss.
- Calculation of the produced power as per equation 3.2. below:

$$P_m = V_m \times I_m \quad (\text{eqn. 3.2})$$

- Calculation of the PV efficiency will be as per equation 3.3. below:

$$\eta = \frac{V_m \times I_m}{G \times A} \times 100\% \quad (\text{eqn. 3.3})$$

Where:

- η = efficiency (%)
- V_m = voltage at maximum power point “measured by solar panel multimeter”
- I_m = current at maximum power point “measured by solar panel multimeter”

- G = solar irradiance on the panel surface (W/m²) “measured by solar irradiance meter”
- A = panel area (m²) “given in PV specifications”
- Calculation of the amount of fuel will be as per equation 3.4. below:

$$\text{FOC (Kg/hr)} = \frac{\text{SFOC (g/Kwhr)} \times \text{Power (Kw)}}{1000} \quad (\text{eqn. 3.4})$$

Where:

- FOC = amount of fuel oil consumption
- SFOC = Specific fuel oil consumption

Comparison between two different types of solar panels was conducted to determine the best behavior and fuel consumption and cost saving.

IV. Results and discussion

In this section, the results will be discussed according to the power, efficiency, and amount of fuel saving, and cost saving for both panel types.

4.1. Power produced from total PV panel array

Along July 2025, the current and voltage were measured and the power was calculated for both panel (A) and (B). From figure 4.1, it was noted that each panels had loosen power due to environmental condition and inverter deficiency. Also, it was noted that panel (A) produced high power compared with panel (B) while both were occupying the same area. This is because the crystal structure of the mono-crystalline has a single and continuous silicon crystal without grain boundaries and the produced electrons are moving freely.

On the other hand, panels (A) and (B) produced power with capacity 693 Kw and 418 KW respectively. This represents 19.5% of the HVAC load for panels (B) while it represented 11.6% of the HVAC load for panel (B). Panel (A) was more efficient than panel (B).

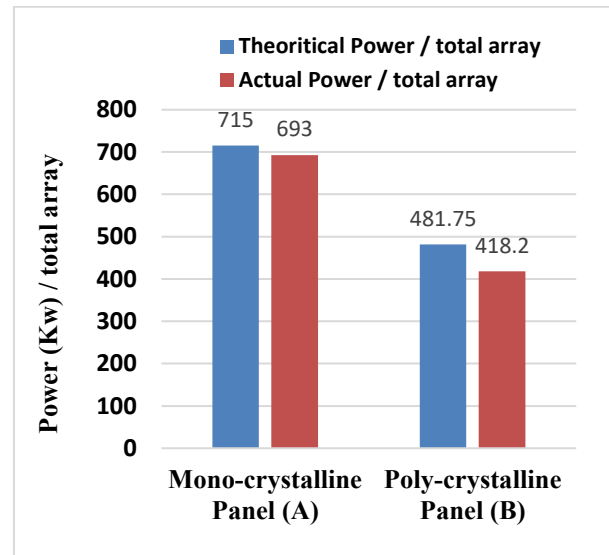


Figure IV-1 Difference between theoretical and actual power produced from both panels

4.2. Power produced from total PV panel array

Along July 2025, The efficiency was calculated and compared with the theoretical mentioned in the datasheet. From figure 4.2, it was noted that efficiency decreased by 3% for panel while it was decreased by 13% for panel B.

Moreover, the efficiency for panels (A) and (B) were 20% and 15% respectively as shown in figure 4.2. Panel (A) has low resistance against the electrons consequently high efficiency compared with panels (B).

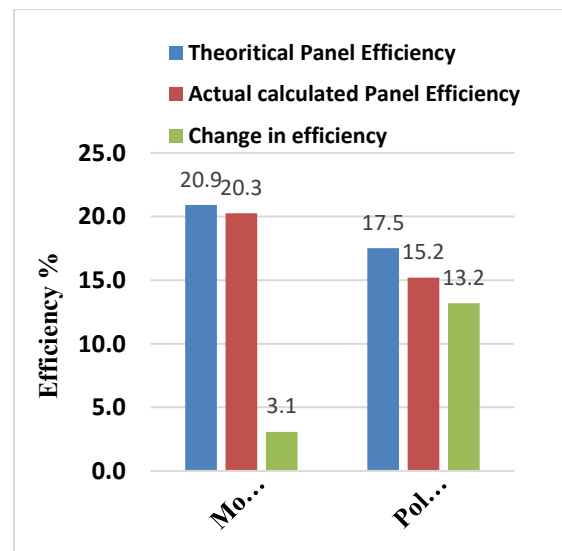


Figure IV-2 Difference between theoretical and actual efficiency produced from both panels

4.3. Fuel consumption and cost saving for both PV panels

For SDARI SEALION 4300 TEU container ship, the specific fuel oil consumption (SFOC) is 170 gram per hour. From equation 3.4, the amount of fuel was calculated for one month. Both panels (A) and (B) saved 84 and 51 ton/month respectively. However, Panel (A) saved fuel more than panel (B) by 33 ton / month as shown in figure 4.3. This is because highly efficient solar panel behavior. Thus, the saving cost was more in panel (A) which reached to 66,000 \$ per month while panel (B) reached 40,000 \$ per month as shown in figure 4.4.

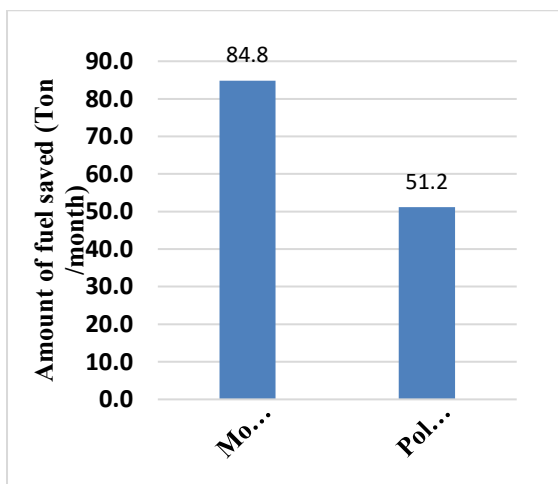


Figure IV-3 amount of fuel saved for panels (A) and (B)

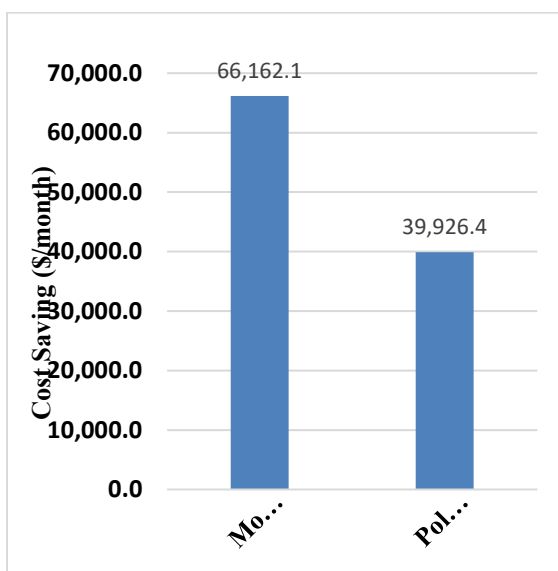


Figure IV-4 Cost saving for both panels (A) and (B)

V. Conclusion

This study lays out an experimental investigation and modelling approach to measure energy saving in case of PV solar panel usage in one of the container ship; SDARI SEALION 4300 TEU. Both mono-crystalline and poly-crystalline were used. The results were concluded as below:

- Panels (A) and (B) produced power with capacity 693 Kw and 418 KW respectively. This represents 19.5% of the HVAC load for panels (B) while it represented 11.6% of the HVAC load for panel (B). Panel (A) was more efficient than panel (B).
- Calculated efficiency for panels (A) and (B) were 20% and 15% respectively. This is because the crystal structure of the mono-crystalline has a single and continuous silicon crystal without grain boundaries and the produced electrons are moving freely. Low resistance against the electrons means high efficiency.
- The amount of fuel was calculated for one month. Both panels (A) and (B) saved 84 and 51 ton/month respectively. However, Panel (A) saved fuel more than panel (B) by 33 ton / month. This is because high efficient solar panel behavior.
- The saving cost was more in panels (A) which reached to 66,000 \$ per month while panel (B) reached 40,000 \$ per month.

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