JOURNAL OF MARITIME RESEARCH

Vol XXII. No. III (2025) pp 142–152

ISSN: 1697-4840, www.jmr.unican.es

Analysis of the Prospects and Possibilities of Using Solar Electrical Energy Systems on the Transport Fleet

V. Nastasenko[1,*], V. Protsenko[2], M. Babii[3]

ARTICLE INFO

Article history:
Received 26 Dec 2024;
in revised from 29 Dec 2024;
accepted 25 Mar 2025.

Keywords:
Marine Solar Energy, Real Capacities and Possibilities, Choice of the Best Systems.

ABSTRACT

In the conditions of the constantly growing threat of global warming, the problem of decarbonization is one of the main ones. Its solution is carried out in different ways, first of all - in the fields of engineering and technology. International Maritime Organization (IMO) introduced restrictions on emissions of harmful substances when burning ships' fuel and recommends wind and solar energy. Since marine wind energy requires the creation of complex technical systems, solar energy has fewer problems in its manufacture and implementation and operates when the vessel is stationary. However, marine solar energy has not been widely implemented, which requires an analysis of this problem. It's the main goal of the performed work, and the search for the most effective implementations of ship solar energy and the development of recommendations based on this analysis is its scientific novelty. Work results. It is shown that the capacity of photovoltaic solar systems of the economical class is 0.175...0.185 kW/m^2, and the annual average, taking into account sunny days, time of day, operating conditions and location, decreases to 0.02 ... 0.04 kW/m^2, which reduces possibilities of their use. For the real square of placement of ship solar batteries, a complete replacement of the main engine with them is possible only for pleasure yachts and excursion vessels. For the transport fleet, it is not possible and can be used only as an additional one, capable of replacing 1 to 5% of the main engine's power. However, this indicator is more than the capabilities of other ship systems that have reached a high level of perfection, which limits the of their efficiency growth to <1%. Conclusions. Refusal from using solar energy systems on the transport fleet is equivalent to waste. It is necessary to use all available opportunities for solar panels on ships.

1. Introduction.

The problem of decarbonization of human activity (reduction of emissions of greenhouse gases CO and CO2) is one of the main ones in the conditions of constantly growing threat of global warming. It is solved in various ways in all spheres of society, primarily in the fields of engineering and technology.

Within the framework of this problem, the transport fleet could not be left out of its solution. Therefore, the International Maritime Organization (IMO) in Annex VI of the MARPOL 73/78 Convention [1], introduced restrictions on emissions of harmful substances when using ship fuel. For this purpose, since 2009, the energy efficiency index Guidelines on the Method of Calculation of the Attained Energy Efficiency Design Index (EEDI) for New Ships has been introduced [2]. It is strictly controlled after MEPC.245(**??**) – 2014 [3].

The transport fleet consumes about 6% of the extracted oil, the combustion of which in ship engines leads to the emission of 3% of CO and CO_2 from their total world quantity [4]. This

[1]Doctor of Technical Sciences, Professor of the Department of Transport technologies and ship repair of Kherson State Maritime Academy, Ukraine. Tel. (+380) 953005804. E-mail Address: nastasenko2004@ukr.net.

[2]Doctor of Technical Sciences, Professor of the Department of Transport systems and technical service of Kherson National Technical University, Ukraine. Tel. (+380) 504947472. E-mail Address: eseu@ukr.net.

[3]Ph.D., Associate Professor of the Department of Ship technical systems and complexes of Kherson State Maritime Academy, Ukraine. Tel. (+380) 990259540. E-mail Address: m_babiy@ukr.net.

[*]Corresponding author: Mykhailo Babii. E-mail Address: M_Babiy@ukr.net.

share is small, however, unlike other options for reducing emissions, this option is technically possible at not very large costs. If the fleet switches to alternative energy and refuses oil fuel, then this will allow in the total annual need to reduce CO, CO_2 emissions by 7.4% [5] to reduce them by 3/7.4×100% ≈41%.

However, EEDI indexation solves the problem only by reducing harmful emissions of CO, CO_2. The complete transition of the transport fleet to alternative energy is a difficult future step that requires solving many technical and economic problems. Their analysis showed that in reality, it is possible only when replacing oil fuel with methanol, ammonia and hydrogen [6]. But each of these ways has its drawbacks: for methanol and ammonia, is a lower heat of combustion (20 and 18.6 MJ/kg versus 49 MJ/kg) [7], so to provide the main engine power required for the movement of the vessel, they need to be burned more. This accordingly increases the volume of fuel tanks and due to this reduces the mass of transported cargo. For ammonia and hydrogen, problems are also added: 1) their production, 2) the operation of the engine and fuel system becomes more complicated [8]. This requires modifications and testing of existing engines, which requires time and technical and economic resources.

For hydrogen (heat of combustion 58 MJ/kg), the problems of extraction are even greater, and especially – its storage and transportation, since H2 molecules are the smallest on Earth and they see through the metal of these systems [8]. But the main thing is that the combustion rate of hydrogen is 9 times higher than the combustion rate of petroleum fuels [8], which complicates the movement of pistons at the upper and lower points due to their inertia, which is caused by their large mass (the diameter of the pistons reaches up to 960 mm, and the weight is > 1 ton [9]). This leads to breakage of pistons and crank mechanisms of the engine.

Because solving these problems requires significant time and technical and economic resources. Therefore, among the main technical means of reducing CO and CO_2 emissions, IMO recommends the use of wind and solar energy [2]. An analysis of shipboard wind energy, which was presented in [10], showed that it is effective only in those areas where the average annual wind speed exceeds 10 m/s. In this case, rather complex sailing systems are used, which require significant costs for their manufacture and maintenance, and their reliability and durability are reduced.

Vessel's solar energetic has fewer problems in its production and implementation, and operates in tropical and subtropical zones, where wind systems are ineffective, due to the low average annual wind speed < 5 m/s, and then while the vessel is moored. Therefore, in this article, detailed analysis of the possibilities of the ship solar energy, which is the main goal of the work being performed. The development of recommendations for the development of ship solar energy on this basis is its scientific novelty.

The research methodology consists of a technical and economic analysis of the advantages and disadvantages of the main fuel projects on the transport fleet and the economy of the best of them on the basis of the adopted scale of criteria. The main ones are: 1) completeness of achieving the final result; 2) simplicity and reliability of the system; 3) minimal costs for production and maintenance.

2. New results of the work and their discussion

The basis is the author's work [11], which is supplemented with new information. The flow of solar energy reaching the Earth is 1.2·1011 MW [12, 13], which significantly exceeds the energy resource of other main ship alternative sources – wind and waves, since wind is a product of the difference in heating of the air by the Sun, and waves – are a product of the action of the wind. However, this energy is scattered over the entire surface of the Earth, which is turned to the Sun and is 1.36 kW/m^2 [13]. At the same time, the real solar irradiation of the Earth's surface depends on a much larger number of factors:

1. Seasons (since the Earth's axis is tilted 67.4° to its orbit around the Sun).
2. Latitude and longitude of the area.
3. Geographical and climatic features of the area (the number of sunny days, which is more or less the same over the oceans).
4. State of the atmosphere (over the oceans its pollution is minimal).
5. Location and inclination of the radiation receiver relative to the Sun's rays.
6. Time of day, etc.

The main regulatory indicators of solar energy: the peak power of solar energy is the highest at noon and at the equator, it is 1.25 kW/m^2, instead of 1.36 kW/m^2, since ≈ 10% is absorbed by the atmosphere. However, the efficiency of modern photovoltaic systems of the economy class based on widely used silicon is 10. . . 18%, which accordingly reduces the power of the initial radiation. Due to other geographical, natural and daily factors, it is reduced to 0.02 – 0.04 kW/m^2.[11].

There are known developments of photovoltaic cells with higher efficiency due to more effective semiconductor materials. However, they are much more expensive than silicon, and their widespread production requires significant time, technical equipment and a natural raw material base, which requires large investments in their development. Only the replacement of polished silicon with cast silicon made its widespread use possible. Therefore, in the next 10 – 15 years, one should only count on power indicators of 0.02 – 0.04 kW/m^2, which is an important factor in the use of such systems in the transport fleet. For their widespread implementation, a detailed analysis of the efficiency of ship solar systems is required, which is performed further in this work.

The total solar radiation of any objects on the Earth's surface consists of 3 component quantities.

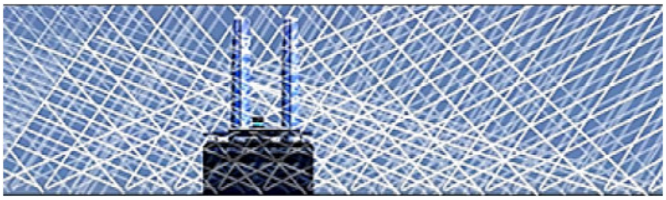
1) Direct solar radiation in the form of parallel rays that arrive from the Sun at the receiving site.

2) Diffuse or molecular scattering of sunlight by atmospheric gases and aerosols.

3) Reflection of rays by the surrounding surface, which for seas and oceans where there are waves can reach 10%.

Their effect on the vessel is shown in Fig. 1 [14].

Figure 1: Effect of direct and reflected light rays on the vessel.



Source: www.walleniuswilhelmsen.com.

During the day, the inclination of the Sun changes, which affects the power and efficiency of the system. Rotating solar systems (trackers) - rotate in the direction of the Sun, which increases their efficiency (fig. 2) [15].

Figure 2: Rotating solar panels for tracking the tilt of the Sun.

Source: www.solargarden.com.ua.

However, the cost of such systems increases significantly, and reliability - a very important factor for ships operating in storms - decreases. As with sail systems, the main problem for solar ship trackers systems is the need for their constant maintenance. When minimizing the number of crew members of transport ships to 16 – 20 people, who already have their main and additional duties, 1 more crew member is needed with the costs of maintaining him. For the ship owner, this option is difficult.

The main problem for solar energy on board ships is the ratio of the power they can generate to the space they occupy.

The solar power plant near the urban settlement of Lazurnoe (Kherson region, Ukraine) has a peak power of 27 MW with a solar panel area of 9 km^2. [16]. There is no such area on any ship.

The internal combustion marine engine WARTSILA 7RT-flex 84T-D with a 24-hour capacity of 29.4 MW, shown against its background, allows us to assess these ratios. (Fig. 3) [16].

Figure 3: Dimensional comparison of a solar system and a ship engine with similar power.

Source: www.khersonline.net.

There are with a ship's engine capacity of 80 MW in 14 cylinders. There are 2 such engines on PostPanamax container ships, of which there are already quite a lot.

The maximum power of marine solar power is provided by the container ship project "NYK Super Eco Ship 2030" (company of Nippon Yusen Kaisha, Japan) [18], in which solar panels are installed on the covers that cover the containers (Fig. 4).

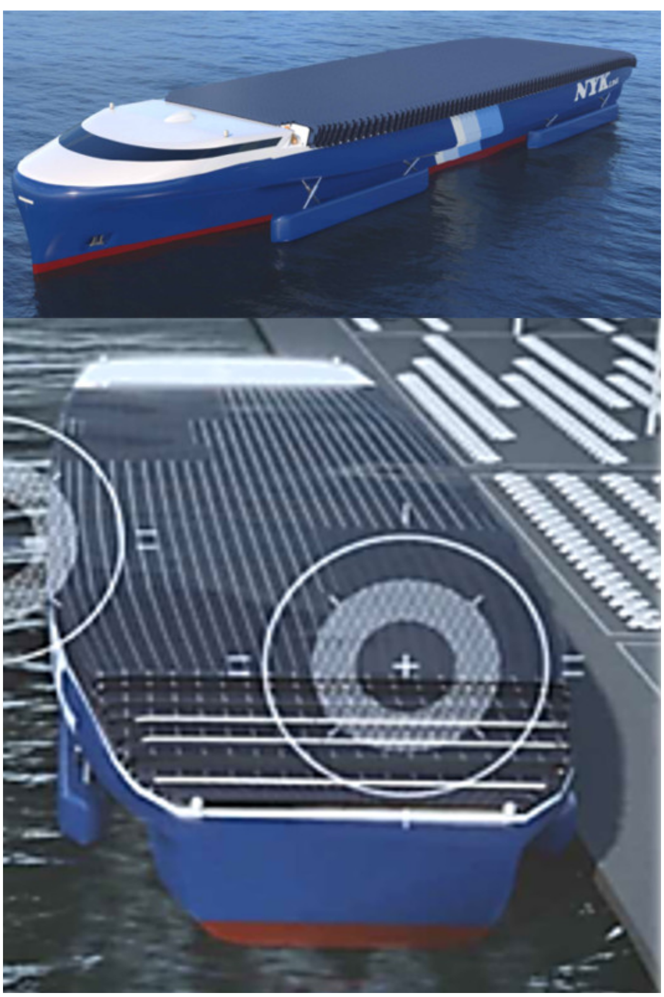
Figure 4: Project of a container ship NYK company with solar panels that cover the containers.

Source: www.no.emb-japan.go.jp.

However, when loading and unloading containers, the lids must be removed and placed somewhere. There is usually no such place on the berths. Therefore, they are stacked on top of each other on a ship, which does not exclude their damage. The lids have additional weight to the solar panels, which reduces the weight of cargo transportation. The power in this version does not exceed 20% of the power of the main engine, so ship solar energy can only be an additional source.

This project has been developed for Car Carrier Vessel "NYK Super Eco Ship 2050" [19]. Solar Power: assumed energy conversion efficiency 45% due to new materials, about 9,000 square meters of solar panels on the roof of the superstructure (top deck) covers 15% of total energy demand (Fig. 5). However, the current efficiency rate of economy-class (cast quartz) panels is 18%, and 45% is still to be achieved when developing new economy-class technologies.

Figure 5: Project Car Carrier Vessel NYK with solar panels on the roof of the vessel superstructure.



Source: www.nyk.com.

The new 2050 project has "lost" the sails that the 2030 project had, since their effectiveness was considered doubtful (at real ship speeds of 14-20 knots, or 7-10 m/s, the wind does not catch up with the ship). The sails are effective only in latitudes 40-50° [10].

The closest to the "NYK Super Eco Ship 2030" project is the ferry project "E/S Orcelle-2005" by the shipbuilding company Wallenius Wilhelmsen (Sweden-Norway). It is more realistic in execution, since it does not have removable covers, solar panels are installed on the roof, sides of the hull and on the sails (Fig. 6) [14].

Figure 6: Ferry project «E/S Orcelle-2005».

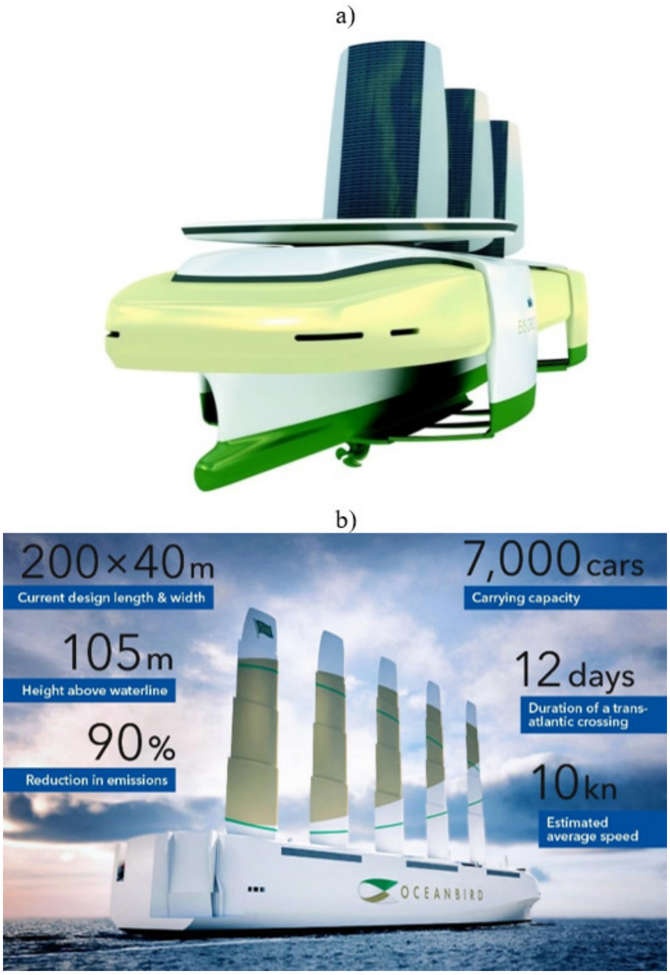
Source: www.walleniuswilhelmsen.com.

However, the efficiency of solar panels on the sides of the ship's hull is only 25% of that of the panels on the roof, even with the additional use of 10% of the energy from the sun's rays reflected by the waves. Therefore, their profitability is low, which ship owners did not like.

In the new project "E/S Orcelle-2025" the company has abandoned solar panels on the roof and sides of the superstructure, keeping them only on the hard lifting sails, which do not have the ability to turn [20]. However, the efficiency of such solar batteries has deteriorated sharply, since they are fully effective only when the ship is moving in the direction to the sun's rays and do not work in the other 3 directions. In the new project, the "E/S Orcelle-2030" does not have solar panels at all [21], which reduces the cost of the ship, but leads to a loss of an average of 240 kW/h of electrical capacity, which would allow reducing CO and CO_2 emissions. Therefore, it is recommended to return to the 2005 project. Project "E/S Orcelle-2025" and "E/S Orcelle-2030" are shown in Fig. 7.

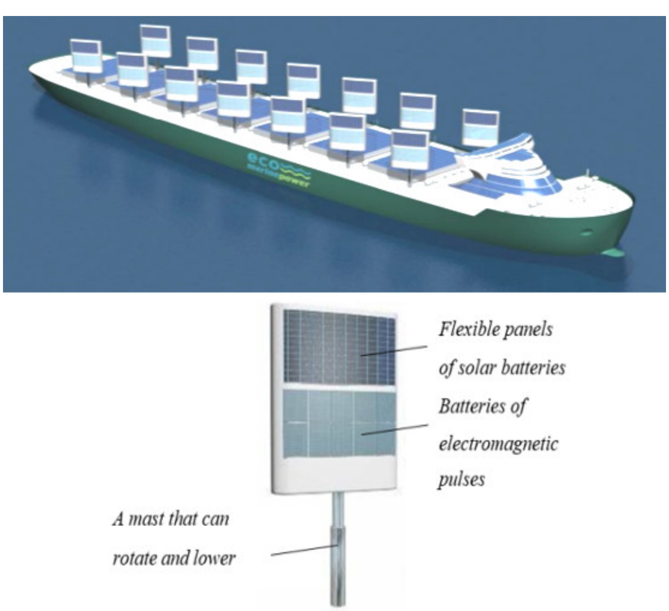
More preferable is project "Eco Marine Power Wind-Solar Ship-2025" of the company Eco Marine Power, (Fuluoka, Japan) [22], with rotating rigid sails, which are equipped with solar panels on 2 sides. In new projects of such a vessel, solar panels are installed not only on the sails, but also on the hatch covers and, on the superstructures, which increases the energy generated to 6. . . 10% of the power of the vessel's main engine. In addition, the panels have sections for operation at night from infrared rays (Fig. 8).

Figure 7: Ship projects “E/S Orcelle-2025” (a) and “E/S Orcelle-2030” (b).



Source: www.dnv.com/expert-story.

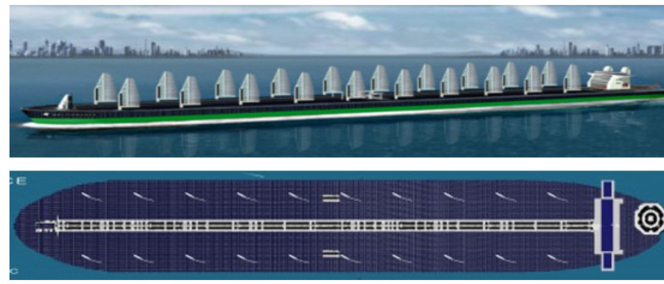
Figure 8: Project of the dry cargo ship “Eco Marine Power Wind-Solar Ship-2025” with solar panels on rotating masts.



Source: www.ecomarinepower.com.

Sauter Carbon Offset Design (SCOD) Swiss Confederation, in 2011 have presented their Green vessel project Deliverance, it’s DynaWing Solar Hybrid Supertanker that qualifies Post Panamax Vessel (Fig. 9) [23].

Figure 9: The DynaWing Solar Hybrid tanker project with solar panels on the deck.



Source: www.charterworld.com.

It has solar panels installed on the deck, which provides 10...12% fuel savings. However, the problem is the safety of using such panels on a fire-hazardous vessel. In addition, in the tropics and subtropics, the deck of tankers is doused with sea water to cool it, which is not a favorable factor for solar panels.

The analysis shows that for all types of transport fleet vessels, solar energy can save no more than 10...20% of fuel with significant modification of the vessel, which leads to its increased cost and complication of maintenance. A more realistic indicator is 1...5%, so it can be used only as an additional factor.

However, the 66m Emax E-Volution Solar Hybrid Sailing yacht project is known, of the NedShip (USA) company in 2011, which, according to Sauter Carbon Offset design, allows you to completely eliminate the oil engine and reach speeds of up to 28 knots, with an average cruising speed of 14 knots (Fig. 10) [24].

Figure 10: The E-Volution Solar Hybrid Sailing yacht project, in which diesel engines are replaced by electric motors.

Source: www.charterworld.com.

The source of 2 MW of energy is 5 rigid sails about 50 m high with sections of solar panels applied to them. Another 3

MW is provided by lithium batteries. However, the masts make loading and unloading cargo difficult, and at such a height, the vessel tilts and rolls due to the wind. In addition, it is unclear whether the yacht will withstand a storm, in which the sails are turned edgewise to the direction of the wind.

It should be taken into account that a storm, in which the wind reaches a speed of > 21 m/s, and the waves are > 5 m high, is a serious test for any sailing systems. It is recommended that all vessels avoid storm zones, but there are situations when this cannot be done. In this case, an important factor is the strength of the sailing systems, an example of which is shown by the heel of the yacht "Maltese Falcon" (Italy) and the size of its masts, which at the base exceed 1 m (Fig. 11) [25]. This leads to additional weight on sail systems and costs for particularly strong materials.

Figure 11: The effect of the wind on the yacht "Maltese Falcon" and the masts that withstand this effect.

Source: www.myskillsconnect.com.

It is necessary to take into account the effect of storm winds when designing all masts with solar panels.

First real projects of "pure" shipboard solar systems – it's the catamaran "Planet Solar Turanor", was built in 2009 by the company Planet Solarc (Switzerland-Germany) [26].

The batteries are manually moved to increase the area. There are automatic systems, but they are expensive and their reliability decreases. The surface area of the batteries is 500 m^2 with 38 thousand photovoltaic panels, which provided a speed of 7.5 knots from 2 electric motors of 85 kW. The length of the vessel is 31 m, the working width is 32 m, the water capacity is 85 tons (Fig. 12).

Figure 12: Catamaran "Planet Solar Turanor" with sliding solar panels.

Source: www.solarnavigator.net.

The batteries of catamaran are manually moved to increase the area. There are automatic systems, but they are expensive and their reliability decreases. Currently, mechanisms have already been created to perform such an action, but they increase the cost of the ship's solar system and reduce its reliability.

For real vessels, the average speed is 15 knots, but for vessels of even a small tonnage of 8.5 thousand tons, an increase in peak power to 8.5 MW is required, which requires an area of 75×660 m^2. This is 6 football fields of 75×110 m^2, which cannot be placed on the hull of such a vessel. You can build a flyover over the hull, but it will be blown away at the first strong wind.

Test routes of the catamaran "Planet Solar Turanor" in 2009-2010 is shown in fig. 13.

Figure 13: Round-the-world trip made by the catamaran "Planet Solar Turanor" in 2009-2010.

Source: www.solarnavigator.net.

The swimming zone is the tropics and subtropics, where the action of the Sun is maximum, and the average annual wind is 5 m/s and storms occur rarely. Restraining factors: 1) the price of solar energy is 3 times higher than the price of petroleum fuel; 2) the high price of the systems, therefore, a reduction in the cost of batteries is required.

However, the cost of the catamaran "Planet Solar Turanor" is very high - 12 million €. To reduce it, the company "Solarwave" (Switzerland) and the Turkish shipbuilding company "Nedship" are building 62-foot yachts "Solar-wave 62" worth ≈ 2 million €. To do this, the area of solar panels was reduced to 80 m^2, which reduced the peak power of the yacht to 15 kW/h and the speed to 7 knots. In addition, for domestic needs, either additional solar panels or a reduction in the power supply of the main electric motors are required [27].

A similar option is available on the catamaran "Chloe" (Holland) [28] and catamarans from other companies. Both of these catamarans are shown in Fig. 14.

Figure 14: Catamarans "Solarwave" and "Chloe" with solar batteries.

Source: www.yachtingworld.com.

To increase the area of solar panels, the yachts have a catamaran architecture.

In addition to cruising yachts for millionaires, yachts are being built for day trips along the coast for tourists who rent a vessel and crew. Projects have been developed for public transport vessels in cities with rivers to replace road transport, they have an average speed of 7 knots (Fig. 15) [29].

Figure 15: Solar river "bus" for 40 passengers, project of company «Eco Marine Power».

Source: www.ecomarinepower.com.

The most widespread are combined versions of yachts that use solar and wind energy systems.

To increase the speed of cruising yachts, they are additionally equipped with sails, including the Sky Sails type, which are effective for slow-moving vessels (Fig. 16). [30, 31]. The speed of yachts has increased from 7 to 10 knots. In this case, electrical power has been freed up for domestic needs.

Figure 16: Catamarans with a hybrid system consisting of a Sky Sails type sail and solar batteries.

Source: www.skysails-group.com.

However, installing and removing a Sky Sails type sail is a relatively complicated process. Therefore, a more preferable option is to equip yachts with a flexible mast sail, for example, ZEN company (Zero Emision Nautic Ltd Incorporated, Malta), NASA developer, which rises and lowers automatically (Fig. 17) [32].

Figure 17: Hybrid catamaran yacht with automatic flexible mast sail.

Source: www.superyachtfan.com.

In parking mode and in calm weather, retractable solar panels can be used to increase energy capacity (Fig. 18) [33, 34].

Figure 18: Yacht with retractable solar panels.

Source: www.en.sunware.solar.

Known variants of high-speed yachts, for example, Ocean Supremacy, project Sauter Carbon Offset Design (SCOD) [35]. Their cost is a secondary factor since such vessels are built for the very rich clients.

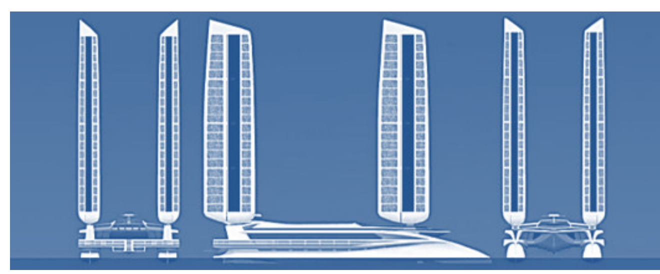
For this, in addition to wind and solar systems, they are equipped with internal combustion engines, which allow speeds of up to 52 knots. They are also recognized as backup systems for movement in emergency cases (Fig 19) [36].

Figure 19: Sauter Carbon Offset Design of a high-speed yacht with solar panels and an internal combustion engine.

Source: www.charterworld.com.

The sailing version of the yacht is shown in Fig. 20. It has the same disadvantages of giant masts that were discussed earlier.

Figure 20: Sailing version of the Sauter Design yacht.



Source: www.superyachttimes.com.

It should be noted that none of the analyzed transport fleet projects have been implemented by 2025. The only transport vessel in the world that has a partial roof covering with solar panels is the car carrier "AURIGA LEADER" (2008) NYK (Japan), which is shown in Fig. 21 [37].

Figure 21: Car carrier with solar panels on the roof of the superstructure, NYK company.

Source: www.shipshub.com.

The real efficiency of marine solar energy is demonstrated by the fact that 328 panels cover only 1/6 of the vessel's deck and generate only 40 kW of energy, which covers only 7% of its domestic needs. However, covering the entire deck will provide 240 kW and 42% of domestic needs. This is less than 1% of the capacity of the vessel's main engine, but other improvements will have a smaller effect, since the engine has already reached its perfection.

The analysis shows that the economic effect of using solar energy systems on transport fleet vessels is insignificant, but it is always there. If for shipowners it manifests itself through a long payback period of projects (5-7 years [38]), then for society there is always a gain due to the saving of ship fuel, which results in a reduction in CO and CO_2 gas emissions. Therefore, their use is always advisable, even when generating a minimum amount of electrical energy.

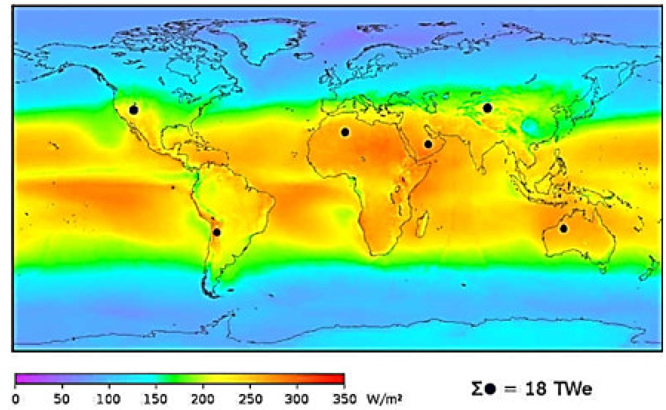
Moreover, all vessels that have a large enough surface to be covered with solar panels can be considered promising. The first of these are vessels for transporting cars and covered ferries, but there are few such ships. Tankers and gas carriers can only be equipped with them after the safety issue has been resolved. All other vessels can be equipped sun systems in zones free for this, which limits the possibilities to 1 ... 5% of the main engine power (Fig. 22). At the same time, the estimated 15-20% fuel savings in the projects [18, 19] are associated with the expected increase in the efficiency of solar batteries from 18 to 45%, however, it is unclear whether this problem will be solved by 2050.

Figure 22: Promising ships for equipping with solar photovoltaic systems.

Source: Authors.

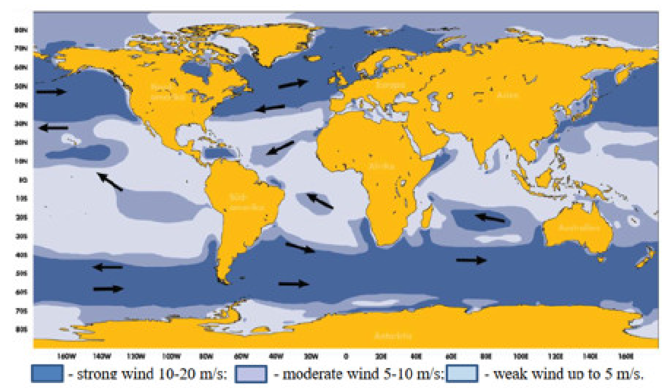
Solar systems provide a stable effect in tropical and subtropical zones where the operation of marine wind systems is ineffective (Fig. 23 [39] and 24 [40]).

Figure 23: Map of the intensity of solar radiation of the Earth.



Source: www.alterenergy.info.

Figure 24: Stable wind currents in the world ocean.



Source: www.earth.nullschool.net.

The analysis carried out in this paper confirms the need to implement solar energy on the transport fleet. The preferred option is to use energy for domestic needs. So far, the project [19] is the best, with a declared solar panel area of 9000 m^2, the actual average daily production of electrical energy could be about 240 kWh, and the peak power in the equatorial region could be about 1.5 MWh. If a row of rotating sails with solar panels [22] are installed on the sides of the roof, which are effective in the morning and evening, this will create 30% additional energy generation capacity, without taking into account the wind force. To reduce costs, these panels can be single-sided. However, it should be taken into account that the placement of heavy solar panels on the highest deck of the vessel leads to an unfavorable change in its metacenter. In addition, the panels are covered with salts from the evaporation of sea water and become dirty in the port where bulk materials are loaded. Therefore, they require periodic washing, for which they must be equipped with washing systems, which further increases the cost of the projects.

Conclusions.

1. Effect of using solar energy systems on transport fleet vessels is insignificant, but it is always there, for society his results in a reduction in CO and CO_2 gas emissions, therefore, their use is always advisable, even when generating a minimum amount of electrical energy.

2. For real areas of ship solar panels, complete replacement of the main engine of the ship with them is possible only for pleasure yachts and excursion ships during daylight hours, with their speed limited to 7 knots. To achieve higher vessel speeds, additional energy sources are needed, such as lithium batteries, which are charged while the vessel is at rest.

3. Real areas for placing solar panels in the transport fleet are capable of replacing from 1 to 5% of the power of the main engine, therefore they are additional systems. However, this is more than the capabilities of other ship systems that have reached a high level of perfection, which limits the growth of their efficiency < 1%.

4. Failure to use solar energy systems in the transport fleet is tantamount to waste, since solar energy does not require costs for its acquisition, and saving the main engine power by 1...5% adequately reduces greenhouse gas emissions CO, CO_2, which provides an additional effect for the entire society.

5. Despite the long payback period of solar energy systems for the transport fleet (5-7 years), shipowners need to invest in such projects, even with minimal profit, since they are effective in tropical and subtropical zones, where wind ship systems are ineffective. Their main effect is to reduce CO and CO_2 emissions; therefore, it is necessary to change the psychology of thinking, both in the transport fleet and in other areas of life and activity of society. The preferred option for the ships is to use energy for domestic needs.

6. Ship owners should not be left alone with additional expenses, so it is necessary to develop a system of incentives for them at the level of state and public programs such as "green energy" or tax reduction.

Conflict of interest.

The work was carried out by the authors on their own initiative, based on their own works [8, 10, 11, 38] and open literary sources, the publication of which does not require permission. There is no conflict of interest.

References.

[1] Annex VI of the MARPOL 73/78: https://homeport.uscg-.mil/Lists/Content/Attachments/891/Brief%20on%20MARPOL-%20Annex%20VI%20(revised)_.pdf.

[2] Attained Energy Efficiency Design Index (EEDI) MEPC-.245(66) – 2014: https://wwwcdn.imo.org/localresources/en/ -KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/-MEPC.245(66).pdf.

[3] https://wwwcdn.imo.org/localresources/en/Knowledge-Centre/IndexofIMOResolutions/MEPCDocuments/MEPC.364-%2879%29.pdf.

[4] https://web.archive.org/web/20211024161949/ https://-www.ng.ru/ng_energiya/2021-10-11/13_8274_methanol.html.

[5] COP 21, from 30 November to 11 December 2015, in Paris, France : https://unfccc.int/event/cop-21.

[6] https://www.hydrogeninsight.com/transport/methanol-a-mmonia-and-hydrogen-are-not-viable-marine-fuels-in-the-short-term-lobby-group/2-1-1586915?zephr_sso_ott=J5aPpb.

[7] Mohamed Djermouni, Ahmed Ouadha (2023). Thermodynamic analysis of methanol, ammonia, and hydrogen as alternative fuels in HCCI engines. International Journal of Thermofluids Volume 19, August 2023, 100372 https://doi.org/10.-1016/j.ijft.2023.100372.

[8] Nastasenko V.A., Protsenko V.A., Babiy M.V., Palagniy V.I. (2020). Vodorod kak perspektivnoye sudovoye toplivo i problemy bezopasnosti yego polucheniya, khraneniya, transportirovki i primeneniya. [Hydrogen as a promising marine fuel and problems of safety of its production, storage, transportation and use] Bezpeka zhyttyediyal'nosti na transporti ta vyrobnytstvi – osvita, nauka, praktyka. Materialy VII Mizhnar. nauk.-praktych. konf. – Kherson, KHDMA, 08-10 veresnya 2020. – S. 348-35 (In Russian).

[9] Wartsila-Sulzer-RTA96-C: https://web.archive.org/web/-20110621012337/http://besttopauto.net/wartsila-sulzer-rta96-c-samyj-moshhnyj-i-bolshoj-dizelnyj-dvigatel/.

[10] Valentyn Nastasenko, Protsenko Vladyslav, Babii Mykhailo (2023). Modern development of ship wind systems within the new rating of Top-7 projects / Journal of Maritime Research. Vol 20. No. 2 (2023) pp 77–88 ISSN: 1697-4040.

[11] Valentyn Nastasenko. (2022). Solar Electrical Energy Systems, Analysis of the Prospects and Possibilities of their Use in the Transportation Fleet. / Peer Review Journal of Solar & Photoenergy Systems 2(2). PRSP. 000533. 2022.

[12] Gorodov RV (2009) Non-traditional and renewable energy sources. In: Gorodov RV, Grubin VE, Matveev AS (Eds.), (1st edn), Publishing House of the Tomsk Polytechnic University, Tomsk, Russia, p. 294. (In Russian).

[13] Ageyev VA (2004) Non-traditional and renewable energy sources (course of lectures), Publishing House Leningrad, University Department of Heat and Power Systems, Saint Petersburg, Russia, pp. 343 (In Russian).

[14] Wallenius Wilhelmsen https://www.solarnavigator.net/-solar_transporter _orcelle.htm.

[15] Solar Panel Trackers: https://www.solargarden.com.ua-/ru/trekery-dlya-solnechnyh-panelej-konstruktsyya-pryntsyp-raboty-effektyvnost/.

[16] Lazurnoye (power plant) (2019). https://khersonline.net-/novosti/ekonomika/126235-na-hersonschine-postroili-pervye--dve-ocheredi-solnechnoy-elektrostancii.html.

[17] WARTSILA 7RT-flex 84T-D: https://engine.od.ua/ufiles-/Wartsila-20085.pdf.

[18] NYK Super Eco Ship 2030 (Japan) (2010). https://www-.no.emb-japan.go.jp/Japanese/KouhoBunka/NTNUHoriuchi.pdf.

[19] NYK Super Eco Ship 2050: https://www.nyk.com/english/esg/pdf/ecoship2050_en.pdf.

[20] E/S Orcelle project 2025: https://www.yumpu.com/en-/document/view/34127949/e-s-orcelle-a-concept-martins-marine-engineering-page.

[21] Oceanbird of the Wallenius company: https://www.dnv.-com/expert-story/maritime-impact/ Oceanbird-ro-ro-Embarking-on-a-new-era-of-wind-propulsion.html.

[22] Eco Marine Power Wind-Solar Ship: https://www.ecomarinepower.com/en/products/8-products-services-and-consulting/-15-wind-and-solar-marine-power.

[23] Post Panamax tanker: https://www.charterworld.com/-news/emax-deliverance-motor-yacht-sauter-carbon-offset-design-dynawing-solar-hybrid-supertanker/emax-deliverence-vlcc-dynawing-post-panamax-supertanker.

[24] 66m Emax E Solar Hybrid Schooner: https://www.charterworld.com/news/66m-emax-evolution-solar-hybrid-schooner-sauter-carbon-offset-design-fastest-greenest-superyacht.

[25] Yacht "Maltese Falcon": https://myskillsconnect.com-/vodnyj-transport/41858-sovremennye-parusnye-suda-59-foto.-html.

[26] Catamaran "Planet Solar Turanor" https://www.youtube.com/watch?v=7ZlhNDqARFw&ab_channel=MercatorInfogr.

[27] Solar-wave 62: https://ru.pinterest.com/pin/74063110-1239174247/.

28. Catamaran "Chloe" (Holland) on solar batteries: https:-//www.yachtingworld.com/practical-cruising/how-to-prepare-b-luewater-sailing-126413.

[29] Eco Marine Power Wind-Solar Ship: http://www.ecomarinepower,com/en/energysail.

[30] SkySails system: https://skysails-group.com/pdf-assets-/SkySailsMarine_Brochure_EN.pdf.

[31] Airseas: https://www.google.com/search?client=avast-a-1&q=airseas+kites&oq=Airseas&aqs=avast.3.69i57j0l7.301-85549j0j15&ie=UTF-8.

[32] ZEN Yach: https://itboat.com/ru/models/16453-50#model-21/.

[33] https://interparus.com/ua/wedgeline-hybrid-77-preview/.

[34] Folding solar panels: https:// https://en.sunware.solar/produkte/solarmodule.

[35] Ocean Supremacy: https://www.charterworld.com/news-/42m-superyacht-ocean-supremacy-scod-largest-greenest-10-fastest-superyachts-world.

[36] https://www.charterworld.com/news/43m-ecofriendly-catamaran-yacht-formula-43-sauter-carbon-offset-design.

[37] AURIGA LEADER: https://shipshub.com/ru/article/1-745-2.html.

[38] Nastasenko V.A. (2018). Sravnitel'nyy tekhniko-ekonomicheskiy analiz ekspluatatsii sudovykh parusnykh i vetryanykh elektrogeneratornykh sistem. [Comparative technical and economic analysis of the operation of ship sail and wind power generator systems.] /Rozvitok metodív upravlínnya ta gospodaryuvannya na transportí: Zb. nauk. prats'. – Vip. 4(65). – Odesa: ONMU. 2018 s. 73-96. DOI: 10.31375/2226-1915-2018-4-73-96 (In Russian).

[39] World map of solar insolation. [Electronic resource]. http://www.alterenergy.info/index.php/eto-interesno/karty-solnechnogo-izlucheniya/1860-mirovaya-karta-solnechnoj-insolyatsii.

[40] Wind flows in the world's oceans: https://earth.nullschool.net.