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Review Article

INVESTIGATION OF THE USABILITY OF RENEWABLE ENERGY IN MARITIME TRANSPORTATION

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ABSTRACT
One of the most important actors of maritime transport is cargo ships where cargo is transported. Nowadays, the expansion of the maritime trade volume with increasing acceleration, the increase in the size and quantity of ships in the world's merchant navy fleet cause transportation costs to decrease per ton while to bring some negative effects such as air pollution. The major cause of ship-source air pollution is the conventional fuel used in propulsion systems. As of 2006, serious steps are being taken in the context of air pollution prevention measures that have been on the agenda in the sector on a global scale. In this study, recent academic literature conducted on this subject reviewed in recent years, renewable energy and other fuel types that can be used in efficiency equivalent to conventional fuel were evaluated. As a result of this thematic review, although the ship projects carried out with renewable energy in the project phase are exciting, the most powerful alternative in the short term seems liquefied natural gas (LNG) which is not accepted as renewable but found to be successful in terms of emissions. It can be used in ships with tonnage nearby coastal voyages, while in the offshore vessels which constitute the main emission problem; renewable energy is evaluated within the scope of additional measures that increase efficiency in the short term. In addition, as a fuel alternative, hydrogen is a candidate for future ship fuel in the medium and long term.

Keywords: *Renewable Energy, Greenhouse Gas, Maritime, Ship, LNG*

1. INTRODUCTION

Since maritime transportation is a more convenient transportation method in terms of cost and efficiency than other transportation modes, therefore, it is the most used mode of transportation and its place in the sustainable global economy is very valuable. In the maritime sector, the usual expectation of stakeholders is that transport must be cheaper, faster and more sustainable. However, international maritime transport is a global system in which safe, fast and green transport efforts are interconnected in different ways without a central decision-making mechanism. In spite of the rapid development of technology such as satellite monitoring systems, incinerators, economizers, scrubbers, sewage and ballast water treatment units etc., this situation causes many serious problems such as marine pollution due to ship pollution, shipborne transport of biodiversity degrading species, fluctuation in fuel prices, changes in international trade routes, cyber-attacks, data theft and geopolitical stresses (IUMI, 2018). Another of these problems is "ship-based air pollution which is our research topic.

On a global basis, maritime trade volume has increased 2.5 times in the last 40 years, population density has increased by about 90% and energy consumption has increased by about 170% (Lindstad et al., 2015). This difference in acceleration results in the global warming and air pollution of harmful gases released into the atmosphere from the chimneys of the global maritime trade fleet, consisting of around 100,000 ships of various sizes. As a precautionary measure, reducing the volume of maritime trade is not an attractive option, and the idea of abandoning the conventional fuel used in the main power units of the ship, propulsion system during the execution of the transport business, has led to controversy around the world. The aim of this study is to find out which systems produce less pollution for maritime transportation such as solar energy, wind power, hydrogen, biofuels and liquefied petroleum gas.

2. VIEW OF INTERNATIONAL ORGANIZATIONS

IMO (International Maritime Organization), which is a member of the United Nations, directs the sector with approximately 98% of the global fleet in the areas of safety, security, pollution prevention, marine law, shipbuilding industry and technology. IMO's mission can be summarized as safe and secure life on board, pollution prevention and efficient transport (IMO, 2018). Regarding the emission problem mentioned in the above paragraph, IMO aims to become an international authority in the global maritime trade and industry.

One of the current issues that IMO has discussed and guided the sector in environmental pollution prevention committees is the use of low-emission alternative energy sources, including renewable energy types, in ship propulsion systems. In the area of maritime transport, the use of renewable energy sources in ship propulsion / propulsion systems, greenhouse gas emissions, which have become a serious problem for humanity, and global warming problems are one of the prescribed ways to solve these problems, although a clear solution strategy for ship-based air pollution is not yet developed (Bouman et al., 2017).

Although maritime transport is more economical per unit ton and more efficient at long distance than other modes; GHG (Green House Gas) emissions from ships account for 2.2 percent of the total emissions, with an increase in international cargo volumes, which is expected to increase by about 50 percent to 250 percent by 2050 (IMO, 2018). According to another scenario, Cames et al., are expecting emission rate to increase to 17 percent in 2050. In the same study, it is stated that the technical and operational measures to be taken regarding energy efficiency will contribute to the decrease of the increase acceleration of the amount of greenhouse gas emissions (Cames et al., 2015). IMO aims to reduce emissions by 20% by 2020 and by 50% by 2050 through measures taken globally (Hughes, 2016).

Therefore, IMO wants to contribute to global preventive activities by using an effective action plan such as focusing on greenhouse gas emissions from international maritime transport (IMO, 2018). The Maritime Environment Protection Committe (MEPC), a sub-committee of the IMO, first developed a Data Collection System for Fuel Oil Consumption of Ships that would provide the necessary discussion environment for a transparent and inclusive policy. Within the scope of the system, vessels of 5,000 gross tonnage or more, which are responsible for 85% of carbon dioxide emissions, are required to report their annual reports on fuel to the local authorities. The Environmental Ship Index (ESI), which includes consumption and transport parameters, is used in this reporting. The data collected according to ESI are sent to the common Ship Fuel Consumption Database. Information such as the index and the technical data of the ship, the process covered, the fuel expenditure, the transported cargo and the Energy Efficiency Design Index (EEDI), if regularly calculated by ships, are recorded in the "Energy Efficiency Management Plan (EEMP), which is required to be present on the ships. The relevant IMO MEPC 22A regulation entered into force on 1 March 2018 and became compulsory for all vessels of 5,000 gross tonnage and above. In addition, the IMO MEPC 73 committee meeting minutes requires that the "fuel oil" sulfur ratio used as a fuel in ships be below 0.50% by January 01, 2020, except for the emission control zones as seen in Table 1 (Hughes, 2016; IMO, 2018d). The establishment of emission-controlled zones under the umbrella of IMO-MEPC and the gradual implementation of the sanctions have attracted the experts, academics and investors of the sector.

Large vessels such as Post-Panamax and oversized tankers-container ships will install scrubbers on their funnels at the cost of $1-5 million. Small vessels will have to switch to the bunker called low sulfur gas oil with doubling the cost from "fuel oil high sulfur". The new rule will directly affect the carriers (ship owner and charterer) while indirectly to the shipper and the loaders. For example, since the "Bunker Adjustment Factor" has a positive impact on freight rate, then it will affect the customer through the freight rate. Since the new rules will bring new problems, only a permanent solution can contribute to sustainability. The issue can be summarized from a commercial point of view like this. However, since environmental pollution is the source of the problem, maritime states (IMO members) have rules for the benefit of the society from an environmental point of view, even if they are against them commercially.

Table 1: Sulfur emission (SOx) upper limit values of ships according to navigation area (IMO, 2019).

SECA (SULPHUR EMISSION CONTROL AREA)	
Before 1 July 2010	%1.50 m/m
Between 1 July 2010 and 1 January 2015	%1.00 m/m
1 January 2015	%0.10 m/m
OTHER AREAS OUTSIDE OF SECA	
Before 1 January 2012	%4.50 m/m
Between 1 January 2012 and 1 January 2020	%3.50 m/m
From 1 January 2020	*%0.50 m/m*

3. AIM AND SCOPE OF THE RESEARCH

The research topic of this study is to investigate the feasibility of fuel types and energy sources, which may be an alternative to conventional fuel, as discussed in the solution of ship-based air pollution, in ship propulsion systems. In addition, it is aimed to evaluate the approaches of academic studies on conventional fuels and alternatives in terms of technical and economic aspects and thus to make a sectoral prediction. In addition, this issue is currently being discussed and the fact that it is not found in the literature sufficiently shows the importance of the research.

4. METHODOLOGY

The data of the study was obtained from "Science Direct" and "Scopus" international databases with the keywords of "Ship", "Renewable Energy", "Maritime", "Greenhouse Gas", "LNG. The search covers the period between 2005 and 2019, when the MARPOL 73/78 Annex VI on "Prevention of Air Pollution from Ships" came into force. 526 studies listed as a result of the search, upon preliminary assessment, specifically, technical and operational strategies developed to prevent greenhouse gas emissions, as well as 43 scientific studies on renewable energy sources to replace fossil fuels and additionally, greenhouse gas studies published by the International Maritime Organization (IMO) GHG Studies. Within the scope of this study, academic studies related to alternative energy sources that can be used in ships are grouped into hydrogen, solar energy, wind energy, biofuels and LNG (not renewable) according to the type of energy that they directly or indirectly emphasize. Other studies that are subject to emission reduction are tried to be excluded from the scope of the research.

Table 2: Classification of literature covered by the alternative energy sources

Alternative Energy Source	Studies
Hydrogen	(Cabrera, Lund and Carta, 2018), (Faber et al, 2009), (Michalski et al., 2018), (Freese, 2017), (Connolly et al., 2014), (Matulić, 2019), (Cames et al., 2015), (Lindstad, 2014), (Tronstad, 2017), (IPCC, 2006), (El-Gohary, 2013), (Clean North Sea Shipping Project, 2014), (Faber et al., 2009), (Tanç et al., 2018), (Breyer et al., 2017)
Wind Power	(Cabrera et al., 2018), (Jain and Jain, 2017), (Algarín, 2017), (Rehmatulla, 2017), (Haas et al., 2019), (Faber et al, 2009), (Bouman et al., 2017), (Haifeng Wang et al., 2013), (Michalski et al., 2018), (Freese, 2017), (Technical, 2012), (Zhang et al., 2014), (Rehmatulla et al., 2017), (Mander, 2017), (Connolly et al., 2014)
Alternative Energy Source	Studies
Solar	(Cabrera et al., 2018), (Jain and Jain, 2017), (Algarín et al., 2017), (Rehmatulla et al., 2017), (Ertay et al., 2013), (Burke and Stephens, 2018), (Haas et al., 2019), (Faber et al., 2009), (Blazquez et al., 2018), (Bouman et al., 2017), (Pata, 2018), (Wang et al., 2013), (Technical, 2012), (IMarEST and Colfax, 2015a), (Algarín et al., 2017), (Hua et al., 2019), (Xu, 2017), (García-Olivares et al., 2018)
Bio-fuels	(Tronstad et al., 2017), (Jain and Jain, 2017), (IPCC, 2006), (Rehmatulla et al., 2017), (Chong et al., 2018), (Ertay et al., 2013), (Algarín et al., 2017), (Connolly et al., 2014), (Kinto et al., 2017), (IMO, 2015), (Freese, 2017), (García-Olivares et al., (Burke and Stephens, 2018), (Cabrera et al., 2018), (Calleya, 2014), (Wan, 2018), (Rahim et al., 2016), (Psaraftis, 2016)

Research questions (RQ):

1. Is it possible to replace the conventional fuel currently used in the propulsion system with a renewable energy source?
2. Is there enough infrastructure to use renewable energy in maritime transportation?
3. Does renewable energy see sufficient interest and value in maritime transport?

4. Can liquefied natural gas (LNG) be used as an alternative energy in ship propulsion systems?

5. FINDINGS

There are potential barriers to achieving the goals set by the IMO. Rehmatulla and Smith (2015) investigated barriers to maritime transport in the energy sector and in low carbon strategies. Energy Efficiency Design Index (EEDI) parameters, regulations contained in the IMO International Convention for the Prevention of Pollution from Ships (MARPOL), the regulations of the IMO Convention on Marine Nitrogen and Sulfur Compounds were in the scope of their carbon-pricing scenarios. They justify that alternative fuels cannot be considered realistic until 2025. Their thought was the contribution of alternative energy sources to emission of greenhouse gas targets as 17% (Rehmatulla et al., 2017). IMarEST and Colfax predicted that alternative energy sources will reduce greenhouse gas generation by 75% in public areas in 2015 (IMarEST and Colfax, 2015). Calleya indicated that very few ships have LNG, biofuel and solar technology (Calleya, 2014).

Mander (2017) investigated the advantages and disadvantages of "wind energy and slow steaming" methods, which means wind energy to generate thrust, which is a more sustainable and reasonable solution rather than discontinuous solutions.

Biofuels, which have been discussed in the sector for a long time, reduce the emission of 50% -90% compared to the low sulfur marine gas oil (Connolly et al., 2014; Kinto et al., 2017). However, since the complexity of the mass production, storage and distribution processes of advanced biofuel projects increase costs, it is necessary to establish a supply chain with solid foundations (Burke and Stephens, 2018; Psaraftis, 2016; Rahim et al., 2016; Rehmatulla and Smith, 2015). New generation biofuel costs are much higher than fossil fuels. This means that if production and logistics costs are not substantially reduced, political incentives and support will be needed to ensure business continuity (Blazquez et al., 2018).

Hydrogen-containing fuel cells are an effective means of generating electricity with low carbon emissions (Lindstad, 2014). However, the hydrogen stock and the low volumetric energy density seem to be the disadvantages of fuel cells. It also requires additional infrastructure and system setup (Tronstad et al., 2017). It is stated in another study that greenhouse gas emissions would not occur when the energy stored in hydrogen fuel cells is converted into kinetic energy (Haas et al., 2019), but it is necessary to consider greenhouse gas emissions that occur in supply chain processes that occur until hydrogen supply. The methods of hydrogen generation differ. Methods such as renewable electrolysis, renewable natural gas or biomass gasification pave the way for different scenarios (Matulić et al., 2019).

The electric drive systems designed using hydrogen have a system in which the stored electrical energy is transferred to the electric motor. Greenhouse gas emissions depend on the source of stored energy. Therefore, the development of the infrastructure necessary to minimize the greenhouse gas emissions generated during the supply process of hydrogen may increase the flexibility of the industry. A study involving economic evaluations of electrical power plant system could not be found in the literature. However, the rapidly decreasing cost of batteries, electricity or fuel costs used for charging can accelerate the usage of fuel cells. (Matulić et al., 2019; Tanç et al., 2018).

In addition to changing the type of fuel, fuel expenditure can be optimized by improving the existing technology on the ship and/or by integrating renewable energy sources into the propulsion system. Energy efficiency can be increased while reducing the oscillation rate (Faber et al., 2009; IMO, 2018e).

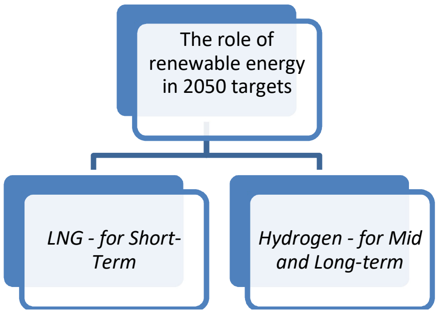

Fig. 1: Short and medium-long term solutions in the literature

As one of the renewable energy types, wind energy is preferred of both conventional sails and propulsion systems in modern designs. These designs include fletner rotors, kite system, soft sails, wing sails and wind turbines. In propulsion systems installed by these devices, wind energy often does not serve as the main propulsion component of a typical ship. However, in bad weather conditions where the intensity of the wind is high, the ship can reach the desired speed by saving fuel without using maximum power. A vessel operated entirely from wind energy can have a maximum carrying capacity of 3000 tons 10,000 tons in size for use on certain coastal voyages (Ertay et al., 2013; Jain and Jain, 2017). This quantity constitutes a small part of total carried freight.

Solar energy is used in propulsion systems of ships thanks to its ability to be stored in fuel cells. Due to the appropriate area boundary on the ship, it cannot be used as a main propulsion in strong and offshore vessels (Adams et al., 2018; Burke and Stephens, 2018; García-Olivares et al., 2018; Mander, 2017; Rehmatulla et al., 2017). Instead, hybrid sails can be used with other alternative fuel types such as LNG to save fuel (Jain and Jain, 2017). As the solar panels on the deck are subject to corrosion, the cost of installation, operation and storage should be taken into account, as shown in Fig. 2 (Bouman et al., 2017).

IMO's strategy includes vision, composition and guidance principles, short, medium- and long-term measures, their impact on possible processes and situations, barriers and supportive measures, followed actions, revised and developed strategies, periodic evaluation of these strategies (IMO, 2018f). The aim of this strategy is to take urgent steps to combat climate change and its impacts, as appropriate, to determine the actions to be taken by the international maritime transport sector, to address the impacts on states and to ensure the continuous development of international maritime transport and global maritime trade. Emphasis has been placed on identifying actions and measures to help achieve the stated objectives, including incentives for research, development and monitoring of greenhouse gas emissions from maritime transport (Chen et al., 2019; Haifeng et al., 2013).

Options for reducing carbon emissions for ships can be summarized as; ship design is categorized into alternative fuel options, including renewable energy, flue gas improvement, improving fuel efficiency with ship design, improving fuel efficiency with machine selection, low-mileage, fuel improvements, improving conventional fuel quality, and renewable energy. Options to reduce carbon emissions in practice are; slow steaming, water emulsion in fuel, conventional fuel distillation, use of liquefied natural gas, diesel fuel particle filtration, use of high sulfur-containing exhaust gas scrubbers (Faber et al., 2009; IMO, 2018g; Lindstad et al., 2015).

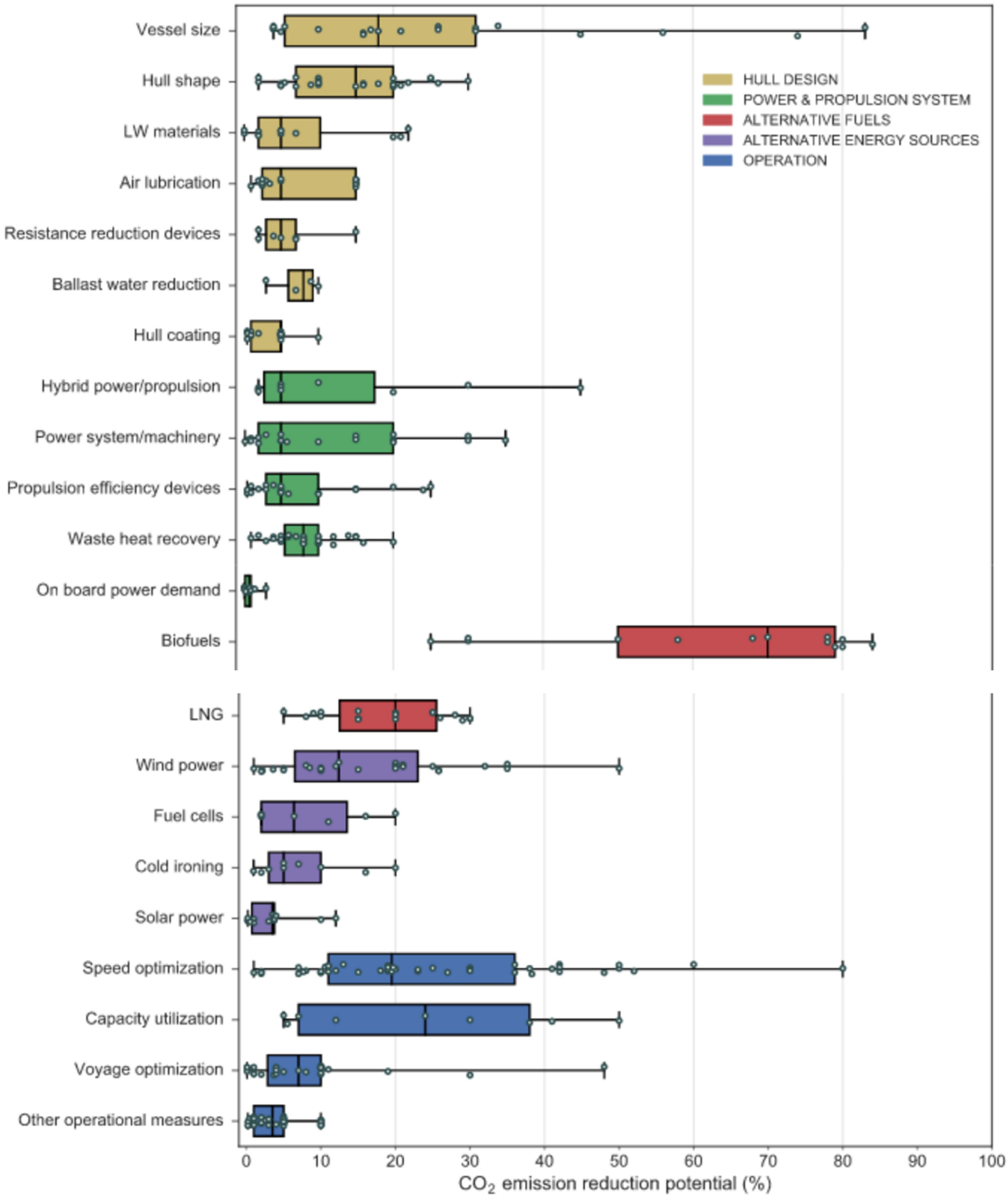

Fig. 2: CO_2 emission reduction potential from individual measures classified into 5 main categories of measures (Bouman, 2017).

Theoretically, although biofuels can reset renewable hydrogen and solar and wind energy greenhouse gas emissions, it is stated that alternative energy sources do not receive sufficient attention in the sector for technical, economic and operational reasons (Wan et al., 2018). When studies on alternative energy sources in the literature are examined, “wind energy”, “fuel cell”, cold ironing ”(using coastal connection instead of auxiliary machines in the port) and the reduction of greenhouse gas emissions of solar energy are 8-22%, 3-10%, 4-10%, 2%, 4% respectively (Bouman et al., 2017; Pekşen and Meter, 2014).

Super tankers, bulk cargo vessels such as post-Panamax type and oceangoing container vessels such as ultra large container ships (ULCS) most likely cause ship-induced greenhouse gas emissions (Freese, 2017). The steps taken to reduce greenhouse gas causes the oceangoing ships with powerful machines to take part in preventive activities until their economic life is completed (Zhang et al., 2014).

Based on these explanations and scientific studies, it can be inferred that current global maritime trade fleet which categorized in line with Fig. 2, current methods to reduce greenhouse gas emissions from the maritime trade fleet and to achieve targeted global warming values should mainly involve large tonnage offshore vessels. Although these measures are also short-term, long-term measures are possible with renewable energy as a fuel alternative regarding our RQ 1.

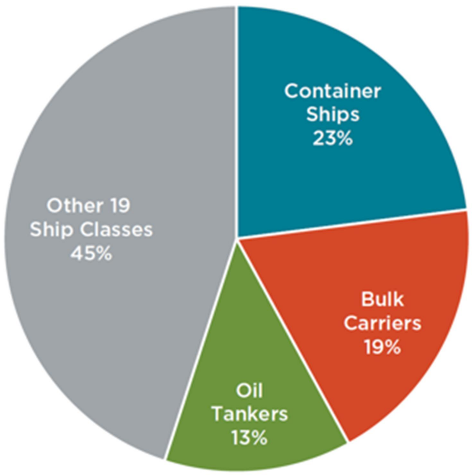

Fig. 3: Carbon emission values by ship types (Freese, 2017).

Our second research question regarding RQ 2 is that, considering the current literature and current conditions, the global energy supply network is intended for the transportation of fossil fuels and that the storage and distribution systems of renewable energy are not in a position to meet the potential demand in case of complete abandonment of fossil fuels. Comprehensive academic studies and simulation applications are needed. It is proposed that natural gas, which is not considered as a renewable energy source since its resources are limited, is considered as the most appropriate solution in terms of both emission value and efficiency in the short and medium term (Mosácula et al., 2019; Pierru et al., 2019). However, in the end, hydrogen can be used in combination with internal combustion diesel engines by spraying directly into the cylinder (Bouman et al., 2017; Morsy El-Gohary, 2013).

Regarding our third research question (RQ 3), it is seen that the projects realized by using completely renewable energy are generally used in small tonnage passenger ships. (Eyring et al., 2005; IMO, 2009; H. Lindstad et al., 2015; Mofor et al., 2015; El-Gohary, 2013; Wärtsilä, 2009) The obtained power is around 50 kW 300 kW and usability in large tonnage cargo ships is not appropriate. One of the most important reasons for this issue is that the limited surface of the ship deck is not suitable for installation of solar panels, masts and sailing equipment due to loading and unloading operations. Additionally, the limitations in storage electricity is a difficult problem to overcome. With the technological developments, it is expected that the battery costs will decrease (Breyer et al., 2017; Tanç et al., 2018). Considering this from an environmental point of view, in addition to technical and operational measures, the use of low-emission fossil fuels should be continued in ships that are currently being operated as a solution proposal for ship propulsion systems. In addition, as much as the free deck areas of the ship allow hydrogen from solar energy to be stored and integrated into the fuel system.

As regards our fourth research question (RQ 4), as shown in Fig. 5, liquefied natural gas (LNG) is used in today's ships at a rate that cannot be ignored (DNV, 2015; Deniz and Zincir, 2016). According to the 2015 report of the DNV-GL class organization, 63 vessels, including primary and secondary fuels, utilize LNG. High sulfur fuel oil and diesel are used in diesel engines. The alternative of these conventional fuels is that they can be easily adapted to the same internal combustion system, which will provide an economic advantage. LNG seems to be the first alternative today and in the near future as it meets this requirement and seems to be able to cope with the traditionally distilled fuel prices. As shown in Fig. 5, LNG has very low emission rates in the process from the storage tank (bunker tank) on the ship to the propeller, while the hydrogen obtained from the biodiesel and methane has high emission values. However, hydrogen derived from water is remarkable with relatively low oscillation values, although the energy capacity is relatively low.

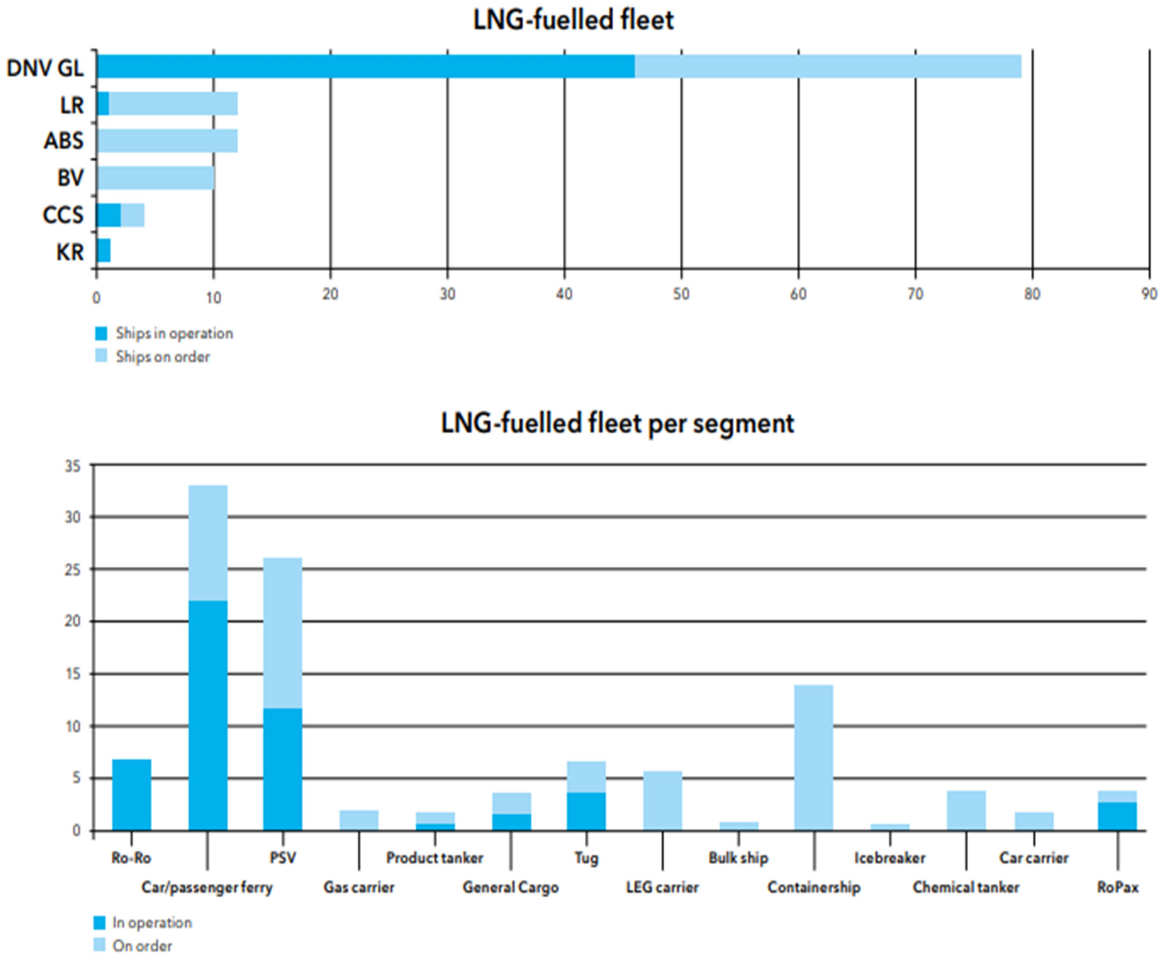

Fig. 4: LNG fueled fleet. Distribution of fleets with LNG propulsion (by class and segment) (DNV, 2015).

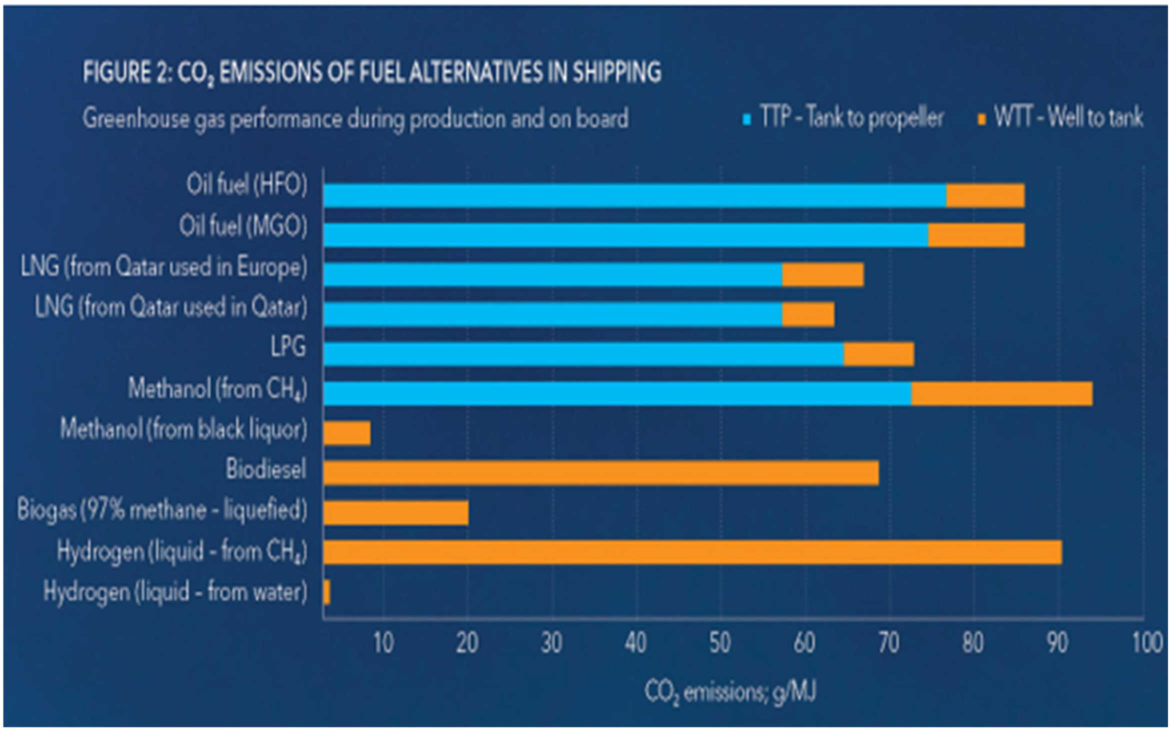

Fig. 5: Carbon emission values of fuel alternatives (DNV-GL, 2019).

6. CONCLUSION

In order to prevent airborne pollution caused by the ship, it seems there is not one energy source that reasonable sufficient. Several solutions need to be addressed together. The main reasons underlying this situation are the lack of homogeneity such as the limitation of solution alternatives, the inadequacy of each solution alternative, economic, political and operational barriers, differences in emission rates according to ship type and size, fuel type, and the characteristic structure of the marine routes used. While the alternative energy sources are given as one of the solutions in the data set examined, they are generally shown as additional measures to reduce emissions.

The increase in maritime trade indirectly increases greenhouse gas emissions. The important point here is not to narrow the global trade volume and to cause a crisis in price policies in order to reduce greenhouse gas emissions. Therefore, sector stakeholders will need to take initiative to achieve the optimum solution. One of the agenda items of the United Nations' IMO is to promote the use of alternative energy sources and to develop projects to prevent greenhouse gas emissions and indirect global warming. Therefore, smart, environmental and green-friendly innovations in the ship industry, operation and operation level, which are compatible with today's technology, should be realized.

Considering the current economic dimension of greenhouse gas emissions, it can be said that a system based on renewable energy sources will be cheap, solution-oriented and sufficient in the future (Kinto et al., 2017; Michalski et al., 2018; Pata, 2018; Xu et al., 2017).

Nevertheless, it is argued that electricity prices are likely to increase due to the increasing demand and disruptions in the supply chain, that the sector may lose its attractiveness and that the sector needs solution proposals in combination with fossil fuels (Blazquez et al., 2018).

Ship-induced greenhouse gas emissions mostly arise from super tankers, oceangoing large bulk cargo and post-panamax container vessels (Freese, 2017). The steps taken to reduce the greenhouse gas consist of partial preventive activities of the distant ships with powerful machines until their economic life is completed (Zhang et al., 2014). Therefore, the focal point of solution strategies should be the vessels offshore. Furthermore, the cost of technical solutions, the support of the sector to technical solutions, and the significant concerns in the use of performance-based indicators to reduce carbon dioxide emissions should be examined.

The obvious advantage and limitation of navigating by abandoning machine power is the necessity of additional operational measures due to the need for ships to accelerate as a result of improved market conditions and increased cargo traffic. The consolidation of renewable energy types in maritime transport seems to be possible with future hybrid systems, especially for oversized vessels. In this case, the most powerful fuel alternative in the short term is liquefied natural gas (LNG), which is not considered renewable, whereas in the medium and long term, hydrogen-containing fuel cells will be the actors of the new era.

The naval projects carried out with renewable energy in the project phase are exciting in today's literature. However, in order to achieve more realistic results, especially for capsize bulk carriers; super tankers and container ships, instead of searching for solutions with a single fuel alternative instead of heavy fuel, energy alternatives, efficiency with the aim of increasing the inclusion of projects will be more appropriate. Additionally, following the completion of the economic life of conventional vessels requiring relatively low power on shore navigation, the design of all new vessels to be constructed using solar and wind energy, especially the fuel cell containing hydrogen as the energy source, will contribute to the achievement of 2050 emission targets.

NOTE: This review article is a comprehensive version of the conference paper that presented previously in "8th national Logistics and Supply Chain Congress" titled "Energy Alternatives and Current Approaches for Ship Power Plants".

REFERENCES

Adams, S., Klobodu, E. K. M. And Apio, A. (2018). Renewable and Non-Renewable Energy, Regime Type and Economic Growth. *Renewable Energy*, 125, 755–767.

Algarín, C.R., Llanos, A. P. and Castro, A. O. (2017). An Analytic Hierarchy Process Based Approach for Evaluating Renewable Energy Sources. *International Journal of Energy Economics and Policy*, 7(4), 38–47.

Blazquez, J., Fuentes-Bracamontes, R., Bollino, C. A. And Nezamuddin, N. (2018). The Renewable Energy Policy Paradox. *Renewable and Sustainable Energy Reviews*, 82, 1–5.

Bouman, E. A., Lindstad, E., Rialland, A. I. And 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.

Breyer, C., Afanasyeva, S., Brakemeier, D., Engelhard, M., Giuliano, S., Puppe, M., Moser, M. (2017). Assessment of Mid-Term Growth Assumptions and Learning Rates for Comparative Studies of CSP and Hybrid PV-Battery Power Plants. *AIP Conference Proceedings* (C. 1850, S. 160001). AIP Publishing LLC.

Burke, M. J. And Stephens, J. C. (2018). Political Power and Renewable Energy Futures: A Critical Review. *Energy Research and Social Science*, 35, 78–93.

Cabrera, P., Lund, H. And Carta, J. A. (2018). Smart Renewable Energy Penetration Strategies on Islands: The Case of Gran Canaria. *Energy*, 162, 421–443.

Calleya, J. N. (2014). Ship Design Decision Support for A Carbon Dioxide Constrained Future, 125.

Cames, M., Graichen, J., Siemons, A. And Cook, V. (2015). Emission Reduction Targets for International Aviation and Shipping. European Parliament - Policy Department, (1), 1–52.

Http://Www.Europarl.Europa.Eu/Regdata/Etudes/STUD/2015/569964/IPOL_STU%282015%29569964_EN.Pdf Accessed from This Website.

Chen, Y., Wang, Z. And Zhong, Z. (2019). CO2 Emissions, Economic Growth, Renewable and Non-Renewable Energy Production and Foreign Trade in China. *Renewable Energy*, 131, 208–216.

Chong, W. W. F. F., Ng, J. H., Rajoo, S. And Chong, C. T. (2018). Sector of Passenger Transportation Gasoline Consumption Due to Friction in Southeast Asian Countries. *Energy Conversion and Management*, 158, 346–358.

Clean North Sea Shipping Project. (2014). Clean North Sea Shipping Final Report: Key Findings and Recommendations, (March), 92. Http://Cnss.No/Wp-Content/Uploads/2014/03/CNSS_Final_Report_Web.Pdf Accessed from Website.

Connolly, D., Mathiesen, B. V. And Ridjan, I. (2014). A Comparison Between Renewable Transport Fuels That Can Supplement or Replace Biofuels in A 100% Renewable Energy System. *Energy*, 73, 110–125.

Deniz, C. And Zincir, B. (2016). Environmental and Economical Assessment of Alternative Marine Fuels. *Journal of Cleaner Production*, 113, 438–449.

DNV, (2015), DNV Annual Report, 2015 Https://Issuu.Com/Dnvgl/Docs/Dnv_Gl_Annual_Report_2015 [Accessed 01.09.2019]

DNV-GL, (2019), Maritime Impact Report of Carbon Emissions, Https://Www.Dnvgl.Com/Expert-Story/Maritime-Impact/Alternative-Fuels.Html, [Accessed 18.09.2019]

Ertay, T., Kahraman, C. and Kaya, İ. (2013). Evaluation of Renewable Energy Alternatives Using Macbeth and Fuzzy Ahp Multicriteria Methods: The Case of Turkey. *Technological and Economic Development of Economy*, 19(1), 38–62.

Eyring, V., Köhler, H. W., Lauer, A. and Lemper, B. (2005). Emissions from International Shipping: 2. Impact of Future Technologies on Scenarios until 2050. *Journal of Geophysical Research D: Atmospheres*, 110(17), 183–200.

Faber, J., Markowska, A., Nelissen, D., Davidson, M., Eyring, V., Cionni, I. Schwarz, W. (2009). Technical Support for European Action to Reducing Greenhouse Gas Emissions from International Maritime Transport. Accessed from Http://Ec.Europa.Eu/Clima/Policies/Transport/Shipping/Docs/Ghg_Ships_Report_En.Pdf.

Freese, N. (2017). International Maritime Shipping CO2 Emissions CO2 Emissions from International Maritime Shipping-Regulations, Challenges and Possibilities.

García-Olivares, A., Solé, J. And Osychenko, O. (2018). Transportation in A 100% Renewable Energy System. *Energy Conversion and Management*, 158, 266–285.

Haas, J., Nowak, W. And Palma-Behnke, R. (2019). Multi-Objective Planning of Energy Storage Technologies for A Fully Renewable System: Implications for The Main Stakeholders in Chile. *Energy Policy*, 126, 494–506.

Haifeng Wang And Lutsey, N. (2013). Long-Term Potential for Increased Shipping Efficiency Through the Adoption of Industry-Leading Practices, (July), 32.

Pekşen, H. N., Pekşen, D. Y. and Ölçer, A. (2014). Cold Ironing Yöntemi; Marport Limanı Uygulaması. *Journal of ETA Maritime Science*, 2(1), 11–30.

Hua, J., Cheng, C. W. And Hwang, D. S. (2019). Total Life Cycle Emissions of Post-Panamax Containerships Powered by Conventional Fuel or Natural Gas. *Journal of The Air and Waste Management Association*, 69(2), 131–144.

Hughes, E. (2016). Recent Developments at IMO to Address GHG Emissions from Ships. International Maritime Organization (IMO), (November). Http://Www.Imo.Org/En/Ourwork/Environment/Pollutionprevention/Airpollution/Pages/UN Accessed from Website.

Imarest And Colfax. (2015). Making the Green Agenda Pay, 16. Https://Www.Imarest.Org/All-Docman-Documents/Representation/Green-Agenda/551-Making-The-Green-Agenda-Pay/File Accessed from Website.

IMO, (2009). No Title. Environment, Marine Committee, Protection Of, Reduction Emissions, G H G Ships, From Abatement, Marginal Effectiveness, Cost Submitted, Energy-Efficiency Measures Engineering, Marine, 61.

IMO, (2018). Note by The International Maritime Organization to The UNFCCC Talanoa Dialogue, (International Maritime Organization), 27.Accessed fromhttps://Unfccc.Int/Sites/Default/Files/Resource/250_IMO

IMO, (2015) Control, A., Technologies, A., Reduce, T. O., Carbon, B., Shipping, I. (2015). IMO - Black Carbon. Accessed from Www.Imo.Org.

IMO, (2018), Low Carbon Shipping And Air Pollution control http://Www.Imo.Org/En/Mediacentre/Hottopics/GHG/Pages/Default.Aspx [Accessed: 01.09.2019]

IMO, (2019) Air Pollution Prevention Regulations Http://Www.Imo.Org/En/Ourwork/Environment/Pollutionprevention/Airpollution/Pages/Sulphur-Oxides-(Sox)-–-Regulation-14.Aspx

IUMI, 2018, IUMI Eye Newsletter December 2018, Https://Iumi.Com/News/Iumi-Eye-Newsletter-December-2018/2018-Iumi-Statistics-The-Global-Economy-Continues-To-Recover-While-Marine-Insurance-Results-Remain-Under-Pressure [Accessed: 01.09.2019]

IPCC. (2006). Volume 2: Energy - Chapter 2: Stationary Combustion, 2006. IPCC Guidelines for National Greenhouse Gas Inventories, 2.1 2.47.

Jain, S. And Jain, P. K. (2017). The Rise of Renewable Energy Implementation in South Africa. *Energy Procedia*, 143, 721–726.

Kinto, O. T., De Oliveira Bernal, J. L., Veiga Gimenes, A. L. And Morales Udaeta, M. E. (2017). Sustainable Energy Technologies in The Industry Using Integrated Energy Resources Planning. *Energy Procedia*, 118, 4-14

Lindstad, H. E. (2015). Hydrogen the Next Maritime Fuel, 12pp. Lindstad, H., Eskeland, G. S., Psaraftis, H., Sandaas, I. And Strømman, A. H. (2015). Maritime Shipping and Emissions: A Three-Layered, Damage-Based Approach. *Ocean Engineering*, 110, 94–101.

Mander, S. (2017). Slow Steaming and A New Dawn for Wind Propulsion: A Multi-Level Analysis of Two Low Carbon-Shipping Transitions. *Marine Policy*, 75, 210–216.

Maritime, G. And Monitor, I. (2018). Global Maritime Issues Monitor.

Matulić, N., Radica, G., Barbir, F. And Nižetić, S. (2019). Commercial Vehicle Auxiliary Loads Powered by PEM Fuel Cell. *International Journal of Hydrogen Energy*, 44 (20), 10082-10090.

Michalski, J., Poltrum, M. And Bünger, U. (2018). The Role of Renewable Fuel Supply in The Transport Sector in A Future Decarbonized Energy System. *International Journal of Hydrogen Energy*, 2018, 1–12.

Mofor, L., Nuttal, P. And Alison, N. (2015). Renewable Energy: Options for Scrutiny, (July).

Morsy El-Gohary, M. (2013). Overview of Past, Present and Future Marine Power Plants. *Journal of Marine Science and Application*, 12(2), 219–227.

Mosácula, C., Chaves-Ávila, J. P. and Reneses, J. (2019). Reviewing the Design of Natural Gas Network Charges Considering Regulatory Principles as Guiding Criteria in The Context of The Increasing Interrelation of Energy Carriers. *Energy Policy*, 126, 545–557.

Pata, U. K. (2018). Renewable Energy Consumption, Urbanization, Financial Development, Income and CO2 Emissions in Turkey: Testing EKC Hypothesis with Structural Breaks. *Journal of Cleaner Production*, 187, 770–779.

Pierru, A., Wu, K., Murphy, F., Galkin, P., Feijoo, F., Rioux, B.Malov, A. (2019). The Economic Impact of Price Controls on China's Natural Gas Supply Chain. *Energy Economics*, 80, 394–410.

Psaraftis, H. N. (2016). Green Maritime Logistics: The Quest for Win-Win Solutions. *Transportation Research Procedia*, 14, 133–142.

Rahim, M. M., Islam, M. T. and Kuruppu, S. (2016). Regulating Global Shipping Corporations' Accountability for Reducing Greenhouse Gas Emissions in The Seas. *Marine Policy*, 69, 159–170.

Rehmatulla, N., Calleya, J. and Smith, T. (2017). The Implementation of Technical Energy Efficiency and CO2 Emission Reduction Measures in Shipping. *Ocean Engineering*, 139, 184–197.

Rehmatulla, N., Parker, S., Smith, T. and Stulgis, V. (2017). Wind Technologies: Opportunities and Barriers to A Low Carbon Shipping Industry. *Marine Policy*, 75, 217–226.

Rehmatulla, N. And Smith, T. (2015). Barriers to Energy Efficient and Low Carbon Shipping. *Ocean Engineering*, 110, 102–112.

Tanç, B., Arat, H. T., Baltacıoğlu, E. and Aydın, K. (2019). Overview of The Next Quarter Century Vision of Hydrogen Fuel Cell Electric Vehicles. *International Journal of Hydrogen Energy*. 44(20), 10120-10128.

Technical, N. (2012). This Document Is Downloaded From DR-NTU Nanyang Technological Operator's Perspective in The Container Shipping.

Tronstad, T., Åstrand, H. H., Haugom, G. P. and Langfeldt, L. (2017). Study on The Use of Fuel Cells in Shipping, 1–108.

Wan, Z., El Makhloufi, A., Chen, Y. And Tang, J. (2018). Decarbonizing the International Shipping Industry: Solutions and Policy Recommendations. *Marine Pollution Bulletin*, 126, 428–435.

Wärtsilä. (2009). Boosting Energy Efficiency, (February), 1–68.

Xu, H., Li, Y. And Huang, H. (2017). Spatial Research on The Effect of Financial Structure on CO2 Emission. *Energy Procedia*, 118, 179–183.

Zhang, Y., Lin, Z. and Liu, Q. (2014). Marine renewable energy in China: Current status and perspectives. *Water Science and Engineering*, 7(3), 288–305.