Karadeniz Fen Bilimleri Dergisi, 15(1), 550-559, 2025. DOI: 10.31466/kfbd.1613824

KFBD

Karadeniz Fen Bilimleri Dergisi
The Black Sea Journal of Sciences
ISSN (Online): 2564-7377 https://dergipark.org.tr/tr/pub/kfbd

Araştırma Makalesi / Research Article

Path to Zero Emissions on Maritime Transport: A Multi-Criteria Perspective on Shipowners' Challenge

İshak ALTINPINAR[1*]

Abstract

The International Maritime Organization has started some studies to reduce emissions from shipping to zero by 2050 and adopted this as a policy. However, discussions continue on the feasibility of this policy. When looking at the near future targets, medium-term, and 2050 targets, ship owners, seafarers, party states, and many other stakeholders are in for tough times. In this study, the challenges awaiting ship owners within the scope of the 2050 targets were evaluated using the Analytical Hierarchy Process (AHP), which is a multi-criteria decision-making method (MCDM). The results showed that financial issues (33.6%) are a critical challenge and that innovations will bring a significant economic burden. Operational issues (19.2%) and access to new fuels (18.9%), the impact of new systems on operations difficulties in accessing fuels, and storage issues are in the 2nd and 3rd place. They are followed by competitive pressure (15.2%), and finally, compliance with new regulations (13.1) was found. Costs are of critical importance for the world economy. Therefore, financial problems must be overcome first. Achieving IMO's 2050 goals requires significant investments, new regulations, international collaborations, and great dedication.

Keywords: IMO 2050 targets, Analytical hierarchy process, Zero emissions, Ship owners.

Deniz Taşımacılığında Sıfır Emisyona Giden Yol: Gemi Sahiplerinin Zorluklarına Çok Kriterli Bir Bakış Açısı

Öz

Uluslararası Denizcilik Örgütü (IMO), deniz taşımacılığından kaynaklanan emisyonları 2050 yılına kadar sıfıra indirmek amacıyla bazı çalışmalar başlatmış ve bunu bir politika olarak benimsemiştir. Ancak, bu politikanın uygulanabilirliği konusunda tartışmalar devam etmektedir. Yakın gelecek, orta vadeli ve 2050 hedeflerine bakıldığında, gemi sahipleri, denizciler, taraf devletler ve birçok paydaş zorlu bir süreçle karşı karşıya kalacaktır. Bu çalışmada, 2050 hedefleri kapsamında gemi sahiplerini bekleyen zorluklar, çok kriterli bir karar verme yöntemi (MCDM) olan Analitik Hiyerarşi Süreci (AHP) ile değerlendirilmiştir. Sonuçlar, finansal sorunların (%33,6) kritik bir zorluk olduğunu ve yeniliklerin önemli bir ekonomik yük getireceğini göstermiştir. Operasyonel sorunlar (%19,2) ve yeni yakıtlara erişim (%18,9), operasyonlardaki yeni sistemlerin etkileri, yakıt temini ve depolama sorunları nedeniyle ikinci ve üçüncü sırada yer almaktadır. Bunları rekabet baskısı (%15,2) izlerken, yeni düzenlemelere uyum (%13,1) son sırada yer almıştır. Maliyetler, dünya ekonomisi için kritik öneme sahiptir. Bu nedenle, öncelikle finansal sorunların aşılması gerekmektedir. IMO'nun 2050 hedeflerine ulaşmak, önemli yatırımlar, yeni düzenlemeler, uluslararası iş birlikleri ve büyük bir özveri gerektirmektedir.

Anahtar Kelimeler: IMO 2050 hedefleri, Analitik hiyerarşi süreci, Sıfır Emisyon, Gemi Sahipleri.

[1]Karadeniz Technical University, Department of Maritime Transportation and Management Engineering, Trabzon, Türkiye, ishakaltinpinar@ktu.edu.tr

[*]Sorumlu Yazar/Corresponding Author

Geliş/Received: 05.01.2025 **Kabul/Accepted:** 10.02.2025 **Yayın/Published:** 15.03.2025

Altınpınar, İ. (2025). Path to Zero Emissions on Maritime Transport: A Multi-Criteria Perspective on Shipowners' Challenge. *Karadeniz Fen Bilimleri Dergisi*, 15(1), 550-559.

1. Introduction

The life of all living things on earth, the ecology, the weather, and consequently, the next generation are all gravely threatened by air pollution. It would not be incorrect to state that air pollution is one of the largest global public health threats, given that it results in millions of fatalities annually (Manisalidis et al., 2020). Many factors cause air pollution, among which domestic pollutants, vehicles, industrial facilities, and forest fires are essential actors of air pollution (WHO, 2024). Vehicles and shipping are recognized to be major contributors to air pollution. In terms of the quantity of cargo transported, maritime transportation is greener than other modes of transportation; but, when general emissions are considered, it becomes evident that the volume of cargo transported by maritime transportation makes a major contribution to air pollution (Kose and Sekban, 2022). Maritime trade is vital to all societies in the world. More than 80 percent of the world's trade volume is carried by sea (UNCTAD, 2024). This great shipping brought with it many effects. To prevent marine pollution caused by ships and the negative effects of transportation, The International Maritime Organization (IMO) adopted the International Convention for the Prevention of Pollution from Ships (MARPOL) in 1973. The MARPOL annex referring to air pollution (Annex VI - Regulations for the Prevention of Air Pollution from Ships) within MARPOL was adopted in 1997 and entered into force in 2005 (IMO, 2017). In the Summer of 2011, the IMO modified MARPOL Annex VI to establish the Energy Efficiency Design Index (EEDI) for new builds and the Energy Efficiency Management Plan (SEEMP) for all ships. Concerning energy efficiency requirements, this modification was the primary official institutionalization and control of greenhouse gas (GHG) emissions from vessels. The IMO Greenhouse Gas Study indicates that in 2018, the shipping industry accounted for 2.89% of all anthropogenic emissions worldwide (IMO, 2020). In 2018, the IMO assumed a policy to reduce greenhouse gas emissions from vessels, setting a target of halving greenhouse gas emissions by 2050 compared to 2008. At its meeting in 2023, IMO announced its strategy to reduce greenhouse gas emissions from ships to net zero by 2050, updating the target it had set in 2018 (IMO, 2023). In response to increasingly tough global environmental regulations, the maritime industry is adopting diverse long-term strategies to align with sustainable development goals. These measures include changing ship designs, often using larger ships to achieve lower costs, optimizing shipping routes to favor new, lower-cost, shorter routes, and decommissioning older vessels. Such initiatives are essential steps for shipping companies to adopt the IMO strategy by reducing emissions of sulphur oxides (SO_x), a significant air pollutant from shipping activities. Major companies are implementing onboard measures to meet near-term goals. These include measures such as installing scrubbers on ships and thus increasing their efficiency, using fuel with lower sulphur content or switching to alternative marine fuels. However, ships discharge all or part of the

water containing pollutants into the sea through their scrubbers, which is a concern for marine life because ships discharge much more copper and zinc than usual from this equipment (Tsimplis, 2020). Numerous researchers are working to assess the potential applications of alternative fuels in the maritime industry as well as their technical qualities, including efficacy, efficiency, accessibility, and applicability, as interest in and significance for these fuels grow (Deniz and Zincir, 2016; Andersson et al., 2020; Ampah et al., 2021; Bilgili, 2023). These fuels have the potential to significantly decrease carbon emissions. However, compared to fossil fuels, they are more costly and scarcer, and the viability of investing in these technologies is highly questionable. Furthermore, there is no agreement on which alternative marine fuels are best suited for each segment of the shipping industry in the short and long term, despite growing awareness of their qualities and potential. It is a complicated matter to train seafarers for these new fuels and technologies (Bilgili, 2023). Another uncertainty in alternative fuels will be related to storage and supply chain. The time it takes for new fuels to be integrated into the supply chain and become widespread, as well as the transformation of ports, is a very important process (Hansson et al., 2020). Major companies that participate in research and development activities and have access to innovative technologies will have an advantage over local companies with fewer ships in making radical changes towards zero-emission targets (Lee et al., 2024). In addition, ship accidents and leaks that occur after accidents and fires occur from time to time are considered a significant pollutant and economic losses (Uğurlu et al., 2015; Uğurlu et al., 2016). It is understood that the equipment, knowledge, skills, and experience required to prevent disruptions or accidents that may occur during the conversion of new fuels and their energy are quite limited. (Popp and Müller, 2021). As part of their research in 2024, Tomos et al. argued that IMO targets are not very possible with today's fuel and propulsion systems and that alternative fuels are especially effective in emissions that may occur during production and consumption. In their study conducted in 2024, Tavakoli et al. stated that the possibility of zero emissions in the near term is relatively low, but instead, a certain reduction is possible, albeit challenging, and they clearly stated that this reduction would bring with it many difficulties such as storage, adaptation to new technologies, fuel efficiency, and cost.

The aim of this study was to examine the possible effects of the significant changes that need to be made within the scope of IMO's 2050 zero emission target on ship owners.

2. Materials and Methods

The Analytical Hierarchy Process (AHP), a multi-criteria decision-making system (MCDM), is used in this study to assess and prioritize the elements that are likely to cause shipowners to encounter difficulties in light of the IMO's 2050 zero carbon policy. Thomas Saaty created the Analytical

Hierarchy Process (AHP), a systematic, quantitative approach to decision-making that measures expert opinions based on a variety of criteria (Saaty, 2008). The AHP allows qualitative expert judgments to be synthesized into quantitative rankings by comparing criteria pairwise and between them (Özdemir et al., 2018). Initially, a survey of the literature was done to determine the difficulties that shipowners would encounter. Following the identification of the criteria, a group of seven experts, including seasoned captains and academics from the operations department, evaluated them. Five main criteria that ship owners should meet were identified as a consequence of the research and interviews. Table 1 contains the criteria and their explanations.

Table 1. Description of criteria.

Criteria number	Explanations of criteria.
C1.	Financial issues
C2.	Operational issues
C3.	Access to new fuels
C4.	Competitive pressure
C5.	Compliance with new regulations

AHP evaluates each factor's relative relevance through pairwise comparisons. Experts rate each pair of criteria on a scale from 1 to 9, with 1 denoting equal importance and 9 denoting exceptional importance of one criterion over the other, in accordance with the importance scale displayed in Table 2.

Table 2. Importance scale (Saaty, 2008)

Intensity of importance	Definition
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2,4,6,8	Intermediate Values

A pairwise comparison matrix A=[aij] is used to arrange the comparisons, where:

aij represents the relative importance of criterion i i over criterion j j.

If aij = k then aij = 1/k to maintain matrix consistency.

For instance, the pairwise comparison matrix A would resemble this if it were comparing five criteria, C1, C2, C3, C4, and C5.

$$A = \begin{bmatrix} 1 & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & 1 & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & 1 & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & 1 & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & 1 \end{bmatrix} \quad (1)$$

Following this phase, the eigenvector computation phase begins.

Add up all of the pairwise comparison matrix A's columns.

Divide each element by the total of its columns to normalize it.

To get the priority vector, calculate the average of each row in the normalized matrix.

The weights assigned to each criterion are given by the formula w= [w1, w2, w3, w4, w5,…wn].

The formula for criterion i i's priority for a matrix of size n is:

$$w_i = \frac{1}{n} \sum_{j=1}^{n} \left(\frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \right) \quad (2)$$

To make sure that the decisions in the pairwise comparison matrix are fairly consistent, AHP does a consistency check. The following formula is used to determine the Consistency Index (CI):

$$\mathrm{CI} = \frac{\lambda_{\max} - \mathrm{n}}{\mathrm{n}-1} \quad (3)$$

Where n is the number of criteria and λ_{max} is the maximum eigenvalue of matrix A. The consistency ratio must be computed as follows in order to test the pairwise comparison matrix's (CR) degree of consistency:

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI} \quad (4)$$

For the pairwise comparison matrix (A_{nxn}), the random index value is denoted by RI, and the consistency index value by CI. The values in Table 3 of the random index values can be used to calculate the random index value RI.

Table 3. Random index (RI) (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Pairwise comparisons are consistent if the CR value is less than 0.1 (Saaty, 2008). Otherwise, the analysis ought to be reexamined and updated with new values if required.

3. Findings and Discussion

Following the evaluations conducted by each expert, normalized decision matrices were developed and examined. The experts then developed weight eigenvectors for every criterion. The geometric mean of the experts' assessments determines each criterion's relative relevance score in the pairwise comparison matrix. A fair amount of overlap exists between the professional viewpoints regarding the challenges that ship owners will face. Table 4 displays the criterion weights that were determined using the pairwise comparison matrices.

Table 4. Experts' weights for the criteria

	E1	E2	E3	E4	E5	E6	E7	FEW	PCT
C1	0,405	0,395	0,324	0,471	0,161	0,120	0,574	0,336	33,6%
C2	0,215	0,168	0,193	0,169	0,310	0,270	0,050	0,189	18,9%
C3	0,105	0,154	0,169	0,062	0,113	0,166	0,116	0,131	13,1%
C4	0,183	0,141	0,187	0,124	0,247	0,248	0,150	0,192	19,2%
C5	0,092	0,141	0,128	0,174	0,169	0,195	0,111	0,152	15,2%

*C: Criteria, E: Expert, FEW: Final Expert Weights

The study results show that the most challenging issue for ship owners within the scope of IMO’s 2050 targets is financial issues (33.6%). Operational issues (19.2%) and access to new fuels (18.9%) are also highlighted, with both factors competing closely in terms of weight. Competitive pressure (15.2%) is in fourth place, while Compliance with new regulations (13.1) is in last place.

According to the analytical hierarchy process, financial problems appear as the criterion with the highest weight, at 33.6%. For both the 2030 and 2050 targets, ship owners need to make significant investments first to reduce emissions and then ultimately reduce them to zero. Utilizing new types of fuels, such as ammonia, hydrogen, and biodiesel, seems to be a necessity at the end of the day, but for small and medium-sized ship owners, this may be challenging to manage (Grzelakowski et al., 2022; Wang et al., 2022). In addition, the fact that public and private sector representatives are distant from the issue makes the situation more difficult (Deng and Mi, 2023). The fact that these technologies are not as old as fossil fuels and, the uncertainty of their long-term

applicability and the economic burden they bring make decision-making even more complicated for ship owners (Piccolo, 2023).

Operational challenges were identified as the second most important criterion, accounting for 19.2% of the total. These include challenges such as the lack of adequate infrastructure. The existing infrastructure is insufficient to meet the increasing demands of new fuel types such as LNG, ammonia and hydrogen, creating significant logistical hurdles (Bullock et al., 2022; Grzelakowski et al., 2022). Additionally, upgrading existing ships to adapt to these new technologies often results in operational slowdowns, which inevitably impacts profitability (Zhang et al., 2024). Another critical issue is the lack of trained and experienced personnel to manage and operate ships equipped with advanced, environmentally friendly technologies (Piccolo, 2023).

With a weighted value of 18.9%, access to alternative fuels comes in third place among the criteria. Access to alternative fuels appears to be difficult both now and in the near future, despite the fact that their development is essential to meeting the IMO's decarbonization targets. The adoption of hydrogen, ammonia, and biofuels—also known as "green fuels"—is constrained by their limited production capacity and delivery networks (Wang et al., 2022; Zhang et al., 2024). Distribution is hampered by storage conditions and safety issues, especially for hydrogen and ammonia (Balcombe et al., 2019). Furthermore, the price volatility of these alternative fuels in comparison to fossil fuels limits their predictability and usage (Grzelakowski et al., 2022).

The competitive pressure criterion accounts for 15.2% of the weighted importance and is particularly difficult for shipowners with fewer ships. Larger enterprises are given an advantage in competitiveness because they can swiftly adjust to new legislation and market needs because of their greater investment power and number of vessels (Deng and Mi, 2023). Smaller businesses are under more pressure to overcome regional variations in practice (Doelle and Chircop, 2019). Ship owners are under increasing pressure to quickly adopt greener practices due to growing customer demand for sustainable logistics (Bullock et al., 2022).

With a weight of 13.1%, adherence to the new IMO requirements is the least significant criterion. It is nevertheless a major worry in spite of this. Ship owners have an increased administrative cost due to the complexity of meeting standards like the Carbon Intensity Indicator (CII) and the Energy Efficiency Design Index (EEDI) (Zhang et al., 2024; Bilgili and Ölçer, 2024). Furthermore, smaller firms are unbalanced impacted by the operational and financial expenses of putting these policies into effect (Grzelakowski et al., 2022). Consistent reporting and monitoring are necessary, which makes compliance efforts even more complex and results in significant labor losses (Piccolo, 2023).

4. Conclusions and Recommendations

The study addresses the challenges that await shipowners in line with IMO's goals and offers a different perspective on the supply and demand problems that are likely to affect the maritime sector in the future and the costs that will come with obtaining and sustaining green energy. Ship owners have very important roles within the scope of IMO's 230-2040 and 2050 targets. While achieving the near-term targets may be possible with innovations to be made onboard, in order to achieve medium and long-term targets, it will be essential for the vessel to change the size and efficiency of their fuel types, perhaps even themselves. It is seen that ship owners will be under a serious financial burden in doing this. This financial burden will be reflected as a price increase to the consumer globally. Another issue will be the safety of new fuels. In future studies, the operational and storage difficulties of new types of fuels will be taken into account. It is seen that the sector, which maintains the world's supply-demand balance and is at the center of trade, will need a serious plan and support at every step in the decarbonization phase. The failure of some consensus provided by climate agreements to be accepted by the countries that produce the most greenhouse gases may result in all the sacrifices made and the difficulties overcome not being reciprocated.

Acknowledgements

I would like to thank the experts who expressed their opinions in the study.

Authors' Contributions

All the paper is designed, created and revised by one author.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

References

Ampah, J. D., Yusuf, A. A., Afrane, S., Jin, C., & Liu, H. (2021). Reviewing two decades of cleaner alternative marine fuels: Towards IMO's decarbonization of the maritime transport sector. *Journal of Cleaner Production,* 320, 128871. https://doi.org/10.1016/j.jclepro.2021.128871

Andersson, K., Brynolf, S., Hansson, J., & Grahn, M. (2020). Criteria and decision support for a sustainable choice of alternative marine fuels. *Sustainability,* 12(9), 3623. https://doi.org/10.3390/su12093623

Balcombe, P., Brierley, J., Lewis, C., Skatvedt, L., Speirs, J., Hawkes, A., & Staffell, I. (2019). How to decarbonise international shipping: Options for fuels, technologies and policies. *Energy Conversion and Management,* 182, 72–88. https://doi.org/10.1016/j.enconman.2018.12.080

Bilgili, L. (2023). A systematic review on the acceptance of alternative marine fuels. *Renewable and Sustainable Energy Reviews,* 182, 113367. https://doi.org/10.1016/j.rser.2023.113367

Bilgili, L., & Ölçer, A. I. (2024). IMO 2023 strategy—Where are we and what's next? *Marine Policy*, 160, 105953. https://doi.org/10.1016/j.marpol.2023.105953

Bullock, S., Mason, J., & Larkin, A. (2022). The urgent case for stronger climate targets for international shipping. *Climate Policy,* 22(3), 301–309. https://doi.org/10.1080/14693062.2021.1991876

Deniz, C., & Zincir, B. (2016). Environmental and economical assessment of alternative marine fuels. Journal of Cleaner Production, 113, 438-449. https://doi.org/10.1016/j.jclepro.2015.11.089

Deng, S., & Mi, Z. (2023). A review on carbon emissions of global shipping. *Marine Development,* 1(4), 1–12. https://doi.org/10.1007/s44312-023-00001-2

Doelle, M., & Chircop, A. (2019). Decarbonizing international shipping: An appraisal of the IMO's initial strategy. *Review of European, Comparative & International Environmental Law,* 28(2), 268–277. https://doi.org/10.1111/reel.12302

Grzelakowski, A. S., Herdzik, J., & Skiba, S. (2022). Maritime shipping decarbonization: Roadmap to meet zero-emission target in shipping as a link in the global supply chains. *Energies,* 15(6150), 1–19. https://doi.org/10.3390/en15176150

Hansson, J., Brynolf, S., Fridell, E., & Lehtveer, M. (2020). The potential role of ammonia as marine fuel—based on energy systems modeling and multi-criteria decision analysis. *Sustainability*, 12(8), 3265. https://doi.org/10.3390/su12083265

IMO. (2017). Amendments to the annex of the protocol of 1997 to amend the international convention for the prevention of pollution from ships, 1973, as modified by the protocol of 1978 relating thereto amendments to MARPOL annex VI, Resolut. MEPC 286 (71) MEPC 71/17/Add.1.

IMO. (2020). Fourth IMO GHG study. [PDF document]. Retrieved from https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%202020%20-%20Full%20report%20and%20annexes.pdf. (Date Accessed: 15 July 2024).

IMO. (2023). Strategy on Reduction of GHG Emissions from Ships 2023. Retrieved from. https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2015.pdf, (Date Accessed: 20 July 2024).

Kose, S., & Sekban, D. M. (2022). Emphasizing the importance of using cold-ironing technology by determining the share of hotelling emission value within the total emission. *Transportation Safety and Environment,* 4(2), tdac010. https://doi.org/10.1093/tse/tdac010

Lee, J., Sim, M., Kim, Y., & Lee, C. (2024). Strategic Pathways to Alternative Marine Fuels: Empirical Evidence from Shipping Practices in South Korea. *Sustainability*, 16(6), 2412. https://doi.org/10.3390/su16062412

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E. (2020). Environmental and health impacts of air pollution: a review. *Frontiers in Public Health,* 8, 14. https://doi.org/10.3389/fpubh.2020.00014

Özdemir, Ü., Altinpinar, İ., & Demirel, F. B. (2018). A MCDM approach with fuzzy AHP method for occupational accidents on board. *TransNav, International Journal on Marine Navigation and Safety of Sea Transportation,* 12(1), 93-98. https://doi.org/10.12716/1001.12.01.10

Piccolo, V. (2023). GHG emissions from shipping: How to overcome persistent challenges. *NUS Centre for Maritime Law Working Paper,* 23(6), 1–20. http://dx.doi.org/10.2139/ssrn.4506467

Popp, L., & Müller, K. (2021). Technical reliability of shipboard technologies for the application of alternative fuels. *Energy, Sustainability and Society*, 11, 1-7. https://doi.org/10.1186/s13705-021-00301-9

Saaty, T. L. (1980). The analytic hierarchy process. New York, NY: McGraw-Hill.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1(1), 83-98. https://doi.org/10.1504/IJSSCI.2008.017590

Tavakoli, S., Gamlem, G. M., Kim, D., Roussanaly, S., Anantharaman, R., Yum, K. K., & Valland, A. (2024). Exploring the technical feasibility of carbon capture onboard ships. *Journal of Cleaner Production*, 452, 142032. https://doi.org/10.1016/j.jclepro.2024.142032

Tsimplis, M. (2020). Marine pollution from shipping activities. In Maritime Law (pp. 403-464). Informa Law from Routledge.

Tomos, B. A. D., Stamford, L., Welfle, A., & Larkin, A. (2024). Decarbonising international shipping–A life cycle perspective on alternative fuel options. *Energy Conversion and Management*, 299, 117848. https://doi.org/10.1016/j.enconman.2023.117848

Uğurlu, Ö., Yıldırım, U., & Başar, E. (2015). Analysis of grounding accidents caused by human error. *Journal of Marine Science and Technology*, 23(5), 19. https://doi.org/10.6119/JMST-015-0615-1

Uğurlu, Ö., Erol, S., & Başar, E. (2016). The analysis of life safety and economic loss in marine accidents occurring in the Turkish Straits. *Maritime Policy & Management*, 43(3), 356-370. https://doi.org/10.1080/03088839.2014.1000992

UNCTAD, 2024. Review of Maritime Transport 2024. Retrieved from. https://unctad.org/system/files/official-document/rmt2024_en.pdf (Date Accessed: 26 December 2024).

Wang, Y., Cao, Q., Liu, L., Wu, Y., Liu, H., Gu, Z., & Zhu, C. (2022). A review of low and zero carbon fuel technologies: Achieving ship carbon reduction targets. Sustainable Energy Technologies and Assessments, 54, 102762. https://doi.org/10.1016/j.seta.2022.102762

WHO. 2024. Air Pollution. Retrieved from. https://www.who.int/health-topics/air-pollution#tab=tab_1. (Date Accessed: 18 August 2024).

Zhang, C., Zhu, J., Guo, H., Xue, S., Wang, X., Wang, Z., Chen, T., Yang, L., Zeng, X., & Su, P. (2024). Technical requirements for 2023 IMO GHG strategy. Sustainability, 16(2766), 1–18. https://doi.org/10.3390/su16072766