



Operational Sense Making of Marine Propulsion Systems in Energy Efficiency Driven Shipping

Pierre Marcello Lopulalan
Politeknik Pelayaran Banten

Corresponding Author: Pierre Marcello Lopulalan pmarcello66@gmail.com

ARTICLE INFO

Keywords: Operational Sense Making, Ship Propulsion System, Energy Efficiency, Shipping Operations, Maritime Energy Management.

Received : 27, December

Revised : 29, January

Accepted: 28, February

©2026 Lopulalan: This is an open-access article distributed under the terms of the [Creative Commons Atribusi 4.0 Internasional](https://creativecommons.org/licenses/by/4.0/).

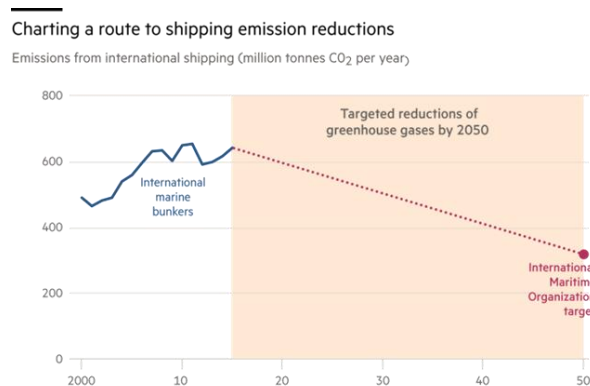


ABSTRACT

The growing demand for energy efficiency and emission reduction in the shipping sector highlights the importance of operational approaches that go beyond technology and emphasize how ship operators make sense of marine propulsion systems. Using a qualitative case-study approach on commercial vessels, this study finds that operators' contextual understanding of engine loads, sea conditions, and operating patterns significantly supports adaptive decision-making, fuel optimization, and system reliability. The study concludes that integrating human, technological, and operational contexts is essential for improving energy efficiency and advancing sustainable ship propulsion management

INTRODUCTION

The global shipping industry is facing increasing pressure to improve energy efficiency and lower greenhouse gas emissions as sustainability demands and international commitments to climate change mitigation increase. The shipping sector is estimated to account for around 2–3% of total global CO₂ emissions, making improving the energy efficiency of ships a top priority in international maritime policy (International Maritime Organization [IMO], 2023; Bouman et al., 2020). In response to these challenges, IMO has established various regulatory instruments such as the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII) that focus on the energy performance of ships during actual operations, not just on technical design aspects (IMO, 2023; DNV, 2022). The historical emission trends and emission reduction targets of the shipping sector until 2050 are shown in Figure 1.



Source: International Energy Agency (IEA); International Maritime Organization (IMO)

Figure 1. CO₂ emission trends from international shipping and emission reduction targets until 2050

In line with the development of these regulations, research in the field of mechanical and shipping engineering shows a significant increase in the development of energy efficiency-oriented marine propulsion system technology. Recent studies discuss propeller design optimization, the development of hybrid and electric propulsion systems, and the implementation of data-driven propulsion control strategies to minimize fuel consumption and emissions (Gao et al., 2024; Yuan et al., 2022). In addition, integrated energy management and digital twin-based performance monitoring approaches are also beginning to be implemented to support more precise operational decision-making (Zhang et al., 2023; Coraddu et al., 2021). This technical approach shows great potential in improving the energy efficiency of ships, particularly in mathematically modelable operating conditions.

Nonetheless, a number of studies confirm that the increase in energy efficiency in real shipping practices is not always proportional to the technical potential available. Variations in energy performance between ships with similar technical specifications are often influenced by operational factors, operator behavior, and decision-making culture on board (Sardar et al., 2025; Psaraftis &

Kontovas, 2021). This indicates that the human aspect has a significant role in determining the success of the implementation of energy efficiency strategies, especially in propulsion systems that are increasingly complex and automated.

In this context, the concept of sense making becomes a relevant theoretical framework for understanding how ship operators construct meaning to dynamic and ambiguous operational situations. Sense making refers to the cognitive and social processes in which individuals interpret information, experiences, and environmental context to support meaningful decision-making (Weick et al., 2020). In shipping operations, operational sense making allows the crew to adjust the operation of the propulsion system based on sea conditions, engine load, speed targets, and energy efficiency and safety demands simultaneously (Hollnagel et al., 2022).

Research related to human factors in maritime systems shows that the operator's ability to understand the relationship between technical systems and operational contexts directly contributes to the energy performance and reliability of propulsion systems (Lützhöft & Dekker, 2021; Wróbel et al., 2023). However, studies that specifically link operational sense making to the energy efficiency of marine propulsion systems are still limited, especially in the mechanical and shipping engineering literature that tends to emphasize a technocentric approach.

Based on these conditions, there is a research gap between the development of energy efficiency-oriented propulsion system technology and the understanding of the operational sense making process by ship operators. Therefore, this study aims to analyze how operational sense making in the management of marine propulsion systems contributes to the achievement of energy efficiency in shipping operations. By integrating technical, human, and operational contextual perspectives, this research is expected to make a conceptual and practical contribution to the development of a more efficient, adaptive, and sustainable ship propulsion system operational strategy.

THEORETICAL REVIEW

Energy Efficiency in Ship Propulsion Systems

Energy efficiency in ship propulsion systems is one of the main focuses of modern engineering and shipping engineering research, considering that propulsion systems contribute significantly to the total energy consumption of ships. Several studies state that more than 70% of commercial vessel fuel consumption is used to support key propulsion systems, so optimization of propulsion performance is a key strategy in reducing emissions and operational costs (Baldi et al., 2020; Balcombe et al., 2019).

Recent research has placed a lot of emphasis on technical approaches such as propeller design optimization, efficient transmission ratio selection, and engine load regulation based on actual operating conditions. Wang et al. (2021) showed that adjusting engine load to wave conditions and ship speed can reduce fuel consumption by up to 8–12% without hardware modifications. In addition, an energy-aware propulsion control approach has also begun to be applied to balance engine performance and ship operational needs (Tillig et al., 2020).

Energy Management System and Ship Operations

In addition to hardware development, recent research also highlights the importance of a ship's energy management system integrated with shipping operations. The system enables real-time monitoring of energy consumption and supports data-driven operational decision-making (Papanikolaou et al., 2022). The use of decision support systems (DSS) in ship operations has been proven to increase crew energy awareness and encourage more efficient operating practices.

However, some studies reveal that the success of an energy management system depends largely on how operators understand and utilize available information. Tran et al. (2021) assert that failure to interpret operational data often leads to suboptimal decisions, even if the technical system has been well designed. This shows that technology alone is not enough without contextual understanding of the system users.

Human Factors in Propulsion System Operation

The study of human factors in the maritime system confirms that ship operators play a crucial role in determining the performance of technical systems, including propulsion systems. Research by Grech et al. (2020) shows that crew workload, experience, and risk perception affect the way propulsion systems operate, especially in dynamic and uncertain sea conditions.

In addition, Hetherington et al. (2019) found that variations in energy performance between ships with similar technical specifications are often due to differences in operational practices and work cultures on board. These findings reinforce the view that energy efficiency is not only a technical issue, but also a socio-technical phenomenon involving interaction between humans and systems.

Sense Making in the Context of Maritime Operations

The concept of sense making has been widely used to explain how individuals and groups understand complex situations in high-risk systems. In the maritime context, sense making helps explain how ship operators interpret technical information, environmental conditions, and operational pressures to produce meaningful decisions (Klein et al., 2021). This process is dynamic and heavily influenced by experiences, situational contexts, and interactions between crew members.

Research by Rankin et al. (2020) shows that sense making failures are often the main cause of inefficient or risky operational decisions, especially in complex and automated systems. In modern ship propulsion systems, where technical data abounds and operating conditions change rapidly, operational sense making capabilities are becoming increasingly important to bridge the gap between technical systems and operational reality.

Research Gap

Based on the literature review, it can be concluded that although research on the energy efficiency of ship propulsion systems and the development of supporting technologies has progressed rapidly, studies that explicitly integrate the perspective of operational sense making in the management of propulsion systems are still limited. Most research still focuses on technocentric approaches or model-based analysis, while the cognitive and operational processes of ship

operators have not been explored in depth. Therefore, this study seeks to fill this gap by analyzing the role of operational sense making in supporting the energy efficiency of ship propulsion systems in the context of real shipping operations.

METHODOLOGY

This study uses a qualitative approach with a case study design to explore in depth the operational sense making process in the management of marine propulsion systems that are oriented towards energy efficiency. The qualitative approach was chosen because this study aims to understand the cognitive, interpretive, and contextual processes of ship operators in operational decision-making, which cannot be fully explained through quantitative measurements alone (Creswell & Poth, 2018; Guest et al., 2012). Case studies are seen as appropriate to examine complex phenomena in real operational contexts, particularly in socio-technical systems such as modern shipping operations.

The object of research is focused on the operation of the main propulsion system of commercial vessels, by involving the engine crew and related operators who are directly responsible for the operation of the main engine and the management of the ship's energy consumption. The selection of participants was conducted by purposive sampling, with the criteria of at least five years of operational experience and active involvement in decision-making related to engine load management, ship speed, and energy efficiency strategies. This approach allows researchers to obtain rich and relevant data from informants who have a deep understanding of the ship's propulsion system and operational context (Patton, 2015).

Data collection was carried out through operational observations, semi-structured interviews, and analysis of technical documents. Observations were made to understand the direct operating practices of the propulsion system, including the operator's interaction with the control system and the response to changing environmental conditions. Semi-structured interviews are used to dig into how operators build understanding, interpret technical information, and make operational decisions related to energy efficiency. This interview approach allows for the flexibility of exploration while maintaining the consistency of the research theme (Kallio et al., 2016). In addition, documents such as engine logbooks, fuel consumption data, and ship operational guidance are analyzed to provide technical context and support data triangulation.

Data analysis was carried out using thematic analysis, with stages of open coding, thematic grouping, and interpretation of operational meanings that emerged from field data. The analysis process is focused on identifying operator sense making patterns in responding to operational conditions, energy efficiency pressures, and technical limitations of the propulsion system. This approach allows researchers to connect the subjective experiences of operators with the context of broader socio-technical systems (Braun & Clarke, 2019). The validity of the findings is maintained through triangulation techniques of sources and methods, as well as reflective discussions to minimize interpretive bias.

With this methodological approach, the research is expected to be able to provide a comprehensive understanding of the role of operational sense making

in supporting the energy efficiency of ship propulsion systems, as well as produce practical implications for the development of operational strategies and crew training in the era of sustainable shipping.

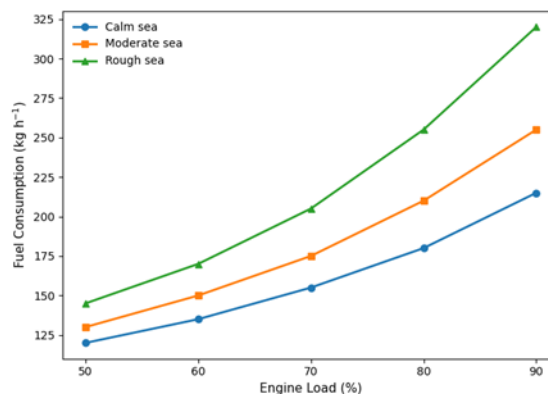
RESEARCH RESULTS

The analysis of qualitative data obtained through operational observations, in-depth interviews, and the review of technical documents resulted in a comprehensive understanding of how operational sense making is formed and carried out by ship operators in the management of energy efficiency-oriented propulsion systems. The results of the study show that energy efficiency is not only influenced by the technical configuration of the propulsion system, but also by the situational interpretation process carried out by the operator on the interaction between environmental conditions, operating demands, and engine system characteristics.

In general, the research findings are organized into four main interrelated themes, namely the meaning of the relationship between engine load and operational conditions, context-based adaptive decision-making, the role of experience and tacit knowledge, and the challenges of sense making in modern data-driven propulsion systems.

Operator's Interpretation of the Relationship between Machine Load and Operational Conditions

The results of the interviews show that the engine operator does not interpret the technical parameters of the propulsion system as a stand-alone variable, but as part of an interrelated operational context. Parameters such as engine rotation (RPM), engine load, fuel consumption, and working temperature are interpreted simultaneously along with marine conditions, currents, and ship stability. This contextual interpretation process allows operators to anticipate changes in engine performance and make preventive operational adjustments, so that the potential for energy inefficiency can be minimized from the early stages of operation.



Source: Authors' elaboration based on qualitative operational findings
Figure 2. Relationship between engine load and fuel consumption under different sea conditions.

As shown in Figure X, similar engine load levels result in markedly different fuel consumption depending on sea conditions. Under rough sea conditions, increases in engine load lead to disproportionately higher fuel consumption, supporting interview findings that emphasize the importance of contextual sense making by operators to avoid inefficient propulsion regimes. A engine room head explained:

"If we only follow the numbers on the panel, we often do not find the efficiency. The important thing is to read the machine's response to sea conditions. Sometimes the RPM drops a little, but the combustion is more stable." (KM-01, interview, February 12, 2025).

This contextual understanding shapes what operators call the "safe and efficient working zone" of the engine, that is, the operating range in which the engine does not work too hard but still meets the speed needs of the vessel. This kind of meaning is not always written down in official procedures, but develops through repetitive operational practices.

Sense Making in Adaptive Operational Decision Making

The second theme shows that operational sense making serves as the basis for adaptive decision-making in shipping operations. Operators interpret changes in sea conditions and schedule demands as signals to adjust the propulsion system's operating strategy. The decisions made often involve a compromise between speed, safety, and energy efficiency targets. A machine officer revealed:

"If the currents and waves are heavy, forcing the speed will make the machine work in the wasteful zone. Normally we agree to lower the speed a little bit, but the engine remains stable." (OM-03, interview, February 18, 2025)

Some operators report that this kind of adaptive decision contributes to the stability of daily fuel consumption. Based on a comparison of engine logs and consumption records, adjustments based on situational interpretation are reported to be able to maintain fuel consumption about 5-10% lower than standard operating patterns oriented towards target speed alone.

The Role of Experience and Tacit Knowledge in Energy Efficiency

The results also show that long-term operational experience plays an important role in shaping the quality of the operator's sense of making. Experienced operators tend to have the ability to anticipate changes in engine performance and can detect potential inefficiencies before system indicators show anomalies. A senior driver stated:

"Every ship has a character. After a long time here, we know when the machine starts to be inefficient, even before the alarms or graphs change." (MS-05, interview, February 25, 2025).

In contrast, relatively junior operators tend to rely more on digital monitoring systems and alarms. This difference suggests that energy efficiency is the result of a combination of technological support and tacit knowledge gained through hands-on experience in the field.

The Challenges of Sense Making in Modern Propulsion Systems

Although modern propulsion systems are equipped with data-driven monitoring technology, this study found that the complexity of information can actually be a challenge in the sense making process. Operators face information overload conditions that demand high selection and interpretation skills. A machine operator explains:

"The data is now very much. The challenge is not a lack of information, but choosing which ones are really relevant for quick decisions." (OM-02, interview, March 3, 2025)

However, not all operators view the adaptive approach as the optimal solution. Some informants show skepticism about meaning-based decision-making that is too complex.

"If there is too much consideration, it is hesitant. Sometimes it's safer to go back to the default setting." (OM-04, interview, March 6, 2025).

This contrasting quote shows that sense making is not a process that is always linear or uniform, but rather is influenced by individual preferences, experience, and operational pressures.

Thematic Summary of Research Findings

To clarify the structure of the findings, the results of the study are summarized in Table 1.

Table 1. Summary of the Research Theme

Main Themes	Subtheme	Informant Code	Implications for Energy Efficiency
Interpretation of machine load	Integration of marine conditions	KM-01, OM-03	Fuel consumption stability
Adaptive decisions	Speed compromise	OM-02, OM-03	Avoidance of extravagant operations
Tacit knowledge	Operational experience	MS-05	Long-term efficiency
Data complexity	Information selection	OM-02, OM-04	Risk of suboptimal decisions

Synthesis of Research Results

Overall, the results show that the energy efficiency of the ship's propulsion system is a product of the dynamic interaction between humans, technology, and the operational context. Operational sense making serves as a connecting mechanism between the technical propulsion system and the reality of complex shipping operations. Operators who are able to build contextual and reflective understanding tend to produce more energy-efficient operational decisions, despite being under technical constraints and operational pressures. These findings provide an important basis for further discussion of the theoretical and practical implications of operational sense making in the management of energy-efficient ship propulsion systems.

DISCUSSION

The results show that energy efficiency in the operation of a ship's propulsion system cannot be understood solely as an output of the engine's technical performance, but rather as a result of the dynamic interaction between humans, technology, and the operational context. The finding that operators interpret technical parameters holistically reinforces the view that modern shipping systems are complex socio-technical systems, where the quality of performance is greatly influenced by the ability of human actors to understand and manage these complexities (Baxter & Sommerville, 2021). The operational sense making process allows operators to bridge the gap between the technical representation of the propulsion system and the ever-changing real operational conditions, so that the decisions taken are not mechanistic, but contextual and adaptive.

Contextual interpretation carried out by operators plays an important role in avoiding energy-inefficient operating zones. The results show that engine load adjustment and speed compromise based on the interpretation of sea conditions and ship stability can significantly reduce fuel consumption compared to a speed target-oriented approach. These findings are in line with research that confirms that fixed-speed-based operating strategies tend to increase energy consumption disproportionately, especially in sub-ideal environmental conditions (Cariou et al., 2021). In this context, sense making serves as an evaluative mechanism that allows operators to assess the trade-offs between energy efficiency, system reliability, and operational demands.

The role of tacit knowledge and operational experience also emerged as key factors in shaping the quality of sense making. Experienced operators demonstrate a stronger anticipatory ability to efficiently manage the propulsion system, even before technical indicators indicate potential inefficiencies. This supports the literature that suggests that experience-based knowledge is an important component in the management of high-risk systems and cannot be completely replaced by automated systems or optimization algorithms (Nonaka & Toyama, 2021). Thus, the energy efficiency of ships depends not only on technological sophistication, but also on the cognitive and reflective capacity of the operator in interpreting the operational situation appropriately.

On the other hand, the research findings also show that the increasing complexity of energy monitoring systems can pose the challenge of information overload which has the potential to hinder the sense making process. While digital systems provide increasingly detailed and real-time data, the operator's ability to filter and prioritize information is a key determinant of decision-making effectiveness. This phenomenon is consistent with studies on situation awareness which emphasize that an increase in the amount of information is not always directly proportional to an increase in situational understanding (Endsley, 2020). Therefore, the design of propulsion systems and energy monitoring interfaces needs to consider the cognitive aspects of the user in order to support, rather than inhibit, the operational sense making process.

Theoretically, this study expands the discourse on shipping energy efficiency by placing operational sense making as a central mechanism in

explaining the variability of energy performance between ships with similar technical specifications. In practical terms, these findings imply the need to develop an energy management strategy and crew training that not only emphasizes procedural compliance, but also interpretive capabilities and adaptive decision-making. By integrating human and technological perspectives, this research makes an important contribution to the development of more efficient and sustainable shipping practices.

CONCLUSIONS AND RECOMMENDATION

This study shows that energy efficiency in the operation of the ship propulsion system is the result of the operator's operational sense making process, not solely the technical performance of the engine. Operators interpret technical parameters and operational conditions holistically to support energy-efficient, adaptive decision-making. These findings affirm the importance of integrating human and technological aspects in the management of propulsion systems, and place operational sense making as a key mechanism in supporting efficient and sustainable shipping practices.

FURTHER STUDY

Future research could extend this study by employing quantitative or mixed-method approaches to examine the relationship between operational sense making, energy efficiency, and fuel consumption across a broader range of vessel types and operating conditions. Comparative studies across different ship categories, propulsion technologies, or regulatory contexts would deepen understanding of how contextual factors influence operators' decision-making. Longitudinal research may also explore how sense-making practices evolve with digitalization, automation, and the adoption of alternative fuels, thereby contributing to more adaptive and sustainable ship propulsion management strategies.

REFERENCES

- Baldi, F., Ahlgren, F., Nguyen, T. V., Thern, M., & Andersson, K. (2020). Energy and exergy analysis of a cruise ship. *Energy*, 199, 117353. <https://doi.org/10.1016/j.energy.2020.117353>
- 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>
- Baxter, G., & Sommerville, I. (2021). Socio-technical systems: From design methods to systems engineering. *Systems Engineering*, 24(3), 211–223. <https://doi.org/10.1002/sys.21562>
- Bouman, E. A., Lindstad, E., Riialand, A. I., & Strømman, A. H. (2020). State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping. *Transportation Research Part D: Transport and Environment*, 52, 408–421. <https://doi.org/10.1016/j.trd.2017.03.022>

- Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise and Health*, 11(4), 589–597. <https://doi.org/10.1080/2159676X.2019.1628806>
- Cariou, P., Cheaitou, A., & Nguyen, N. T. (2021). Speed reduction and maritime emissions: A quantitative analysis. *Transportation Research Part D: Transport and Environment*, 92, 102723.
- Coraddu, A., Oneto, L., Baldi, F., Anguita, D., & Figari, M. (2021). Data-driven ship energy efficiency analysis and optimization. *Applied Energy*, 286, 116485. <https://doi.org/10.1016/j.apenergy.2021.116485>
- Creswell, J. W., & Poth, C. N. (2018). *Qualitative inquiry and research design: Choosing among five approaches* (4th ed.). SAGE Publications.
- DNV. (2022). *Maritime forecast to 2050: Energy transition outlook*. DNV AS.
- Endsley, M. R. (2020). Designing for situation awareness in complex systems. *Human Factors*, 62(1), 12–24. <https://doi.org/10.1177/0018720819877669>
- Gao, F., Brodtkorb, A. H., Zadeh, M., & Mo, S. M. (2024). Power management and optimization of marine hybrid propulsion systems. *Ocean Engineering*, 290, 118354. <https://doi.org/10.1016/j.oceaneng.2024.118354>
- Grech, M. R., Horberry, T., & Koester, T. (2020). *Human factors in the maritime domain*. CRC Press.
- Guest, G., Namey, E., & Saldaña, J. (2012). *Collecting and analyzing qualitative data*. SAGE Publications.
- Hetherington, C., Flin, R., & Mearns, K. (2019). Safety in shipping: The human element. *Journal of Safety Research*, 70, 107–116.
- Hollnagel, E., Wears, R. L., & Braithwaite, J. (2022). From Safety-I to Safety-II: A white paper. *Safety Science*, 134, 105130.
- International Maritime Organization. (2023). EEXI and CII—Ship carbon intensity and rating system. IMO. <https://www.imo.org>
- Kallio, H., Pietilä, A. M., Johnson, M., & Kangasniemi, M. (2016). Developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing*, 72(12), 2954–2965. <https://doi.org/10.1111/jan.13031>
- Klein, G., Moon, B., & Hoffman, R. R. (2021). Making sense of sensemaking 2: A macrocognitive model. *IEEE Intelligent Systems*, 36(4), 8–14. <https://doi.org/10.1109/MIS.2021.3071556>
- Lützhöft, M., & Dekker, S. (2021). Human factors in maritime operations. *Cognition, Technology & Work*, 23(3), 375–389.
- Nonaka, I., & Toyama, R. (2021). Knowledge creation and management in dynamic environments. *Knowledge Management Research & Practice*, 19(1), 1–10. <https://doi.org/10.1080/14778238.2020.1831521>
- Papanikolaou, A., Zaraphonitis, G., & Boulougouris, E. (2022). Holistic ship energy management in the era of decarbonization. *Ocean Engineering*, 266, 112857. <https://doi.org/10.1016/j.oceaneng.2022.112857>
- Patton, M. Q. (2015). *Qualitative research & evaluation methods* (4th ed.). SAGE Publications.
- Psaraftis, H. N., & Kontovas, C. A. (2021). Speed models for energy-efficient maritime transportation. *Transportation Research Part C: Emerging Technologies*, 129, 103213. <https://doi.org/10.1016/j.trc.2021.103213>

- Rankin, A., Lundberg, J., & Woltjer, R. (2020). Resilience engineering in high-risk systems: The role of sensemaking. *Safety Science*, 132, 104972. <https://doi.org/10.1016/j.ssci.2020.104972>
- Sardar, R. A., Islam, R., Anantharaman, M., & Garaniya, V. (2025). Advancements and obstacles in improving the energy efficiency of maritime vessels: A systematic review. *Marine Pollution Bulletin*, 199, 116020. <https://doi.org/10.1016/j.marpolbul.2024.116020>
- Tillig, F., Ringsberg, J. W., Mao, W., & Ramne, B. (2020). Energy-efficient ship operation – A review. *Renewable and Sustainable Energy Reviews*, 121, 109593. <https://doi.org/10.1016/j.rser.2019.109593>
- Tran, T. A., Yu, Q., & Fang, F. (2021). Data-driven decision support for ship energy efficiency management. *Ocean Engineering*, 235, 109409. <https://doi.org/10.1016/j.oceaneng.2021.109409>
- Wang, H., Yuan, Z., & Chen, L. (2021). Operational optimization of ship propulsion systems for energy efficiency improvement. *Journal of Marine Science and Technology*, 26(3), 457–469. <https://doi.org/10.1007/s00773-020-00772-4>
- Weick, K. E., Sutcliffe, K. M., & Obstfeld, D. (2020). Organizing and the process of sensemaking. *Organization Science*, 31(1), 1–17.
- Wróbel, K., Montewka, J., & Kujala, P. (2023). Towards human-centred ship operation: The role of operators in complex maritime systems. *Reliability Engineering & System Safety*, 230, 108896.
- Yuan, Z., Wang, H., & Chen, L. (2022). Energy-efficient control strategies for marine propulsion systems: A review. *Journal of Marine Science and Engineering*, 10(8), 1104. <https://doi.org/10.3390/jmse10081104>
- Zhang, D., Li, X., & Yang, Y. (2023). Digital twin-driven energy management for ship propulsion systems. *Energy*, 263, 125652.