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ARTICLE

An overview of sociotechnical research on maritime energy efficiency

Martin Viktorelius[1] · **Hanna Varvne**[2] · **Hannes von Knorring**[3]

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Abstract

A qualitative synthesis is presented covering the literature on operational energy efficiency in shipping based on research from a sociotechnical perspective. Three themes were identified, using thematic analysis, as particularly significant for the management of energy: (i) cooperation, communication, and knowledge sharing between stakeholders; (ii) organizational information processing (cognitive bottlenecks and sense making practices); and (iii) professional education and training. We conclude that while previous research has uncovered many of the barriers to increasing energy efficiency, few studies have examined the interdependence of practices and technologies underlying organizational cognitive systems and change. The identified research gap calls for more longitudinal process-based case studies investigating the design, implementation, and use of information technologies supporting organizational planning and decision-making required for improving energy efficiency.

Keywords Energy efficiency · Maritime informatics · Organization · Management · ICT, Sociotechnical cognitive systems

✉ Martin Viktorelius
Martin.viktorelius@lnu.se

Hanna Varvne
hanna.varvne@gu.se

Hannes von Knorring
hannes.von.knorring@dnv.com

1 Faculty of Technology, Kalmar Maritime Academy, Linnaeus University, Kalmar, Sweden

2 Department of Business Administration, Gothenburg Research Institute, University of Gothenburg, Gothenburg, Sweden

3 DNVs, Gothenburg, Sweden

1 Introduction

The literature on how to decarbonize the international maritime transport sector is rapidly growing. In order to reach the goals stated in the Paris Agreement, or even the weaker goals agreed on by countries in the International Maritime Organization's Initial GHG Strategy, several research strategies and actions need to be taken. Modeling studies show that substantial reductions can still be achieved at low costs. While new low-carbon ship propulsion systems are very expensive, many operational options are still available for improving energy efficiency and reducing carbon emissions (Eide et al. 2009).

Some energy efficiency measures require low capital costs while reducing operating costs. More recently, Schwartz et al. (2020) showed how more than 50% reductions in CO_2 emissions could be achieved in the sector by implementing "profitable" measures. This puzzling situation has in turn generated research on "barriers" to energy efficiency in the sector (Dewan et al. 2018; Jafarzadeh and Utne 2014; Johnson et al. 2014; Rehmatulla and Smith 2015). Here, barrier is often defined as a mechanism that hinders a decision to implement a particular measure. Similarly, surveys carried out by DNV-GL, the world's largest classification society, showed that very few companies were able to implement more complex measures and achieve savings above a few percentages. This provokes the question: if many actors in the sector are not able to implement even the simpler, economically rational cost-effective measures, how should they be able to deal with more complex measures under an uncertain future climate policy regime?

To increase the understanding of this type of question, we draw upon a broader trend in general energy research, that is, the "social turn" (Sovacool 2014), emphasizing the need to address problems related to energy use from a multidisciplinary perspective (Palm and Thollander 2020). Schwanen et al. (2011) for their part argued for an increased focus on (qualitative) research methods and questions from the social and cognitive sciences, in particular practice theories and socio-technical perspectives. This could be generalized to current research on maritime transport, which is dominated by quantitative methods, often focusing solely on parameters such as (operating and capital) costs of measures and their associated reductions in emissions. While this research yields important insights into the most cost-efficient technological pathways for reducing emissions, these methodological choices also inadvertently limit the discussion. For example, if only costs and emissions are modeled, the most important means of attempting to change the sector becomes a carbon price. Other research frameworks may lead to other kinds of discussions on what points of leverage are available. Such a broadening of the disciplinary scope and research questions related to decarbonization in the maritime sector has recently started to be seen.

The literature with broader social focus and inclusion of disciplines acknowledges that most of the measures described to mitigate climate impact of the sector need to be characterized as *sociotechnical* in nature. This means that measures always depend on mutually constituted resources of humans, organizations and technologies, and the practical capacity of shipping companies (i.e. managers and crew members) to organize work and manage the complexity associated with decarbonization. From the perspective of this research tradition, a slow take-up of new measures is only to be expected. As Markard et al. (2012) showed, pathways that involve changes to multiple technologies, infrastructures, organizations, and institutions are often explored slowly. They require development and testing of novel concepts on a global scale, large investments in technologies, and infrastructures with little immediate benefits and complex coordination between regulatory and private bodies. Even the most rational, cost-effective measures may be overlooked if they do not fit into existing work practices, competences, or institutions (Shove 1998; Viktorelius 2020; von Knorring 2019).

In this paper, we review studies on the organization and management of operational energy efficiency in the maritime sector. Our analysis indicates that conceptions of the implementation of energy efficiency measures, as represented in policy discussions and research studies, is often a purified and rationalistic model of an idealized end state with little empirical attention towards the implementation process itself. Removed from its real-life context of conflicts and contingencies, the existence of a large potential looks irrational. But when energy efficiency is examined as it occurs—or not—a greater appreciation of the challenges is achieved. We explore this sub-field concerned with the practice of maritime energy efficiency by asking: *What has research on ship energy efficiency, concerned with cognitive and social factors, revealed so far?*

We synthesize the fundamental difficulties and possibilities related to *changing* current *practices* towards a more sustainable sector of transportation as identified in these studies. We then return to what these insights, gained from social and cognitive sciences, can offer research grounded mainly in engineering or economic frameworks. Finally, given the still small amount of cognitive and social science research on energy use and decarbonization of maritime transport, we suggest future research directions as suggested by research in other domains.

2 Method

A qualitative research synthesis was conducted according to the recommendations of Major and Savin-Baden (2010). This is a qualitative method to analyze, synthesize, and interpret the results from previous studies in order to present a narrative account of the findings and provide recommendations for policy or research. It consists of three primary phases of analysis: (1) summarizing findings across studies and identifying which of those findings are clear and supported; (2) comparing and aggregating these findings; and (3) interpreting findings in relation to core themes that emerge across studies.

The material used in the synthesis included peer-reviewed journal articles indexed in two online databases (Scopus and Web of science). The search string used for identifying articles was (energy efficiency) AND (ship* OR maritime), with a timespan between 2009 and 2020. The search included all journal or review articles containing the search terms in the title, abstract, or keywords section. This generated 448 records in Web of Science (WoS) and 821 records in Scopus. In the next stage (screening), all abstracts were read in order to identify articles that explicitly addressed, discussed, or had direct implications for the cognitive, cultural, organizational, or socio-technical dimension of energy efficiency or energy management. This meant that the paper needed to include cognitive and sociomaterial factors that de facto were shown to influence human work and praxis, for example, how commercial decision or collaboration take place and what implications this have on the social realities of those working in the shipping industry. However, this also meant excluding articles that on a purely abstract level investigated mathematical decision-making and such, unless the study also included an analysis on what this type of tool would mean in practice. A qualitative judgment was made whether the articles fulfilled these criteria which only excluded articles that were purely written from a technical or engineering perspective. In cases where reading the abstract was not sufficient to make the judgment, the rest of the article was read as well. The screening stage generated 27 records for further analysis (Fig. 1). During the third stage, the content in the articles' results and discussion sections was coded and analyzed using thematic analysis (Braun and Clarke 2006; Dixon-Woods et al. 2005).

3 Results

The literature on the organization and management of energy in shipping covers a broad range of shipping segments and includes cases illustrating both successful efforts and practices as well as challenges and barriers (Ölçer et al. 2018). In this review, three major themes were identified: (i) cooperation, communication, and knowledge sharing between stakeholders; (ii) organizational information processing (cognitive bottlenecks and sensemaking practices); and (iii) professional education and training. While emphasizing these themes, we do not claim that they are exhaustive of the issues related to the organization of maritime energy efficiency but merely indicate some of the examined prominent concerns. Many studies report various challenges associated with the practical realization of energy efficiency and that a significant potential for improving energy efficiency still exists (Bouman et al. 2017). The following sections synthesizes the identified issues reported in the literature.

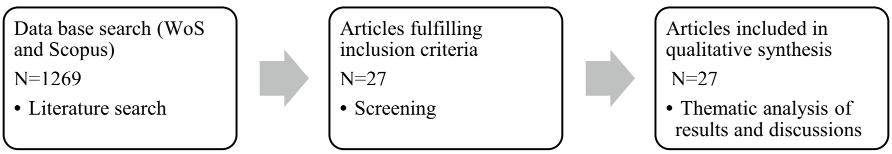

Fig. 1 Stages of review process

3.1 Cooperation, communication, and knowledge sharing between stakeholders

The work to improve ship energy efficiency cannot be reduced to the accomplishment of a single decision-maker but depends on the active engagement and collaboration among several distributed professional groups and actors. The actors with influence on energy efficiency range from individual ship officers (navigators, engineers, etc.) to ship yards, shipowners, operators, charterers, cargo owners, ports, and traffic management services (Jafarzadeh and Utne 2014; Poulsen and Sampson 2019). The diversity of actors and the divergence of their practices, cultures, and concerns, grounded in their different roles and responsibilities, create boundaries and tensions in interaction, which complicates collective efforts of improving energy efficiency (Poulsen and Sampson 2020).

One example of this was identified by Armstrong and Banks (2015) who distinguished between operational, technical, and commercial stakeholders and described them as having differing functions, roles, and responsibilities, limiting their interactions. Armstrong and Banks (2015) illustrated their point with the example of hull maintenance during dry docking. The example showed how the lack of a coherent approach, including gaps in responsibilities between the stakeholders, mutually exclusive goals, and focus areas as well as differing conceptions of performance monitoring, leads to reactive and minimal maintenance. Consequently, hull cleaning is often made after the deterioration is well established and confirmed rather than as part of proactive planning based on forecasts and projections generated by integrated business processes and systems.

The studies by Johnson et al. (2014) and von Knorring (2019) indicate how the efforts of implementing an energy management system and a number of identified measures was permeated by and eventually fell apart because of various contingent organizational issues that could not easily have been dealt with solely at the planning stage but had to be resolved when encountered. As described in the study of von Knorring (2019), a consultant was hired by the shipping company to conduct an energy audit which generated several recommended measures amounting to a substantial expected increase in energy efficiency if implemented. However, due to a plethora of organizational reasons and strategic decisions with unexpected effects, many of the measures were never implemented, and some that were had not been planned from the beginning. von Knorring (2019) argue that “there was no specific point at which personnel at ShipCo [the shipping company] took the decision to move forward with some suggestions provided in the audit, and not to implement others.” Rather, the decisions just “happened” as a result of organizational priorities and practices. Borg and von Knorring (2019) and Borg and Yström (2019) conducted an ethnographic case study on a multi-actor collaboration project. The project aimed at knowledge sharing between companies for increased energy efficiency and included development of a database with energy efficiency measures, a series of workshops to educate onboard personnel in matters related to energy efficiency, and the establishment of a network of energy efficiency experts in the partner organizations. However, the longitudinal study showed that the database was never finalized. Few participants engaged in the workshops and expert networks because of difficulties of engaging people to participate and managing conflicting opinions about collaboration structures and goals as well as problems in concretizing and agreeing on shared visions. Borg and von Knorring (2019) and Borg and Yström (2019) showed that the failure to create the energy efficiency database and expert-network project had mainly to do with the inability of the stakeholders to agree on a mutual agenda and shared goals.

Focusing on the relation between ship crew and onshore management, Poulsen and Sornn-Friese (2015) found that problems in communication and cooperation was a crucial barrier in energy-efficient voyage execution. Crews did, for instance, rarely get any decision support or guidance on matters of optimal speed, ship trim, or onboard power demand, although managers did not think these issues were properly handled by the crews onboard. The lack of communication was conceived as a particularly devastating problem since the outcome of individual fuel-saving initiatives can, according to the authors, seldom be properly anticipated a priori. In many cases, real-world experiments need to be performed onboard ships, and the actual savings can only be properly assessed subsequently. This requires trust and continuity in relationships among stakeholders, including crews, ship managers, and performance monitoring specialists, and depends on continuous interaction and collaboration between ship and shore over an extended period of time (Poulsen and Johnson 2016). Similarly, Hansen et al. (2020) emphasize that successful planning and implementation of measures for improving energy efficiency is dependent on the cooperation of crews and shore managers in order to ensure that the measures are adjusted to fit individual vessels, the working patterns and contractual conditions, and to make the defined goals meaningful to the crew on board. Johnson et al. (2014) described a similar paradox related to the cooperation in shipping. They found that since the potential for improvement in energy efficiency was divided into many smaller areas in various parts of the organizations that they investigated, no one was fully responsible or held accountable for energy use within the companies they studied.

The review showed that it is a common practice in the shipping industry not to involve the crew in the implementation of new technologies (Allen 2009; Bhardwaj et al. 2019; Sampson and Tang 2015). This was seen to be the case in a study on the implementation of a fuel monitoring system onboard RoPax vessels conducted by Viktorelius and Lundh (2019). While managers in the company that installed the system on its ships were convinced that the system would be used to improve energy efficiency, most crew members thought the system was misaligned with their current skills, practices, and resources. Without any support or collaboration between the crews and the managers onshore regarding the use of the system, it never became integrated with or influenced the onboard practices. In a contrasting case study of the implementation of a similar fuel monitoring system, the managers onshore pursued another strategy, characterized by an engaged and interactional approach analyzing and adapting the implementation strategy to the particular context, which involved and empowered the crews in the exploration phase of the newly installed system (Viktorelius 2020). In this company, more work and effort by the shore management had been put into making the system a meaningful tool in the development of the officers' skills and navigational practices. Consequently, most officers claimed to have changed their old habits by learning from using the system.

Investigations of the cooperation between, rather than within formal organizations, have revealed additional challenges of coordinating collective efforts to improve energy efficiency. Johnson and Styhre (2015) studied unproductive waiting time in ports and the potential for energy efficiency associated with decreased speed. They emphasized the large number of actors and stakeholders that need to collaborate and organize their resources and knowledge to achieve efficient unloading/reloading of cargo from the ships. They argued that the inefficiencies found in their case study could for instance have been reduced by better cooperation and communication between ports, the ship operator, the ship agent, stevedores, and crews.

3.2 Organizational information processing: cognitive bottlenecks and sensemaking practices

Many authors see access to reliable and detailed information on energy consumption as a prerequisite for the improvement of energy efficiency and the development of energy-saving practices (Armstrong and Banks 2015; Jafarzadeh and Utne 2014; Johnson and Styhre 2015; Man et al. 2018; Schøyen and Bråthen 2015). This information should be collected over time and be distributed to different actors in and across shipping organizations and departments. Information is, according to many scholars, necessary for accurate and timely decisions on investments in energy efficiency measures. Information is seen as generally raising awareness about energy consumption among all decision-makers at sea and onshore. It is emphasized that energy management requires real-time data and extensive sub-metering of all energy consumers throughout a ship in order to identify and realize cost-effective fuel-saving initiatives and adjust practices accordingly (Poulsen and Johnson 2016). However, studies suggest that lack of information is a central barrier in the work of improving energy efficiency (Dewan et al. 2018; Johnson and Andersson 2014). Based on a large number of interviews with managers in different maritime organizations, Poulsen and Johnson (2016) argued that many shipping companies lack accumulated real-time data based on sub-metering of the energy performance of their vessels. This was considered to prevent decision-makers at sea and onshore from making adequate and prompt changes in ship operations to save fuel and from seeing the effects of their decisions and correct for inefficiencies. Data is often gathered manually and electronically through numerous logbooks onboard vessel (e.g., the engine room logbook, navigation logbook, cargo logbook, oil record book). Utilization of this data for vessel performance analysis and improvement is thought to pose a challenge as noon data only consists of aggregated or summative single data points (distance traveled, total consumed fuel, overall weather conditions, etc.). In other words, there seems to be a bottleneck of information processing in shipping companies where potential sources of information are not synthesized and utilized for the purpose of better decision-making (Viktorelius and Lundh 2016).

However, while the collection of information on energy efficiency measures and ship performance is often argued to be a necessary component in energy management, an equally important aspect of information is how, or whether, it is used. As expressed by Johnson et al. (2014, p. 323): “not only does data need to be gathered;

resources need also to be put into analyzing." Just presenting fuel statistics to crews is not enough since the complexity of the data does not allow unambiguous causal inferences and clear implications for actions (Viktorelius and Lundh 2019). Hence, information management refers here not only to the collection of information but, more crucially, to the processing and understanding of the data and the distribution of the conclusions to relevant actors. Indeed, the review indicates that there are major challenges associated with the sensemaking practices related to information on fuel consumption and energy performance of ships, including the identification of trends and assessments of fuel-saving initiatives as well as feedback to crew members (Poulsen and Johnson 2016; Viktorelius and Lundh 2019). The challenges include normalizing the data and accounting for the considerable noise caused by varying operational and weather conditions (Armstrong and Banks 2015; Johnson and Andersson 2014; Viktorelius and Lundh 2019). Consequently, studies have shown that the availability of information does not necessarily lead to change in the practices and skills of managers and crew members and that the use of information depends on cultural, organizational, and institutional factors (Viktorelius 2020; Viktorelius et al. 2021). Johnson et al. (2014) conducted a case study on the implementation of an energy management system (ISO 50001) and found that while efforts to systemize data gathering from the main shore organization had been done, there still was a lot of confusion on the performance.

Another difficulty associated with sensemaking practices assessing energy performance of ships relate to organizational boundaries and responsibilities. Jafarzadeh and Utne (2014) noted that the organizational processing of information might be facilitated in companies that have all parties, such as crewing, in-house. This was elaborated by Poulsen and Sornn-Friese (2015) who showed that the provision and distribution of information and training to crew members may be limited by operations under third-party management, making it difficult to achieve energy efficient ship operations during such organizational arrangements. Further, Poulsen and Johnson (2016) argued that adequate information management practices take a long time to develop and that one of the reasons for the insufficient information management practices are the current business models in shipping and the types of charter contracts which build on temporary organizations with durations of weeks or a few months.

According to Armstrong and Banks (2015), it is sometimes expected that the staff onboard should "decipher the information or data gathered by the different systems onboard, service providers and shore staff, and then implement optimized operations onboard the vessel." However, the authors continue, "with minimal staff onboard it could be a far stretch to expect integration of information and analysis provided by different systems." Armstrong and Banks (2015) therefore conclude that "there should be an integration of the systems used onboard ships, to allow for analysis and distribution of consistent and not conflicting performance feedback: minimizing the responsibility and burden of integration by staff." Man et al. (2018) elaborated on the design requirements of an onboard decision support system for ship energy efficiency and highlighted the informational needs of navigators and engineers during voyage planning, execution, and evaluation. They also suggested that the design framework should enable social interaction, learning, and the creation of a mutual ground between crewmembers in bridge and engine departments. Lützen et al. (2017) emphasize that a real-time support system has to be meaningful to both the crew and to managers to support the decisions made onboard and ashore. In particular, it has to take the requirements of different stakeholders (authorities and charters) into account as well as the environmental (weather), technical (ship and equipment), and operational (e.g., navigation vs. harbor work) conditions and present "the best option in the given situation." However, Rasmussen et al. (2018) found that the availability of fuel consumption indicators on the bridge did not have a large impact on the practices because the ship speed was predefined in the charter contract which made officers less motivated to use the information from the fuel meters for adjusting the speed or implementing other energy efficient initiatives. While the fuel was paid by the charterer and not the shipping company seafarers were not encouraged to save fuel, which could even lead to a penalty if the specified ship speed was not maintained. The type of charter and the priorities of the company thus influenced the attitudes of the seafarers and the use of the fuel consumption indicators.

3.2.1 Professional education and training

Several researchers emphasize the role of crew members' knowledge, motivation, and awareness for the realization of energy efficiency (Baldauf et al. 2018; Banks et al. 2014; Bännstrand et al. 2016; Rasmussen et al. 2018; Viktorelius 2018). Bertram et al. (1983, 162) argued, for instance, already almost 4 decades ago that the "development of crew understanding, motivation, cooperation, and participation" has "the greatest potential for saving fuel." Kitada and Ölçer (2015, 5) suggest, more recently, that the "human element in energy management should be treated as equally important as technology."

The International Convention on Standard of Training Certification and Watchkeeping for Seafarers (STCW) was updated in 2010 to include changes in each chapter for marine environmental awareness training. However, the requirements have been criticized for being vague and that maritime education and training (MET) rarely include energy efficiency as a learning objective (Banks et al. 2014). Moreover, while the SEEMP guideline (IMO 2016) states that effective and steady implementation of the adopted measures requires "raising awareness of and providing necessary training for personnel both on shore and on board", it is unclear what "necessary training" means. Few studies have addressed education and training in energy efficient ship operation. One notable exception is the study by Jensen et al. (2018) on simulator-based training of energy efficient operation. The educational approach suggested in the study builds on the idea of creating an environment where students can learn to reflect in and on action and develop their understanding of how to navigate the ship and what competence in relation to energy efficiency means in their community of practice.

However, the need for learning in relation to energy efficiency can not only be met by formal training but does also require workplace, or on-the-job, learning. This was illustrated in a study by Viktorelius (2018) on the acquisition of skills for energy efficient navigation. Since the potential actions for improving energy efficiency are highly contingent on the particular ship and operational tasks assigned to crew members, they have to identify the particular possibilities for saving energy in the situation they find themselves. In order to do this, crews have to develop their understanding and gain deep knowledge about the particular systems they are operating and how to meet various contradictory objectives in unpredictable circumstances. An important source for this understanding is the development of collective know-how among colleagues (Viktorelius 2020).

4 Conclusions and further research

The synthesis of the literature on the cognitive and sociotechnical aspects of energy efficient ship operation revealed three interrelated themes: (i) cooperation, communication, and knowledge sharing between stakeholders; (ii) organizational information processing (cognitive bottlenecks and sensemaking practices); and (iii) professional education and training.

It is clear from previous research that substantial potential exists for further improving energy efficiency in maritime transportation. To a large extent, previous research has focused on technical and/or economical assessments of the potential and the development of theoretical models of optimal decision-making. This has left a gap in explaining, first, why such a large potential can exist without being implemented in practice, and second, how this gap can be closed. In this paper, we reviewed research that focused on the actual realization of energy efficiency or energy management by accounting for the human, cultural, and organizational dimensions.

The reviewed research demonstrate that the development and implementation of energy efficient practices takes time and depends on collaboration, trust, negotiation, interaction, and knowledge sharing. It was seen to be affected by organizational arrangements, business models, contractual demands, technological infrastructure, learning opportunities, crew empowerment, and implementation strategies. With energy efficiency practices being influenced by these matters, it is likely that there might be some differences between shipping segments in how to approach these matters. However, due to the thematic focus of this study and low number of studies, it was difficult to detect any such patterns. There was a low level of discrepancy identified in the literature and the dissimilar findings seems to rather be a result of different enquiries and scholarly interest than conflicting findings.

While the collection of information in performance monitoring practices related to energy consumption was seen to be lacking in many companies, it was also highlighted that information, monitoring, and measuring per se does not automatically improve energy efficiency. Instead, it seems to be the interaction of human, organizational, and technological resources that determine the capacity of shipping companies and ports to identify and implement technical and operational measures that improve energy efficiency. The review suggests that the cognitive challenges of processing collected energy data and drawing practical conclusions for daily operational decisions should not be underestimated. The multiplicity and complexity of factors involved in optimizing a voyage is likely to require further development of current informational practices and technologies.

We therefore suggest more studies on how different actors in different maritime organizations make sense of information systems facilitating energy efficiency and how it is used in fleet management, voyage planning, and execution. It is important to understand how better cognitive practices of information management, including technologies for collecting and analyzing information, can be developed and how such practices relate to actual decision-making in relation to energy efficiency. The promising area of maritime informatics research is therefore likely to grow in importance (Lind et al. 2020). An insufficiently studied area associated with energy management identified in the review is the actual activities and organizational change processes required by the digitalization and automation of the shipping sector, also known as the fourth industrial revolution. In particular, how machine learning and artificial intelligence can be practically utilized in both analysis and decision support for energy efficient ship operations has only recently started to be investigated. Interesting research questions include: How do organizational cognitive practices, supported by these technologies, emerge and develop over time and what factors influence their establishment? Longitudinal and process-based studies (cf. Langley and Tsoukas 2016) on how shipping companies and other maritime actors organize and implement digital technologies and changes to improve energy efficiency are of particular importance in this regard.

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