Proceedings of the 35th European Safety and Reliability & the 33rd Society for Risk Analysis Europe Conference
Edited by Eirik Bjorheim Abrahamsen, Terje Aven, Frederic Bouder, Roger Flage, Marja Ylönen
 Published by Research Publishing, Singapore.
doi: 10.3850/978-981-94-3281-3_ESREL-SRA-E2025-P8014-cd

Health and Safety in the Norwegian Offshore Wind Industry: Knowledge Gaps and Research Needs

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Offshore wind is a growing industry with inherent safety challenges. Previous research has concluded that the safety of offshore wind maintenance personnel remains an understudied topic. A literature search conducted as part of this study confirms these findings. Our study explores potential knowledge gaps regarding maintenance personnel safety in the emerging offshore wind industry in Norway. Data collection includes a) a survey sent to members of the Norwegian Offshore Wind Health, Safety and Environment (NOW HSE) working group, and b) notes from researcher guided group discussions at a NOW HSE workshop. The results show that research participants experience an overall knowledge gap regarding health and safety themes in the industry, particularly related to the coming regulatory framework. We argue that there is a need for developing research-based knowledge, in particular studies with a system perspective considering the whole value chain. Given the study's relatively limited scope we argue that more thorough studies of safety knowledge in the industry is needed.

Keywords: Offshore wind, energy transition, emerging industry, safety, health, sociotechnical systems, high-reliability organizations.

1. Introduction

In the transition towards green energy production, offshore wind is held as a promising component of future energy mixes for countries with access to suitable offshore sites. EUmember countries alone aim to produce a total of 111 gigawatt (GW) by 2030 and 317 GW by 2050 (European Commission, n.d.). However, the installation, maintenance, and dismantling of offshore wind turbines involves specific health and safety (H&S) risks. Although actors in the existing offshore wind industry have accumulated knowledge and experience regarding offshore wind H&S, this knowledge may be unequally distributed and cover some aspects better than others. Additionally, in countries where offshore wind production is in its infancy, there is a need for an overall increase in knowledge.

At present, scientific literature on these matters is scarce (Rowell et al., 2024; Karanikas et al., 2021). As will be argued in this paper, there is a need for research with a system perspective to raise awareness of H&S matters which arise and manifest themselves across system levels, organizations, and work processes. Applying a system perspective may be particularly important in countries where offshore wind is at an early stage, since accounting for risks in the design phase may reduce or eliminate risks which otherwise would be designed into the system. For this reason, we argue that work condition considerations, including H&S risks, should be integrated into the planning of the system.

In this paper, we aim to address some of the H&S knowledge gaps which exist in the emerging offshore wind industry on the Norwegian continental shelf (NCS). In Norway, offshore wind is regarded an important part of future energy mix; the aim of the current government is 30 GW offshore wind energy production by 2040 (Regjeringen, 2022). While Norwegian-based companies have supplied goods and services to the global offshore wind market since the late 1990s, the offshore wind production on the NCS is in an early phase. The largest petroleum producing company on the NCS, Equinor, established the world's largest floating offshore wind installation, Hywind Tampen, in

2023, to supply the petroleum fields Snorre and Gullfaks with electricity. For the purpose of mainland energy consumption, the first fields on the NCS were made available for offshore wind production in 2020. In 2023, the field Sørlige Nordsjø II was allocated to the operator company Ventyr SN II. A second field (necessitating floating wind turbines), Utsira Nord, is scheduled for allocation in 2025. The forthcoming *Administrative regulation for safety and work environment for offshore renewable energy production* is currently prepared by the Norwegian Ocean Industry Authority (Havindustritilsynet, short form: Havtil).

The aim of this paper is to identify and discuss knowledge gaps that exist regarding H&S for workers involved in the installation, maintenance, and dismantling of wind turbines in the Norwegian offshore wind industry. The research question is as follows: *Which knowledge gaps in offshore wind H&S can be identified among actors in the emerging offshore wind industry in Norway and how can research address these gaps?* Data material includes a survey sent to members of the health, safety, and environment (HSE) working group of the industry cluster Norwegian Offshore Wind (NOW), as well as group discussions based on results from this survey at an NOW HSE workshop. The survey and the workshop are informed by a system perspective, meaning that they cover topics involving different system levels. Moreover, we build upon literature with a system perspective in the discussion. This implies a particular interest in aspects involving several system levels (e.g., the relation between regulatory frameworks and H&S work conducted by operators) or organizations (e.g., contractors and sub-contractors).

2. Literature Review

In this section, we review previous studies on H&S in the offshore wind industry (2.1). Then, we introduce theories regarding system safety to provide a framework and background for filling current knowledge gaps (2.2).

2.1. *Research on offshore wind H&S*

So far, few scientific publications have thematized the safety and health of offshore wind installation and maintenance workers (Rowell et al., 2024; Karanikas et al., 2021). Moreover, these primarily concern fixed bottom turbines. Rowell et al. (2024) notes that floating wind turbines may create other hazards than those studied for bottom-fixed turbines, and also mitigate some hazards associated with the latter type of turbines.

Our review of relevant literature confirms that there are few peer-reviewed publications on offshore wind H&S. We conducted a literature search in Scopus in July 2024 using the search string ("offshore wind" AND (safety OR health) AND (work* OR employ*)). The search returned 469 results, but a review of titles, abstracts, and full papers respectively, left us with only three relevant (and three unavailable) articles. Based on our limited findings, our literature review includes 5 articles obtained through snowballing as well.

In the reviewed literature, health issues are somewhat better covered than safety issues. Karanikas et al. (2021) has identified specific health hazard topics which to a larger or lesser degree have been studied: exposure to noise, vibration, electromagnetic fields, shadow flicker, hazardous chemicals and materials, and biological hazards, physical/musculoskeletal risks, and weather-related risks. In some areas, like vibration exposure, Karanikas et al. (2021) found no studies concerning windfarm workers, whereas others, like exposure to hazardous chemicals and materials, have been thematized in several studies. Karanikas et al. (2021) notes that since several materials and processes are not unique to the wind industry, research from other sectors can inform our understanding of health hazards in the wind industry. However, these authors argue that the *combination* of hazards may be particular to this industry (Karanikas et al., 2021).

The health-related studies include studies of specific tasks and/or risks as well as studies of general health aspects relating to offshore maintenance work. One example of first type of studies is Milligan et al. (2019), which provided a job task analysis assessing the most physically demanding job tasks for offshore wind turbine maintenance technicians. In the analysis, five critical tasks were identified: transfer between the vessel and transition piece of the

turbine, climbing of internal ladder, manoeuvring through hatches, bolt torque and tensioning, and (in emergency situations) hauling a casualty up the tower for transport by helicopter. Exemplifying the second type of studies, Mette et al. (2018) studied occupational strain, health aspects, and coping strategies of offshore wind employees in the German offshore wind industry. Their interview respondents reported a state of fatigue related to long work hours and shift setup and physically demanding job tasks. The majority reported a poorer sleep quality offshore than onshore, as well a stress at work. At the same time, the workers reported good general health and wellbeing.

Regarding safety aspects, the few studies we have identified concern regulatory aspects (Wifa et al., 2021), vessel-turbine transfer (Puisa et al., 2021), and emergency response (e.g., Pedersen and Ashan, 2020). For the purpose of this paper, we focus on regulatory aspects and emergency responses. Wifa et al. (2021) studied possibilities applying the offshore petroleum health and safety regulatory framework to the emerging offshore wind industry in Australia. Based on a functional analysis, these authors conclude that the two industries share many hazard risks and argue that the regulatory framework for offshore petroleum should be extended to offshore energy (ibid). Pedersen & Ashan (2020) mapped stakeholders involved in emergency preparedness and response in the Danish offshore wind industry. These authors argue that enhanced stakeholder cooperation, including the establishment of common rescue helicopter clusters, would improve emergency preparedness. The main obstacle for achieving this is operators' reluctancy to share knowledge and experience with each other (Pedersen and Ashan, 2020).

In addition to scientific publications, incident data reports from the Global Offshore Wind Health and Safety Organisation (G+) provide relevant information on the types of processes and sites which historically have been associated with injuries. G+ affiliates several lead offshore wind field owners, operators, and turbine generator equipment manufacturers, and require members to report incident data (G+, 2024). However, G+ incident reports have some obvious limitations as sources for overview of H&S issues. Firstly, data is provided by members only. Secondly, incident data is used for lagging indicators, such as the total recordable injury rate (TRIR) and lost time injury frequency (LTIF). In other words, historic records are reflected in the data, without considering how relevant these are for future risks. Last, the incident reports focus on risks associated with delimited areas, such as parts of work processes or accident sites. While this may be suitable for some purposes, like developing manuals for specific work tasks, it overlooks the relation between different parts of work processes (e.g., between vessel transfer and subsequent maintenance work) as well as the relevance of organizational and contextual factors (e.g., economic pressure to complete maintenance work). To advance our understanding of offshore wind H&S challenges, we argue that it is necessary to move beyond fragmented representations. For this reason, we suggest applying a system perspective on H&S.

2.2. *A system perspective on health and safety*

Though system thinking has roots to antiquity, the origin of general system theory has been attributed to the biologist von Bertalanffy, who in the 1930s and 1940s described how systems are composed of interacting components (Laszlo & Krippner, 1998; Checkland, 1999). According to this theory, a system is understood as a hierarchy, where each level conditions activities of the below level. System theory advocates a holistic rather than reductionist approach: A system has emergent properties, meaning that it should be understood as more than the sum of its parts (Laszlo & Krippner, 1998). Moreover, complex systems are often open and interact with their environment (Cilliers, 1998). In addition, they are dynamic and changing, usually due to self-organization (Cilliers, 1998).

Within safety sciences, several leading theorists have argued for a system perspective on accidents (e.g., Turner, 1976; Perrow, 1984). Other safety scholars have applied system theory more directly. For instance, Rasmussen (1997) advocated a sociotechnical system understanding of accidents. Rasmussen's (1997) system model included hierarchical levels, from the government at the top of the hierarchy to the work carried out

by staff at the bottom, with each level imposing control on the next. Leveson (2012) extended this model, emphasising how higher system levels constrained rather than controlled lower system levels. Sociotechnical system approaches have also been advocated within fields which focus more directly on workplace safety rather than larger-scale accidents (e.g., Carayon et al., 2015).

Though the sociotechnical system approach is valuable for understanding offshore wind H&S, we argue that this approach underplays the roles of the *horizontal* system relations. We therefore supplement the socio-technical system approach with a network perspective building on so-called high-reliability theories (cf. Ramanujam and Roberts, 2018). The initial studies of high-reliability organizations (e.g., La Porte and Consolini, 1991; Roberts, 1990) focused on single hazardous organizations which managed to combine safety and stable outputs under variable circumstance. Drawing upon these initial studies, later studies have extended the scope to how reliability is achieved *across* organizations, including in networks consisting of both horizontal and vertical relations (e.g. Berthod et al., 2017; Cedergren et al., 2018; de Bruijne and van Eeten, 2007).

Insights from studies of inter-organizational reliability are relevant for offshore wind H&S work involving multiple organizations. For instance, Cedergren et al. (2018, p. 56) found that organizations' pursuit of individual goals and unclear responsibilities regarding shared goals may hamper the achievement of the shared goals, resulting in "micro-efficiency but macro inefficiency". While contracts can counter some of these effects by defining roles and responsibilities, contracts may be insufficient for resolving conflicts (Slotsvik et al., 2023). Rather, establishing and maintaining informal communication and cooperation across organizational interfaces can be crucial for success (de Bruijne and van Eeten, 2007; Berthod et al., 2017; Slotsvik et al., 2023).

3. Method

The study design relies on triangulation, with data collection in two steps: a) a survey sent to members of the NOW HSE working group, and b) workshop discussions regarding the results of the survey.

3.1. *Survey*

To get an overview of the experienced knowledge needs among stakeholders within offshore wind, a short survey was developed in cooperation with NOW employees. The survey was sent to a panel of "experts", i.e. company and/or stakeholder group representatives in the NOW HSE working group. We expect this group to have updated insights on knowledge gaps and research needs, given that dissemination of new knowledge is one primary aim of NOW. The survey was administered by the NOW employees and sent to 60 participants from 50 member companies in the NOW HSE working group in August 2024. Respondents were informed that results would be used anonymously for research purposes. Participants were asked about their opinion on research needs for eight different topics, with a guiding text about each topic. For each topic, respondents were given five response options (see Figure 1 for details). 21 respondents participated in the survey, giving a 35 percent response rate.

3.2. *Workshop*

In September 2024, NOW employees organized a workshop for working group members and academics. 24 participants attended the workshop. The program included industry and academia presentations and a group work session organized by the researchers. Prior to the group work session, participants were informed that group level responses would be used for research purposes, and that they could disagree to this (including in retrospect), in which case discussion notes would not be used as research results.

In this session, participants were split into three groups. Two groups were led by a researcher and one by a working group administrator. Each group was asked the same questions regarding 1) H&S topics needing more knowledge and research; 2) barriers for knowledge development; and 3) relevant actors for knowledge development. Group leaders coordinated the group discussions and took notes. Given the group characteristics, the groups did not address all the questions to the same extent.

4. Results

In this section, survey results and workshop discussion results are presented.

4.1. *Survey*

Survey results are presented in Figure 1. For each of the topics, a clear majority of the respondents expressed that that "This topic urgently needs more research" or that "This subject is a potential candidate for further research initiatives". This indicates an overall experienced need for, and interest in, research on H&S-related topics. In the survey, supervision and regulation stands out as the topic where most respondents express that research is urgently needed, followed by the development of industry standards (which depends on the forthcoming administrative regulation).

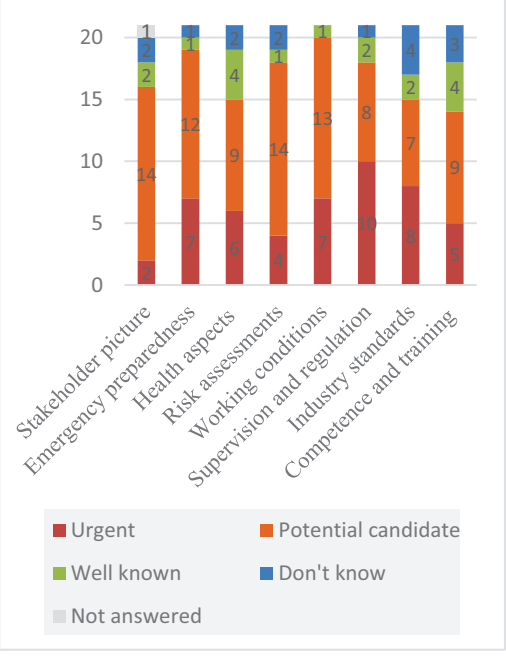

Figure 1: Survey results. Knowledge priority for different topics. Number of answers (n=21).

The survey has some methodological weaknesses and should be regarded as a preliminary step towards gaining insight on knowledge needs in the industry. First, the number of respondents was low. At the same time, the survey was targeted towards respondents who are or will be working specifically on this theme. Their views are therefore highly valuable. Second, the survey would have benefited from a clearer question and response option formulation. Given these weaknesses, the results are best suited to give an overall indication of the present H&S knowledge gaps.

4.2. *Workshop*

Results from the workshop discussions are presented according to the three discussion topics. We acknowledge that there are some limitations regarding our use of workshop discussions as research method. First, the workshop participants do not represent all relevant actors in the industry. For instance, trade unions were not represented. Second, notes are less accurate than audio recordings. Again, we emphasize that the results of this study should be seen as preliminary, suited to highlight some early research needs within offshore wind H&S, and not claiming to cover all.

4.2.1. *Knowledge needs in offshore wind*

In group discussions, several participants highlighted that waiting for the coming administrative regulation creates uncertainty. Some of them pointed out that, for the time being, actors lean towards oil and gas frameworks instead. Given that Norway has a well-established, large petroleum industry, this is perhaps not surprising. Several of the workshop participants have backgrounds from this industry. Moreover, the petroleum industry is a point of reference for many stakeholders, including Havtil and employer/employee organizations.

Participants acknowledged that once the administrative regulation is in place, many issues still need to be resolved. For instance, standards based must be created and adopted to the administrative regulation. A participant pointed out that this concerns concrete areas like providing the appropriate training, but also long-term aspects like creating organizational cultures in line with the regulatory framework and standards. Overall, effects and implications of the administrative regulation – once established – was seen as a relevant topic for scientific studies.

Participants also described an insufficient understanding of roles and responsibilities among offshore wind actors. This is partly due to the lacking regulatory framework. For instance, in the case of emergency preparedness, a participant pointed out that clarifying roles and responsibilities depends partly on the wording of the administrative regulation. Additionally, it reflects that the industry is at an early stage. One participant had experienced that government agencies were uncertain about their own responsibilities, and were not currently rigged (i.e., sufficiently staffed) for the coming industry. Another participant described that their company experienced difficulties when writing tender proposals, as their clients were unable to adequately articulate their own needs. Furthermore, one workshop participant stated that they had observed gaps between each phase of the project life cycle. The mapping of actors and their roles was identified as a relevant research topic.

4.2.2 *Barriers for knowledge development*

Workshop participants described the lacking overview of other actors as a main barrier for developing knowledge relevant for H&S. Also, several participants argued that, at present, there is a lack of transparency and a "common language" for H&S work between the involved companies. The participants who put forward these arguments had experience from the petroleum industry, and, when comparing the two industries, found the willingness to share knowledge as well as the common language or understanding to be pronouncedly higher among petroleum actors. Although such statements are based on individual experience and their importance should not be exaggerated, it reflects that offshore wind presently is an immature industry where relations and a common understanding is yet to be established.

Also, participants described the existence of national (rather than international) regulatory frameworks and standards as a significant disadvantage for operators and service suppliers, since they must adapt to the regulations of each country. These participants argued that shared frameworks and standards would be beneficial for H&S work.

4.2.3. *Relevant actors for knowledge development*

Workshop participants identified a broad scope of actors as relevant for developing knowledge on offshore wind H&S. This included several public actors. Havtil was mentioned by many participants, but other government institutions were also referred to. Additionally, it was highlighted that municipality authorities must be involved, for instance in establishing emergency preparedness structures. Moreover, "The collaboration forum for offshore wind" (Samarbeidsforum for havvind) and the Regulators' forum (Regelverksforum) were seen as important. The collaboration forum for offshore wind was established in 2021/2022 by the Department of Oil and Energy (currently Department of Energy). The Regulators' forum, which was established in 1968 and is led by Havtil, consists of state authority, employer and employee representatives, and enables work life parties to be updated on and contribute towards the development of regulations.

One participant pointed out that so far, there has been a lack of involvement of the sharp end (i.e., maintenance workers with (international) operational experience), and that workers' unions have been missing in the H&S discussions so far. Other participants in the group disagreed with this second statement but agreed that the industry should look towards the tripartite cooperation in the petroleum sector.

In addition, several workshop participants highlighted that knowledge development should have an international perspective, not least due to the value of learning from countries with more experience.

5. Discussion

The knowledge needs identified in this study reflect the current situation of the Norwegian offshore wind industry. The industry is expected to grow significantly in the next decades but is currently in an early phase where important issues, including in the H&S field, are yet to be resolved. In the following, we discuss some of these issues from a sociotechnical system perspective supplemented with insights from high-reliability studies in networked/ interorganizational settings.

5.1 Waiting for higher-level constraints

Survey results indicate that supervision and regulation is an area where more knowledge is needed, and workshop discussions confirmed a knowledge gap in the offshore industry related to the forthcoming administrative regulation. Moreover, workshop participants acknowledge that once the regulation has been effectuated, standards, work protocols, and training programmes must meet the new regulation requirements. A sociotechnical system perspective reminds us of why this is the case: legislation introduces constraints on behaviour in the system levels below, including on industry standards, individual company standards and procedures, and certification (Leveson, 2012). The new administrative regulation will leave industry with certain degrees of freedom to form standards and certification. It remains to be seen how these degrees of freedom will be spent.

In addition, sociotechnical systems involve feedback from lower to higher levels (Rasmussen, 1997; Leveson 2012). From this perspective, involving sharp-end workers with operational experience in the design and operation of the system is crucial. In our study, workshop participants disagreed on whether operational personnel have been sufficiently involved so far. Though our results are not suited to draw conclusions on that matter, they serve as a reminder that worker involvement is important.

The Norwegian offshore wind industry draws upon experience from the petroleum industry. However, offshore wind will have smaller economic margins than petroleum. Given that safety is one among several goals in a sociotechnical system, and that increasing economic pressures may result in a mitigation towards unsafe operations (Rasmussen, 1997), offshore wind H&S will remain an important topic for scientific investigation in the future. Moreover, investigating H&S effects of e.g. stringent economic margins can complement research on offshore wind work processes by providing insight into how macro and meso level conditions affect H&S matters.

5.2 *H&S in the organizational interfaces*

Gaining overview of the actors involved in offshore wind H&S was by most survey participants regarded a potential topic for research rather than one where research was urgently needed. However, in group discussions, the mapping of actors, and of their roles and responsibilities, was identified as important. The current knowledge gaps and uncertainties regarding roles, responsibilities and interfaces appears to contribute towards actors focusing on their own deliveries without a holistic understanding of the offshore wind system. There is in other words a need to understand the system the actors are part of. This involves the entire value chains and networks of actors, i.e., the horizontal relations in addition to the vertical.

However, mapping the actors is only the first step. Clarifying roles and responsibilities between the actors, is a vital next step. This will involve defining responsibilities in contracts and bridging documents.

Additionally, in accordance with high-reliability studies, a third step is encouraged: the maintenance of informal relations. Though contracts are vital for customer-supplier relations, establishing informal relations characterized by holistic give-and-take attitudes is often necessary for such relations to work in practice (Cedergren et al. 2018; Slotsvik et al., 2023). Regarding H&S, maintaining informal relations may encourage continuous H&S work across organizations. Not least for emergency preparedness, it is advantageous to establish and maintain relations between the involved actors, so that these can be called upon in times of emergency (de Bruijne & van Eeten, 2007; Berthod et al., 2017). By comparison, offshore wind emergency preparedness in Denmark involves deficient stakeholder cooperation and limited knowledge sharing (Pedersen & Ashan, 2020). This serves as a reminder for the planned offshore wind emergency preparedness actors in Norway to emphasize cooperation from the very beginning. Moreover, emergency preparedness is one of the areas where research can provide valuable identification of improvement points.

6. Conclusion

Although small, our study demonstrates a need for more knowledge regarding H&S topics in the Norwegian offshore wind industry. The

development of petroleum industry and focus on H&S on the Norwegian Continental Shelf enables suitable arenas for filling these knowledge gaps by the industry actors themselves. However, we argue that research can play an important role in monitoring topics across several system levels, such as the effects of the coming administrative regulation. Also, research can contribute towards holistic perspectives on maintenance work and work processes, thus avoiding the fragmented picture of safety advocated by e.g. G+. Moreover, research on offshore wind H&S should aim for an international perspective, thereby encouraging comparisons and learning across different national contexts. This implies that the research topics we have identified here may be relevant for further investigation in other countries as well.

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