

Limits of safety: Scenario-based analysis of the distribution of responsibilities and challenges in maritime emergency management at offshore wind farms

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Abstract—As hybrid maritime threats increase, authorities and infrastructure operators are confronted with additional challenges in offshore emergency management, especially concerning critical infrastructure such as offshore wind farms. The requisite responses and responsibilities in maritime emergency management are based on the distinction between safety and security incidents. Therefore, this paper addresses the question of which challenges and vulnerabilities occur in maritime emergency management due to the various responsibilities at the German safety infrastructure. Initially, the legal basis regarding responsibilities in emergency situations is elaborated and used to introduce response domains. Using the example of offshore wind farms, a general scenario grounded in realistic events are generated, followed by the identification of responsibilities across the scenario stages.

Index Terms—Maritime emergency management, critical infrastructures, scenario development, maritime safety and security

I. INTRODUCTION

Offshore windfarm operators are obliged to have appropriate protection and safety concepts to deal with accidents and other work-related incidents. [1] This process typically encompasses meticulously planned operations involving a predetermined number of personnel and vessels within the facility, monitored by a wind farm control center. However, past incidents, such as the "PETRA L" in 2023, demonstrate that unexpected factors can also necessitate the implementation of maritime emergency management by operators and safety and security actors in such scenarios. On 24 April 2023, the freighter PETRA L collided with an offshore wind turbine at the Gode Wind 1 wind farm after the captain on watch had presumably fallen asleep. The collision caused severe damage to the ship's bow, resulting in water ingress and damage to the turbine. [2]

The PETRA L incident raises the question of where responsibilities lie and if, in times of increasing hybrid threats, a potential attack on critical infrastructure is taking place. The legal framework specifies responsibilities based on whether an incident is a safety or security scenario - that is whether an incident is an intentional attack or an unintentional accident.

Yet it is often difficult to assess a developing scenario in real-time with certainty and whether it should be treated as a safety or security case. Consequently, during an ongoing scenario responsibilities are often overlapping and obscured by a construct comprising multiple maritime authorities that deal with the situation.

Therefore, this paper develops a general scenario grounded in realistic events, with the aim of identifying the various responsibilities and vulnerabilities in maritime emergency management without regard to the safety-security distinction. The paper starts with an introduction to the various maritime safety and security actors involved (II). This is followed by an examination of the legal framework (III) and an introduction to response domains (IV). The subsequent section V details the scenario, which is then analyzed in results section concerning the duties and responsibilities of maritime actors VI. Finally, the vulnerabilities are identified in the conclusion (VII)

II. BACKGROUND INFORMATION

This section will provide a brief overview of the major maritime actors involved in safety and security scenarios, along with a description of their respective roles within the German maritime safety framework. These insights are then used to determine the allocation of responsibilities in accordance with the relevant legal framework. The German maritime safety framework is divided into safety and security actors, forming the incident response infrastructure in German Seas.

A. Maritime authorities for safety cases

Major maritime safety actors in Germany include the maritime rescue services represented by the German Maritime Search and Rescue Service (DGzRS) and the Maritime Rescue Coordination Centre (MRCC), as well as the Central Command for Maritime Emergencies (CCME). The MRCC is responsible for coordinating the DGzRS's rescue operations, and together they are tasked with the management of day-to-day operations in maritime emergencies. [3] In the event of

larger and more complex incidents, such as environmental disasters, salvage operations or hazardous materials incidents, the CCME assumes responsibility for coordinating the response. [4]

B. Maritime authorities for safety and security cases

The Maritime Federal Police is a security authority that is specifically tasked with law enforcement at sea and in the Exclusive Economic Zone (EEZ), including the protection of German maritime borders, vessel inspections and combating of maritime crime. [5] Coastal state police forces are responsible for securing German's coastal waters up to 12 nautical miles. Customs police forces specialize in countering maritime smuggling operations.

The German Coast Guard functions as an intermediary between safety and security. As a coordination network rather than an independent authority, it includes the maritime federal and state police forces as well the DGzRS with tasks such as maritime safety monitoring, border and environmental protection, as well as rescue and salvage operations. [6] Other key actors in the field of maritime safety and security include the Maritime Safety and Security Centre (MSSC), an association of several federal and coastal state authorities that facilitates the collective monitoring and coordination of safety and operational measures. The primary function of the MSSC is to facilitate early warning and coordination in the event of maritime incidents, including overall situation monitoring and coordination to ensure maritime safety through cross-agency resource management. [7]

III. LEGAL BASIS

The protection of maritime infrastructures requires a systematic differentiation between safety and security cases, as responsibilities, powers of intervention and legal frameworks differ fundamentally depending on the type of threat. While safety cases are primarily function-related and aim to avert danger and limit damage, security cases follow a zone-based logic of jurisdiction with clearly delineated sovereignty and intervention competences. The requirements of international law in particular are decisive here.

A. Legal basis for safety cases

The international legal basis for maritime safety is provided by the Convention on the Law of the Sea (UNCLOS), notably through Art. 98 and 221. Coastal states are obliged to establish suitable search and rescue services, while all masters are required to render assistance.

The International Convention on Maritime Search and Rescue (SAR Convention) establishes a system of functional responsibilities based on search and rescue regions (SAR regions), within which a state coordinates rescue operations. This responsibility is not tied to maritime zones but to operational requirements, enabling an effective response to emergencies regardless of sovereign borders.

In addition, the International Convention for the Safety of Life at Sea (SOLAS) specifies technical and operational safety

requirements and ensures that ships are capable of preventing and responding to hazardous situations. Together with Art. 98 of UNCLOS, the SOLAS forms the central basis for the protection of human life at sea. At the national level, state responsibility for maritime safety arises in particular from the Maritime Shipping Responsibilities Act (SeeAufgG). The SeeAufgG assigns responsibility for ensuring maritime traffic safety, hazard prevention and the protection of the marine environment by assigning responsibilities and tasks to the competent authorities.

Overall, safety-related measures in the maritime domain are primarily organized functionally and deliberately deviate from the zone-based logic of maritime security legal frameworks.

B. Legal basis for security cases

In contrast to safety-related measures, which are primarily function-orientated and largely independent of maritime zones, maritime security follows a strictly zone-based logic. Security interventions, in particular measures such as stopping, searching or boarding ships, are closely linked to the respective maritime zones and the relevant responsibilities under international and national law. Building on the UNCLOS framework, maritime security enforcement is structured according to a zonal allocation of jurisdiction and intervention powers.

Within the territorial sea, the coastal state exercises sovereignty subject to the right of innocent passage and may enforce its laws where security, public order or applicable regulations are violated. In the EEZ, the coastal state only has limited functional sovereign rights for interventions related to economic activities such as fishing regulations, environmental protection and protection of offshore installations, while key high seas freedoms and the flag state principle remain applicable. On the high seas, jurisdiction is primarily governed by the flag state principle, with enforcement by third states limited to defined exceptions under UNCLOS including hot pursuit and the right of visit in cases such as piracy, statelessness, slave trade or unauthorized broadcasting.

In Germany, maritime security is implemented through a combination of the SeeAufgG as the legal framework for federal responsibilities and specific enforcement powers under the Federal Police Act, the Customs Administration Act and environmental legislation. These tasks exercised by the Federal Police, State Police, customs authorities and, in specific cases, the German Navy within the limits of administrative assistance or international mandates.

Overall, maritime security measures, in contrast to safety-related approaches, follow a territorial structured system of competences, in which the scope of state intervention is largely determined by the respective maritime zone.

IV. RESPONSE DOMAINS

The applicable legal frameworks consistently predicate jurisdictional allocation among maritime security actors upon the fundamental question of whether a given situation is to be characterised as a safety or a security case. However, in the majority of instances, this question cannot be answered with

the requisite degree of certainty, nor does the presence of one case necessarily preclude the concurrent manifestation of the other.

Consequently, an autonomous allocation of responsibilities within maritime emergency management should be operationally viable without necessitating a definitive prior determination as to whether the situation in question falls within the classical safety or security paradigm. The more pertinent question, particularly in hybrid situations characterised by an ambiguous or inconclusive assignment to either category, is whether a capability-oriented response posture may enhance overall operational effectiveness in maritime emergency management.

In consideration of the previously mentioned aspects, five response domains have been defined. Each of these domains reflects the functional task areas that have been derived from the relevant legal frameworks and relates them to the corresponding actors and authorities. The response domains are designated as follows: General Duty, Maritime Traffic Safety, Emergency Response, Search and Rescue and Maritime Security. An allocation of the key stakeholders and their respective legal bases to each domain is provided in Table I.

The **General Duty** domain encompasses the exercise of general sovereign responsibility for the maintenance of safety, public order, and the enforcement of applicable law within the maritime sphere. The primary concern of the **Maritime Traffic Safety** domain is to ensure the safe and orderly conduct of vessel traffic. These include the monitoring of traffic, the implementation of traffic management strategies, and the prevention of maritime casualties. The domain of **Emergency Response** is the management of acute damage and hazard situations at sea, directed towards the preservation of human life as well as the mitigation of material damage and environmental harm. The **Search and Rescue** domain encompasses the search for persons in maritime distress, their recovery, and their subsequent transfer to a safe place. Finally, the function of **Maritime Security** provides for the protection for the maritime domain against deliberate illegal acts, including terrorism, piracy, smuggling, and sabotage.

V. SCENARIO DEVELOPMENT

Scenarios are an established methodological tool in risk and emergency management research, enabling the analysis of complex and uncertain situations. In this paper, scenario development is used to examine the distribution of responsibilities during maritime emergencies concerning offshore wind farms, which represent complex socio-technical systems involving multiple stakeholders and overlapping regulatory frameworks.

The scenario development follows three core principles. One principle is the clarity of purpose, plausibility and realism with maritime actors alignment. Accordingly, the scenarios are designed to reflect realistic operational conditions and credible threat situations while considering the roles of relevant maritime actors outlined before.

TABLE I
ALLOCATION OF RESPONSE DOMAINS

Response Domain	Major Maritime Actors	Legal Basis
General Duty	All vessels, Operator	Art.98 UNCLOS, SOLAS, Sec.1,3 SeeAufG
Maritime Traffic Safety	Maritime Federal Police, Maritime State Police	Sec.1,3 SeeAufG
Emergency Response	CCME, MSSC	Federal-State Agreement
Search and Rescue	DGzRS, MRCC	SAR Convention, Art.98 UNCLOS
Maritime Security	Maritime Federal Police, German Navy, Special Forces	UNCLOS (several Art.), Sec.1,3 SeeAufG, Federal Police Act, Customs Administration Act

To illustrate the dynamics of responsibility allocation, the scenario developed in this paper is based on three stages: (1) an initial situation, an (2) ambiguous situation characterized by increasing uncertainty and an (3) escalation stage marked by further escalation and security deterioration.

A. Use Case Scenario

In recent years, an increasing number of vessels, including oil tankers operating under flags of convenience such as Panama, have been observed in European maritime areas. These vessels typically follow regular shipping routes and operations. At the same time, routine maritime traffic can be observed in proximity to the German EEZ, including vessels navigating relatively close to offshore wind farms.

Overall, the situation appears normal and consistent with standard maritime operations. However, the increasing strategic importance of energy infrastructure, combined with rising oil and gas prices, contributes to a heightened sensitivity regarding potential risks in these areas.

Stage 1: Initial Situation

A service vessel is operating within the 500-metre safety zone of an offshore wind farm during routine maintenance operations. Weather and sea conditions are calm and communication with the wind farm control center is functioning normally.

Stage 2: Ambiguous Situation

During the operation, the service vessel begins moving on a steady course with increasing speed towards a wind turbine structure without notifying the control centre. Attempts by the wind farm control centre to establish radio communication with the vessel remain unanswered.

Stage 3: Escalation

The vessel continues its approach despite repeated warnings

and does not transmit a distress signal. Its behavior remains unchanged and the vessel collides with the turbine.

VI. RESULTS

Based on the major maritime actors identified in section II, the legal basis in section III and the implementation of response domains in section IV, the following section outlines the allocation of responsibilities across the individual phases of the illustrative scenario. The allocation of responsibilities in table II takes into account the stakeholders who, in their respective roles pertaining to response domains, may be involved in the present stage of the scenario. The scenario is set entirely within the 500-metre safety zone of the wind farm. In the course of events, the scheduled maintenance work evolves into a safety-related threat to the wind turbine, resulting in damage to the turbine.

In the first stage, there are no anomalies. Consequently, during the maintenance work, the responsibility rests solely with the wind farm operator under its general duty obligations, particularly with regard to occupational health and safety through appropriate protection and safety measures for the employees. As the anomaly emerges in the second stage, primary responsibility remains with the operator, who must assess the situation and decide whether to report the ambiguous situation to the relevant authorities. This situation accompanies by a concomitant escalation towards a security risk. Concurrently, as the control centre becomes aware of an anomalous behavior exhibited by the vessel elements of Maritime Traffic Safety arise due to the potential risk to navigation. In the absence of information resulting from unsuccessful attempts to communicate with the maintenance vessel, a potentially Emergency Response becomes relevant in case of a possible medical emergency on board. The unanswered radio calls and the continuation of the voyage are also indicative of a security incident. Maritime Security considerations emerge as intentional misconduct cannot yet be ruled out, potentially requiring the involvement of the Maritime Federal Police. This unclear situation highlights the discrepancy between the powers of security authorities and the operational realities faced by operators.

Following the collision in the third stage, multiple responsibility domains become relevant simultaneously. As no distress signal has been transmitted thus far, a medical emergency remains unconfirmed. Nevertheless, the collision is likely to pose a risk to the people on board. In addition to the operator's continuing responsibility, Emergency Response is required to manage a complex incident at sea. It is possible that the collision may have caused serious damage to the maintenance vessel, potentially leaving the vessel in distress. In instances where the operator's resources prove inadequate to manage such a scenario, the Search and Rescue domain need to get involved. Maritime Traffic Safety is affected by the impact on navigation and to protect maritime infrastructure. If the collision is determined to be intentional, Maritime Security responsibilities are added, requiring close coordination between

the operator, rescue services, and security authorities. This kind of diffusion of responsibility has the potential to result in delays to the necessary rescue efforts.

TABLE II
ALLOCATION OF RESPONSIBILITIES ACROSS THE SCENARIO STAGES

Stage of Scenario	Response Domain	Major Maritime Actors
Stage 1	General Duty	All vessels, Operator
Stage 2	General Duty, Marine Traffic Safety (, Maritime Security)	All vessels, Operator, Maritime Federal Police, Maritime State Police (, German Navy, Social Forces)
Stage 3	General Duty, Marine Traffic Safety, Search and Rescue, Emergency Response, Maritime Security	All vessels, Operator, Maritime Federal Police, Maritime State Police, DGzRS, MRCC, CCME, MSSC, German Navy, Social Forces

VII. CONCLUSION

The scenario-based analysis highlights the need for close cooperation among maritime safety and security actors and private offshore wind operators, whose differing responsibilities and priorities increase the risk of coordination and information-sharing challenges as incidents become more complex. Improving information exchange through joint exercises, enhanced assessment mechanisms for distinguishing hybrid situations. The more accurately the scenario can be assessed, the more precisely responsibilities can be defined. Clearer legal frameworks can strengthen transparency, define responsibilities more precisely, and prevent delays caused by unclear authority. This minimizes the risk that emergency responders will be hampered by unclear lines of authority in ambiguous situations.

The 500-metre safety zone constitutes a time-critical vulnerability, as only a few minutes may separate an intrusion from a collision. Continuous monitoring and direct information exchange are therefore essential to minimize response time across all response domains. Coordination platforms such as the MSSC should consequently facilitate information sharing not only among maritime safety and security authorities but also between maritime actors and private operators.

The analysis further shows that the responsibility in hybrid scenarios often distributed over the stages across multiple response domains. However, the division into response domains has the advantage of reducing the number of parties involved and can serve as a more structured framework for information and communication. Throughout all stages, the principle of "Safety First" must prevail: as long as a safety incident cannot be excluded, all necessary measures to protect human life must be taken, requiring safety and security actors to operate as an integrated community based on standardized procedures.

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