*European Research Studies Journal*
*Volume XXVI, Issue 1, 2023*

*pp. 595-611*

# Identification of Navigational Risks Associated with Wind Farms

*Submitted 05/02/23, 1st revision 22/02/23, 2nd revision 11/03/23, accepted 30/03/23*

Krzysztof Marcjan[1], Diana Kotkowska[2]

***Abstract:***

***Purpose:*** *This paper analyses navigational hazards associated with vessel traffic around wind farms. Monitoring ship movements in the area of an offshore wind farm has a significant impact on the safety not only of the wind farm itself, but also on the safety of navigation. The study investigated the monitoring of ship traffic in the area of the Southern Baltic Sea in the region of planned wind farms to identify risks associated with new offshore renewable energy projects.*
***Design/Methodology/Approach:*** *The analysis of hazards and their consequences in the study area was carried out using the risk matrix method. The study was based on AIS data from the years 2021, 2020 and 2019, related to the area of the planned project and adjacent areas. Risk identification and analysis was performed for the three life stages of the wind farm: construction, operation and decommissioning.*
***Findings:*** *Based on the research and analysis of extensive information on the traffic of vessels including various vessel types and functions, the authors have made an in-depth analysis of maritime safety around planned investment projects related to the construction of renewable energy sources along the Polish coast. The results made it possible to identify factors affecting navigational safety, as well as to analyse the risks associated with vessel traffic in the vicinity of planned wind farms.*
***Practical Implications:*** *The results obtained in the study allow the estimation of navigational safety in the region around wind farms in the Southern Baltic Sea.*
***Originality/Value:*** *Numerous investments in renewable energy sources such as offshore wind farms are planned along the Polish coast in the years to come. Investing in offshore wind energy ideally addresses Europe's current energy problems and European projects, which include the need to replace coal-fired power stations with much more environmentally friendly sources of renewable energy. An essential factor in planning such future investments is navigational safety in the vicinity of these facilities. This analysis is a new approach to identifying the various risks associated with the construction of wind farms.*

***Keywords:*** *Wind farm structures, offshore wind energy, AIS.*

***Paper Type:*** *Case Study.*

[1]*Navigation Department, Maritime University of Szczecin, Poland, ORCID 0000-0002-9455-0403, k.marcjan@pm.szczecin.pl*
[2]*The same as in 1, ORCID 0000-0001-8233-2356, d.kotkowska@pm.szczecin.pl;*

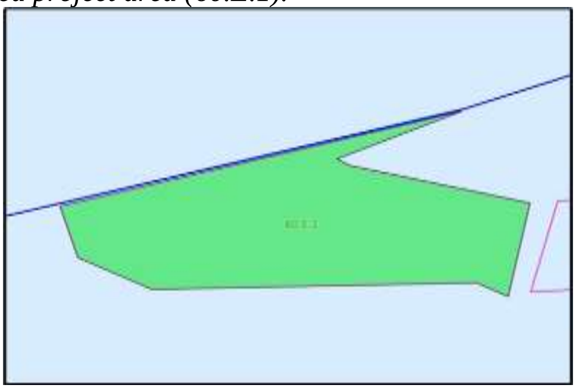
## 1. Introduction

Today, with the energy crisis and a strong emphasis on environmental protection, the number of planned offshore wind power plants is on the rise. Unfortunately, the newly established renewable energy sources pose a potential danger to shipping as well as to the environment. Therefore, a thorough analysis should be carried out to examine the impact of a wind farm in the area of intended construction.

The level of navigational risk is mainly influenced by the location of offshore wind farms relative to the existing fairways and traffic patterns, as well as the vulnerability of the environment. The identification of all possible risks arising from the establishment of wind farms in a given area has a significant impact on the risk assessment process (Królikowski *et al.*, 2013).

This article analyses vessel traffic streams and presents work done to identify hazards and determine risks arising from the planned location of renewable energy installations along existing vessel passage routes. An area designated as 60.E.1 was selected for the study (Figure 1).

***Figure 1.*** *Examined project area (60.E.1).*



***Source:*** *Own study.*

The study area of the project is a polygon with nine sides, belonging to the larger POM 60E area mostly intended for the construction of renewable energy sources. The northern limit of the area marked in green in Figure 1 is the border of the Polish exclusive economic zone (EEZ). Vessel traffic analysis was carried out in the Polish EEZ mainly south of the marked area down to the Polish coast and in a nearby area north of the investment boundary. Further offshore wind farm (OWF) projects are planned around the area, which was partly included in the present study.

The priority criteria when undertaking the construction of offshore wind farms in a selected water area include navigational safety and the environmental impact of the investment project facility. In this article the authors focus exclusively on the analysis of navigational safety.

The construction and operation of a wind farm may significantly affect the conduct of safe navigation also in adjacent waters. The aim of the study is to identify navigational hazards associated with the offshore wind farm developments based on observations of vessel traffic streams. The analysis was based on AIS data from the three years (2021, 2020, 2019), both in the area of the planned project and in adjacent areas.

Prior to the analysis of vessel traffic around the planned wind farm, a number of measurements were made to find and analyse the main traffic flows. The area around the project site was divided into zones, at which gates were set up to record the number of entries and exits of vessels from the zone. The zones were grouped into those adjacent to the wind farm for which the vessel traffic analysis was carried out over a 3-year period, while the traffic analysis in the areas south of the project site down to the Polish coast was based on one-year observations.

## 2. Study Area - Location of Wind Farms

### 2.1 Requirements for Wind Farm Location

Navigational safety is the most important factor to be considered when determining the siting of a wind farm. As early as the design stage, the following requirements are to be taken into account:

- offshore wind farms must not impede coastal and especially deep-sea shipping;
- the site of the wind farm must not restrict access to the ports;
- future wind farms must not, under any circumstances, be located in areas subject to protection or other restrictions, i.e. offshore military training grounds, protection zones and other marine engineering structures, wrecks, grounds of dumped ammunition, etc;
- wind farm must not deteriorate existing aids to navigation (Herdzik J. , 2018),
- level of changes in shipping and navigational safety following the construction of a new wind farm in a given area should be as low as possible compared to the previous state. This is one of the most important aspects to consider when selecting the location of a new development.

Areas designated for the construction of wind farms are closed areas, i.e., they are excluded from normal navigation and fishing. They are accessed by vessels that erect, repair and dismantle wind turbines at the end of their operational life (Herdzik, 2018). It is possible for the relevant state authorities to establish restricted areas for vessel traffic around wind farms without excluding small recreational vessels and vessels engaged in fishing (IALA, 2013). It is therefore also reasonable to properly mark the area excluded from navigation as recommended or required by international regulations.

The general principle guiding the IALA in its recommendations in relation to wind farms is that the development of investment projects involving the establishment and subsequent use of offshore wind farms should not adversely affect the safe use of traffic separation schemes, coastal traffic zones, main shipping routes and safe access of vessels to anchorages, harbours, etc. This is why, in some cases, in order to enhance navigational safety around offshore wind farms, national authorities may consider establishing exclusion or safety zones in which vessel traffic around wind farms would be prohibited or severely restricted (UNCLOS, 1982).

### 2.2 Location of Wind Farms in the Southern Baltic Sea off the Polish Coast

The analysed sector of the Baltic Sea intended for the offshore wind farm 60.E.1 belongs to the larger area POM.60.E, which is predominantly designated for the production of renewable energy from wind by means of offshore wind power plants, and partly for the extraction of minerals from submarine deposits (Regulation of the council of Ministers, 2021). The site is located to the northeast of the port of Ustka, approximately 33 nautical miles north of the traffic separation scheme, which carries the main stream of vessels travelling along the Polish coast.

Analysis of vessel traffic based on AIS data covered the waters around the area designated 60.E. 1 (Figures 1 and 2). Area 60.E.1 is partly adjacent to the border of the Polish EEZ. Its depths of 25-35 metres decrease towards the Central South Bank. There are no anchorages or navigational obstructions within the designated area that would significantly affect navigational safety. The nearest TSS is located 17 Nm north of area 60.E.1.

***Figure 2.*** *The area of the 60.E.1 wind farm under study marked in green.*

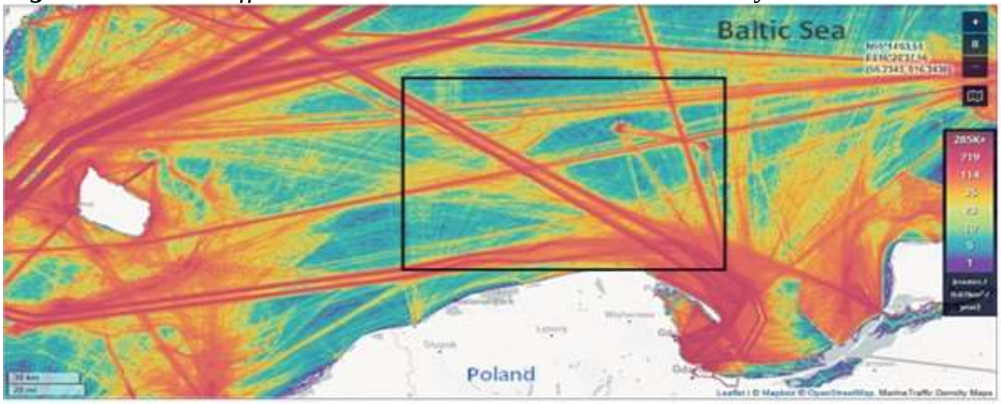
***Source:*** *Own study.*

## 3. Analysis of Shipping Routes in the Southern Baltic Sea

### 3.1 Monitoring of Vessel Traffic in the Area of Wind Farms

Vessel traffic in and around the project area was analysed to investigate the risks to navigational safety arising after the construction of the planned wind farm. In addition, a larger area ( Figure 3) was analysed to examine the expected changes in vessel traffic streams after the start of the project. Figure 3 depicts the vessel traffic in the Southern Baltic area in 2021. The resulting network of vessel traffic streams made it possible to identify areas of increased risk and to determine the main vessel traffic routes in the selected area.

***Figure 3.*** *Vessel traffic based on 2021 AIS data around the study area.*



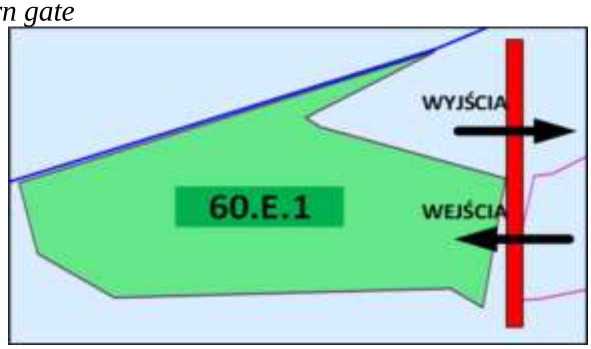

**Source:** *https://www.marinetraffic.com/*

In order to carry out a detailed analysis of vessel traffic in area 60.1.E, the study area was divided into zones, where four gates were set up to record the number of entries and exits of vessels from a given zone. The set-up of the gates made it possible to take measurements at critical points to find and analyse the main traffic flows. This type of gate set-up has facilitated the recording of the different types of vessels passing through each gate. In this way, not only do we know how many vessels passed through, but also what type they were.

### *3.1.1 The Eastern Gate*

One gate was placed on the eastern side of the analyzed area 60.E.1 (Figure 4). The eastern gate extends along longitude 017° 25.8' E, while its limit north and south points of latitude are, respectively, 55° 35.4' N and 55° 28.2' N.

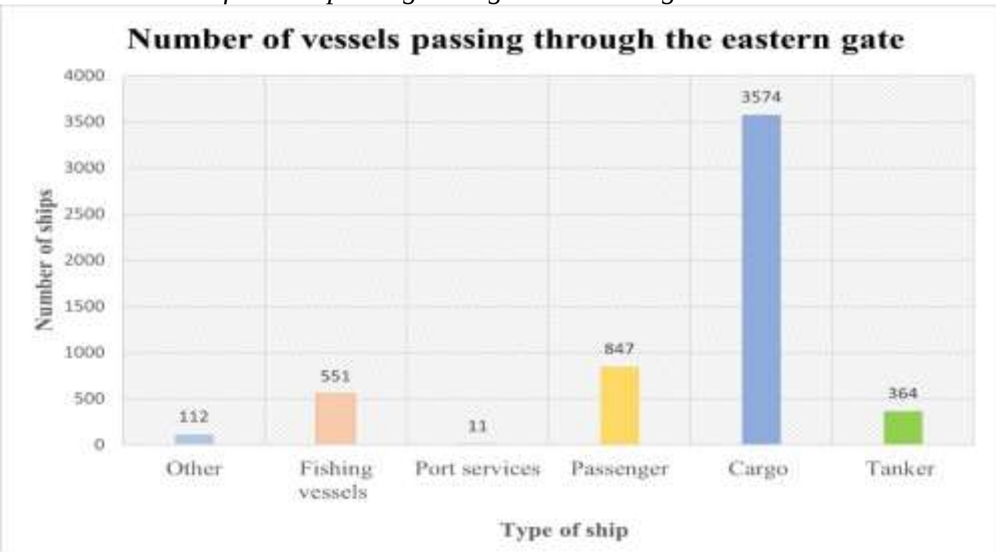
***Figure 4.*** *Eastern gate*




**Source:** *Own study.*

An analysis of vessel traffic in the years 2019 to 2021 has been based on the AIS data for the eastern gateway (Chart 1).

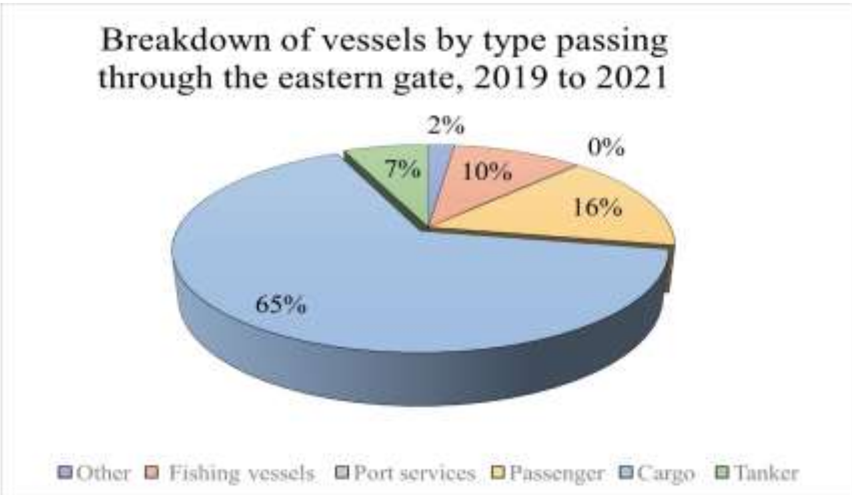
***Chart 1.*** *Number of vessels passing through the eastern gate*




***Source:*** *Own study.*

The collected 2019-2021 data show that 5459 vessels crossed the eastern gateway. 65% of all vessels were cargo vessels, while passenger ships, with 16% of the traffic, made up the second largest group (Chart 2).

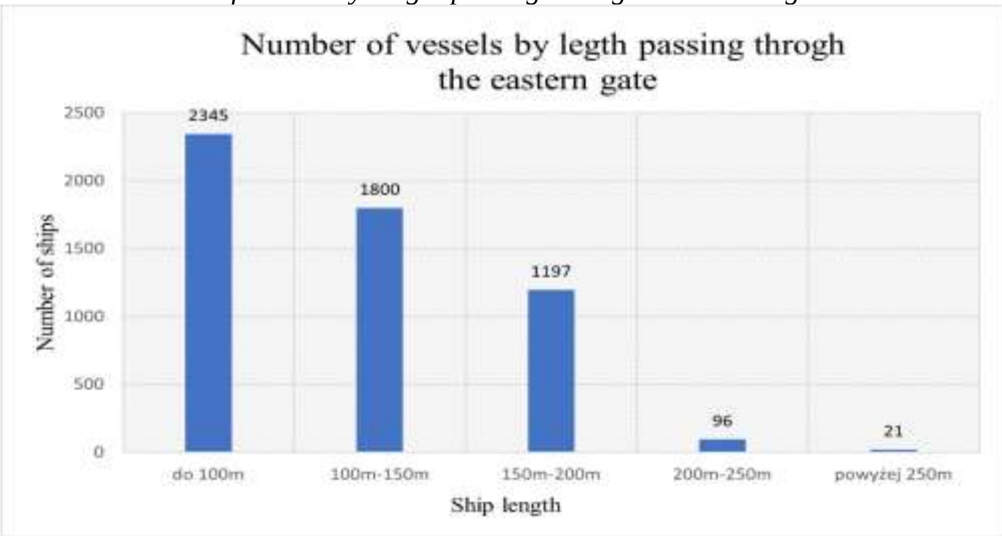
***Chart 2.*** *Percentage breakdown of vessels by type passing through the eastern gate from 2019 to 2021*




***Source:*** *Own study.*

The gate set in the eastern part of the project area (Figure 4), with a total length of approximately 7.2 nautical miles, between the years 2019 and 2021 was frequently crossed mainly by small cargo, passenger and fishing vessels, of which nearly 76% were not more than 150 m in length (Chart 3).

***Chart 3.*** *Number of vessels by length passing through the eastern gate*



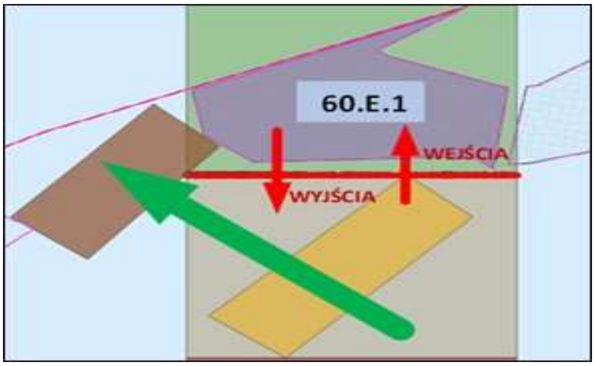

***Source:*** *Own study.*

The average number of vessels passing through the eastern gate is 1,820 vessels/year

### *3.1.2 The Southern Gate*

Another gate around the 60.E.1 area was set up on its southern side. It extended along latitude 55°28.2' N, connecting the points of longitude 17°07.8' E and 17°25.8' E.

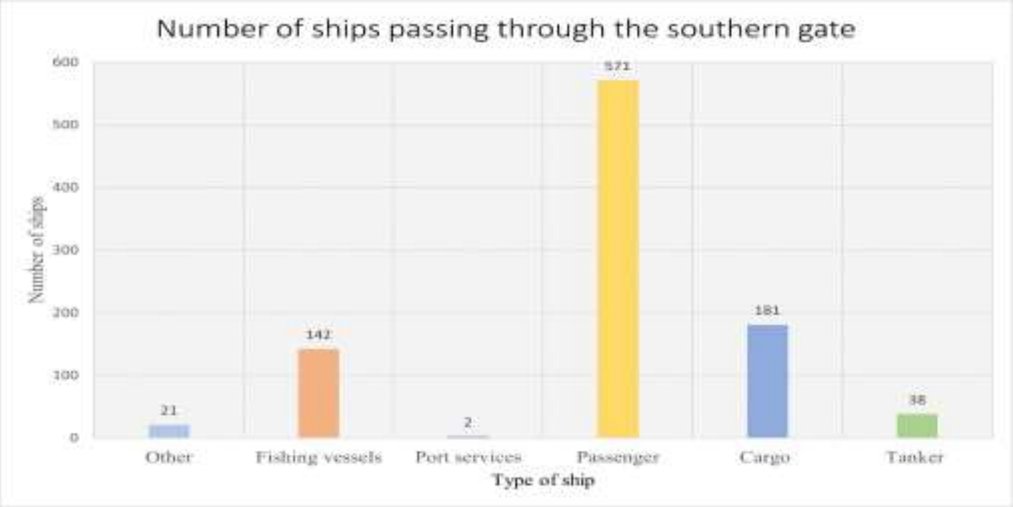
***Figure 5.*** *Southern gate showing the main route of vessel passages in the vicinity of the planned project.*




***Source:*** *Own study.*

Figure 5, in addition to the southern gate, indicates the main route of vessel passages around the planned developments marked by a green arrow. In the years covered by the 2019-2021 survey, 955 vessels crossed the southern gate entering or leaving the area of the planned development (Chart 4).

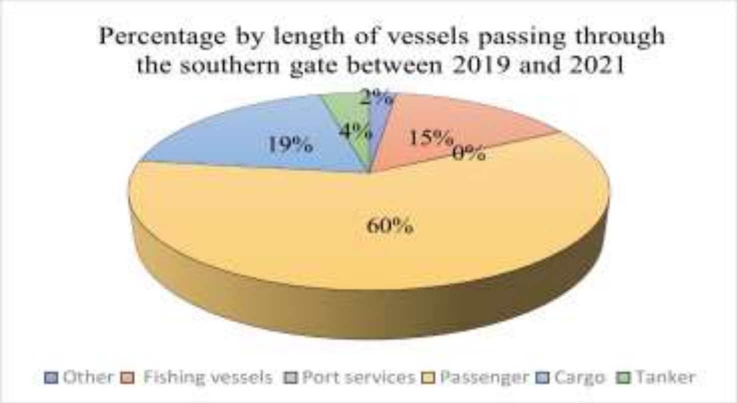
***Chart 4.*** *Number of vessels crossing the southern gate*




***Source:*** *Own study.*

Over the three-year period, passenger vessels made up 60% of those observed to cross the southern gate, followed by cargo and fishing vessels (Chart 5*).*

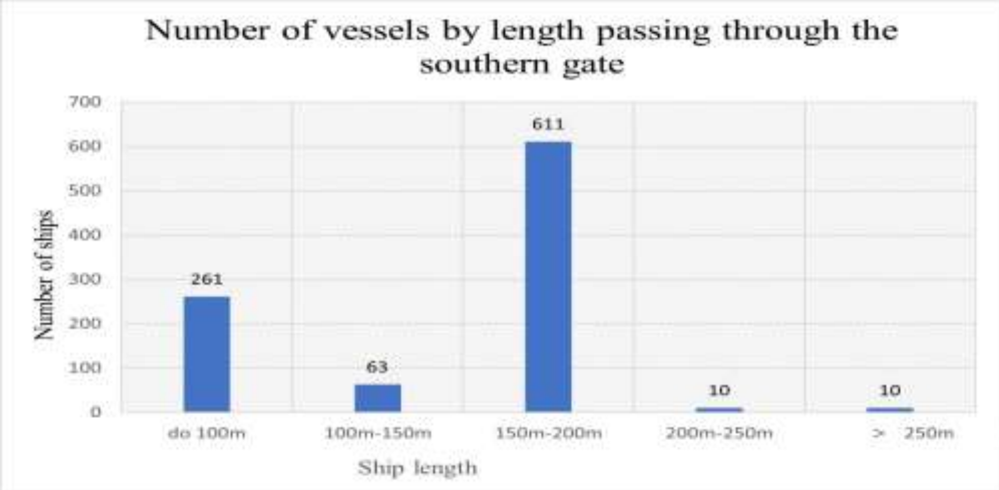
***Chart 5.*** *Percentage by length of vessels passing through the southern gate between 2019 and 2021*




***Source:*** *Own study.*

The pie chart depicting length groups of vessels that passed through the southern gate clearly shows that the vast majority falls within the 150m-200m range, i.e. nearly 76% of the traffic (Chart 6).

***Chart 6.*** *Number of vessels by length passing through the southern gate*



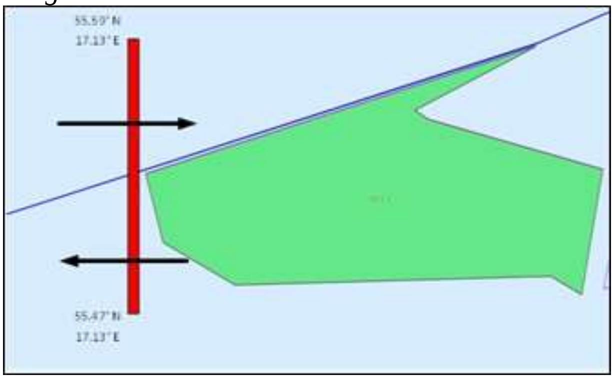

***Source:*** *Own study.*

Based on AIS data, the average annual number of vessels crossing the southern gate over the three-year period was found to be 318 vessels per year.

### *3.1.3 The Western Gate*

The western gate was set along the 17.13° meridian and extended between latitudes 55.59° N and 55.47°N.

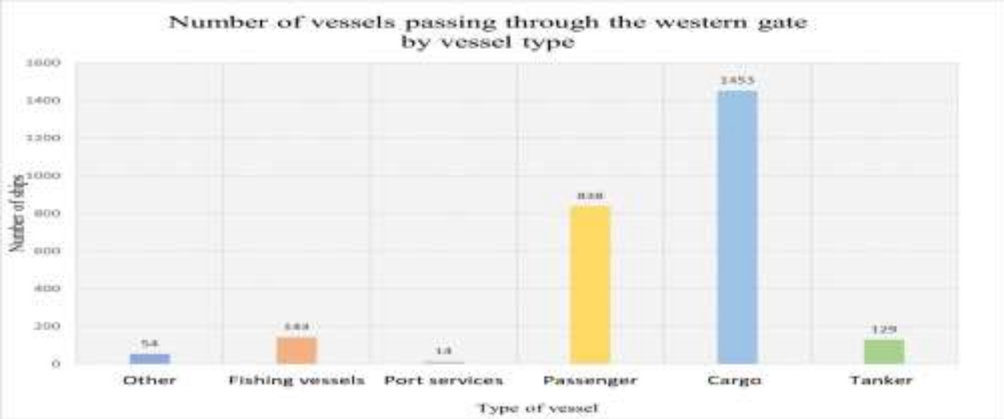
***Figure 6.*** *Western gate*




***Source:*** *Own study.*

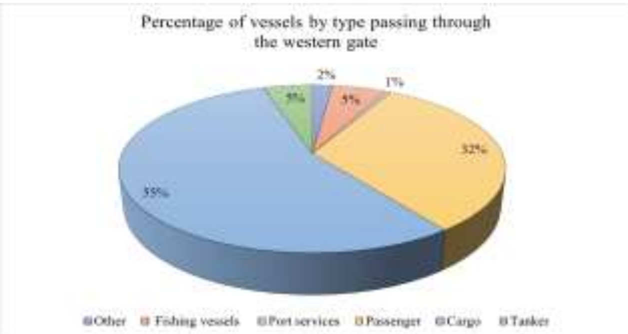
Between 2019 and 2021, a total of 2,631 vessels passed through the gate west of the 60.E.1 area designated for an offshore wind farm. The two largest groups were cargo vessels - 1453 (55%) and passenger vessels - 838 (32%) (Charts 7 and 8).

***Chart 7.*** *Number of vessels passing through the western gate by vessel type*




***Source:*** *Own study.*

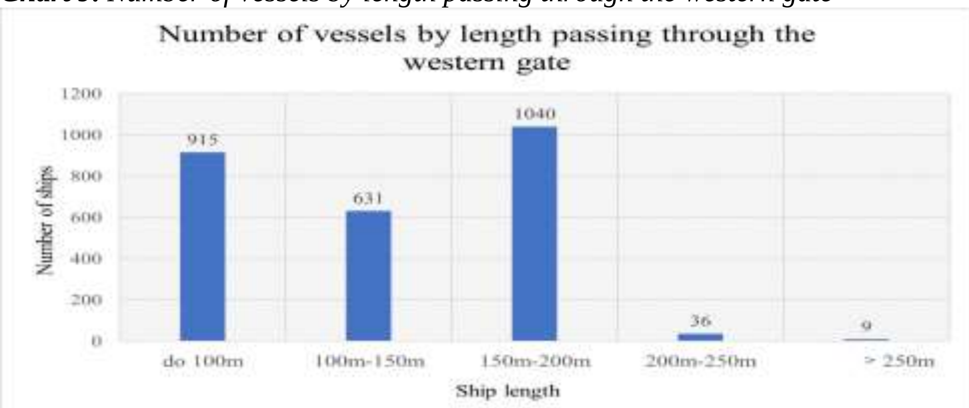
***Chart 8.*** *Percentage of total number of vessels by type passing through the western gate.*




***Source:*** *Own study.*

The gate was mostly crossed by vessels up to 200 m in length (Chart 9).

***Chart 9.*** *Number of vessels by length passing through the western gate*



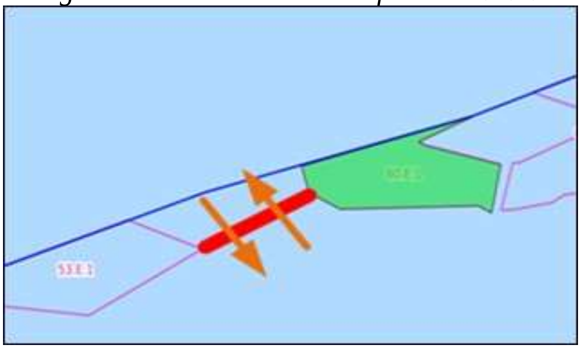

***Source:*** *Own study.*

The average annual number of vessels passing through the gate in the three years was 877 vessels/year.

### ***3.1.4 Vessel Passage on the Southwest Side of Area 60.E.1***

Due to the vastness of the water area designated as POM.60.E, intended for wind farm sites (Figure 7), which comprises smaller areas shown in Figure 8 - 60.E.1, 60.E.2, 60.E.3 and 60.E.4, vessels heading north may choose the narrow passage between area 60.E.1 and area 53.E.1 as one of the routes.

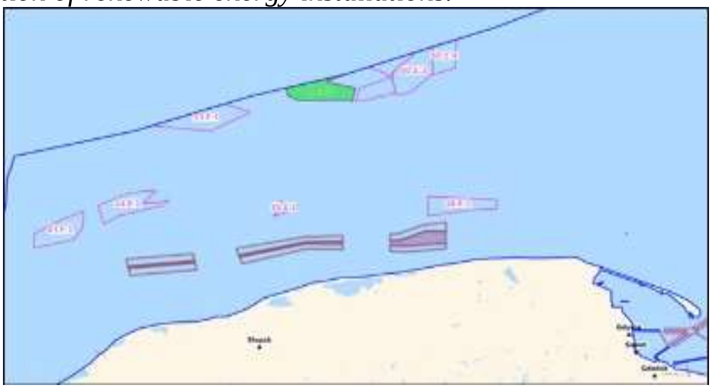
***Figure 7.*** *Vessel passage on the south-west side of area 60.E.1.*




***Source:*** *Own study.*

The passage under analysis extends from position 55.43182° N 16.99207° E to position 55.498188° N 17.145854° E. The width of the passage is nearly 6.5 nautical miles.

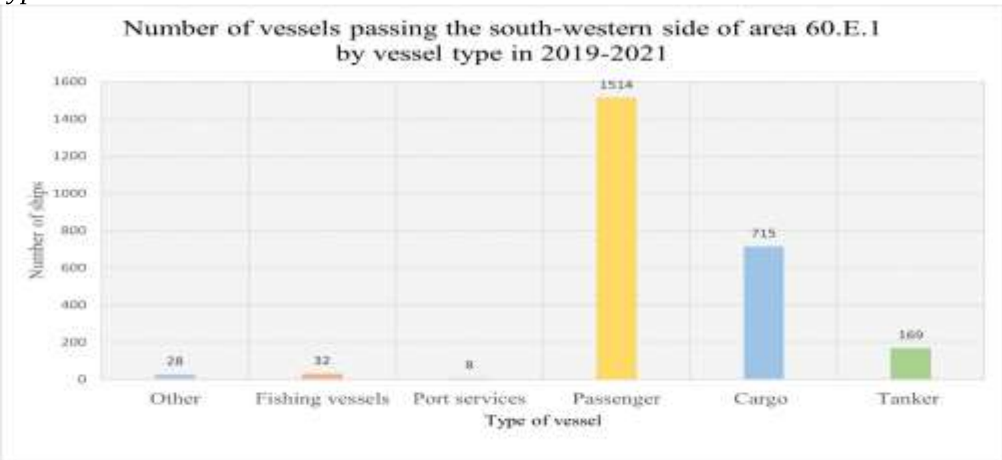
***Figure 8.*** *A section of the Polish EEZ with areas marked in magenta intended for the construction of renewable energy installations.*



***Source:*** *Own study.*

Between 2019 and 2021, 2466 vessels were recorded at the crossing between areas 60.E.1 and 53.E.1, most of them passenger ships - 61% (Chart 10).

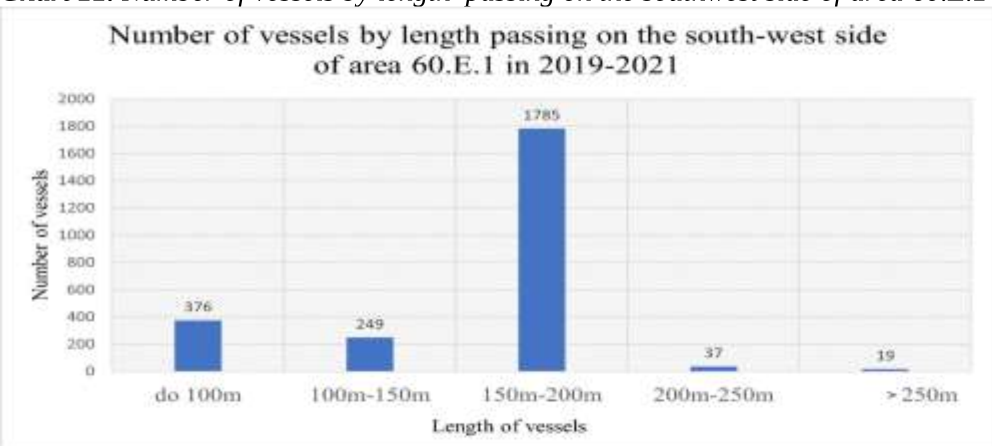
***Chart 10.*** *Number of vessels passing on the southwest side of area 60.E.1 by vessel type*




***Source:*** *Own study.*

Vessels 150 m to 200 m in length made up a majority of those crossing the gate (Chart 11).

***Chart 11.*** *Number of vessels by length passing on the southwest side of area 60.E.1*




***Source:*** *Own study.*

The average annual number of vessels passing through the gate over the three years was 822 vessels/year.

## 4. Analysis of Navigational Hazards Based on Available Literature and Performed Analysis of Vessel Traffic in the Study Area

For safety reasons, areas around wind farms are closed to normal navigation. Despite protection zones established around them, there is still a risk of potential hazards.

This is mainly due to a lack of caution when navigating, unintentional entry due to navigational error, insufficient marking, etc. This usually results in the risk of a ship colliding with a wind farm facility (Herdzik, 2018).

Fishing vessels and recreational or sport watercraft make up an important factor affecting navigational safety. These small vessels in bad weather conditions (e.g., strong gusts of wind or tides) cannot navigate safely in the vicinity of an offshore wind farm. Other situations where the area closed for navigation is violated occur in emergencies related to e.g. loss of propulsion, major machinery breakdown, etc. Human errors, resulting from a variety of reasons, also increase the risk (Herdzik, 2018).

According to the available literature, there are important factors at the wind farm design and location stage for vessels navigating around wind turbine fields, i.e. the minimum distance that should be kept - a comfortable buffer, such that when an incident occurs on board a vessel, or in a ship encounter situation, it will allow a safe evasive manoeuvre. Another important aspect is the visibility of a wind farm. Its infrastructure may obscure smaller craft i.e. recreational, fishing and maintenance vessels. If there is sufficient distance from the boundary of the wind farm field, the decision making time to make a collision avoiding manoeuvre will be longer (Rawson and Rogers, 2015).

There are also concerns about the impact of wind turbines on marine radar. Reflections, false echoes and other side effects have been observed when sailing in the vicinity of the wind farm (Maritime and Coastguard Agency and QinetiQ, 2004).

According to research, it is not the wind turbines themselves that cause this interference, but most often inappropriate radar settings and configuration (Marico, 2007). A vessel navigating in the vicinity of wind farms may therefore choose to increase its distance to reduce these effects and improve its situational awareness (Rawson and Rogers, 2015).

The safe distance, or berth, a vessel chooses to travel around the wind farm is also an important factor. Commercial pressures always forces the ship's command to minimize additional deviations from the route to avoid obstacles, because each such departure increases costs and transit times (Rawson and Rogers, 2015).

Another important aspect affecting navigational safety in the vicinity of wind farm fields is the increased risk of collisions due to high density of shipping routes. This occurs when a wind farm is located in the vicinity of another navigational obstruction or another wind farm. Vessels passing between them then have limited room in which to manoeuvre, resulting in a high risk of collision. This is referred to as 'choke points' (MCA, 2008).

In the available literature analysis, the study by Qing Yua et al. is worth looking into. Those authors use a model to investigate ship collisions with offshore wind turbines. They propose a method for modelling ship-turbine collision risk based on Bayesian networks, which aim to use AIS data by employing evidential reasoning methods. The research takes into account factors such as traffic flow (e.g. number of passing vessels, vessel types, traffic density), characteristics of vessels navigating in the area (e.g. vessel speed, vessel size, time), passing distances, offshore windfarm safety area and seasons of the year (Yu *et al.,* 2020).

### 4.1 Analysis of Navigational Hazards Based on Surveys Carried out in the Area 60.E.1

The performed analysis of vessel traffic in the area 60.E.1 of the planned wind farm shows that the traffic flow has a significant impact on navigational safety. The location of the wind farm itself will not significantly affect vessel traffic in the area, but the analysed route along the south-western boundary of the planned project will shift westward due to the need to maintain a safe distance around the wind farm. This route is mainly used by passenger vessels 150 m - 200 m in length. However, the construction of another facility in the 53.E.1 area will result in high traffic density along the passage between the two projects.

Thanks to the research carried out and the analysis of the results obtained, the authors were able to identify the most significant factors affecting the level of navigational safety in the area:

- the number of vessels travelling to and from the planned project – with the focus on vessels that will have the greatest impact on the movement of other vessels, i.e. towing vessels with restricted ability to manoeuvre, delivering oversize components for the construction of wind turbines;
- location of the supply port for the farm;
- recreational craft traffic during the summer season;
- choice of passage route between planned developments by large passenger ships.

## 5. Results of the Analysis

Hazards and their consequences in the examined area were analysed using the risk matrix method. Vessel traffic data based on AIS data was used for the purpose. The matrix method was designed to estimate the risks by assigning a probability value to specific events and then assessing the consequences within four categories (material loss, human injury and loss, environmental loss, impact of events on the correct and timely completion and operation of the planned investment project).

The scale of event occurrence probability and the impact scale for the event adopted for the study have five levels each, where 1 means very low probability and 5 means high probability. Based on the risk matrix, the following adverse events were identified:

- Collision of a wind farm supply vessel with another sea-going vessel navigating in the wind farm area. Vessels leaving the supply port that cross the TSS system and head for the area of the planned development create a potential navigational hazard for vessels using the TSS. This is due to the density of the vessel traffic in the TSS. Thus, collision avoiding manoeuvres are quite restricted by shipping lane widths and limited by the separation zones where shoals are not uncommon or where fishing vessels operate.
- Vessel collision with recreational craft or fishing vessels. Due to often insufficient equipment of recreational craft, which may lack, among other things, up-to-date navigational charts both electronic and paper, up-to-date nautical publications, systems for receiving navigational warnings i.e. NAVTEX, such boats or vessels pose a high risk in restricted areas with high traffic density and in areas where the available manoeuvring area changes along with ongoing progress of wind farm construction. A similar situation may refer to fishing vessels, where reduced fishing areas are a major factor leading to dangerous situations.
- Vessel collision in an area where vessel traffic density increases due to the commencement of construction works and/or operation of offshore wind farms. Such collisions are related to the concentration of ship traffic in a small area in the operation phase of the analysed investment project and after the development of the other areas designated for renewable energy source installation (narrowing of the passage between areas 53.E.1 and 60.E.1.). This is of considerable significance in the process of wind farm operation or later in the decommissioning stage, when further installations will be built in the vicinity of the analysed area, blocking the passage of ships through the Polish EEZ to the north. As a result of the high traffic density, accidents may occur due to collisions with ships proceeding along high-density routes and accidents involving fishing vessels that operate in the immediate vicinity of the shipping routes.
- Unexpected entry of a recreational craft into the area of offshore wind farms when the various kinds of works are in progress: construction, maintenance work or decommissioning of an OWF, creating risk of collision or damage to the relocated wind farm components, resulting mainly from such reasons as:

    - improper observation;
    - lack of information on changes in the area that affect navigation;
    - inadequate watchkeeping using the Global Maritime Distress and Safety System equipment including, most importantly, VHF radio Channel 16.

- Damage to power transmission cables of a wind turbine by a passing vessel due to inadvertent anchor dropping by the vessel, emergency anchor dropping, and the use of certain fishing gear by fishing vessels in the immediate vicinity of the cable.

Attention should also be paid to recreational craft and small fishing vessels which may be inadequately equipped to notice changes in the traffic and new restrictions in the area under consideration. The charts used on these vessels, although increasingly electronic, in paper versions are often not kept updated, mainly due to the price of updates.

A collision between a ship and offshore wind farm structure can only occur after the ship first enters a restricted area delineated at a minimum distance of 0.5 nautical miles from the wind farm boundary, and then fails to respond and collides with the structure, which should be visible by eye and marked on any available navigational aids. Vessel collisions with offshore wind farm structures can occur primarily due to vessel's technical failures, adverse weather conditions, or through errors in observation and misinterpretation of navigational marks.

## 6. Conclusions

As a result of the analysis that takes into account the identified factors and hazards that may exist with the commencement of offshore installation construction, these authors propose a number of solutions that may reduce the likelihood of the occurrence of individual hazards and thus reduce navigational risk.

1. Introduce increased exclusion zones for all seagoing vessels, including fishing vessels and recreational craft, around wind farms on the side of the main vessel passages. The size of the zones should be determined adequately to the number of vessel passages and vessel sizes. The latter is important in terms of vessel manoeuvrability and thus the sea room needed for collision avoiding manoeuvres.
2. Increase the role of VTS in overseeing the work associated with the passage of vessels delivering wind turbine components to the project area, particularly the movements of towing vessels restricted in their ability to manoeuvre through the TSS and in the navigation of towing vessels proceeding at the intersections of the main shipping routes.
3. Provide advance information to vessels in the vicinity of the traffic separation scheme about towing vessels manoeuvring within the TSS boundaries;
4. In order to reduce the navigational risks associated with encounters of seagoing vessels with recreational craft, free sources of navigational information for small craft should be made available in the form of mobile phone apps, and providing free updates to the most commonly used electronic navigational charts used on recreational craft.

## References:

Herdzik, J. 2018. Zagrożenia dla żeglugi od morskich farm wiatrowych. IALA.

Królikowski, A., Stupak, T., Wawruch, R. 2013. Zasady oceny ryzyka stwarzanego przez elektrownie na morzu.

Marico, M. 2007. Investigation of Technical and Operational Effects on Marine Radar Close to Kentish Flats Offshore Wind Farm. British Wind Energy Association.

Maritime and Coastguard Agency. 2008. Offshore Renewable Energy Installations (OREIs) Guidance to Mariners Operating in the Vicinity of UK OREIs. MGN 372 (M+F).

Maritime and Coastguard Agency and QinetiQ. 2004. Results of the electromagnetic investigations and assessments of marine radar, communications and positioning systems undertaken at the North Hoyle wind farm by QinetiQ and the Maritime and Coastguard Agency. MCA MNA 53/10/366.

Rawson, A., Rogers, E. 2015. Assessing the impacts to vessel traffic from offshore wind farms in the Thames Estuary.

Regulation of the council of Ministers of 14 April 2021.

UNCLOS. 1982.

Yu, O., Liu, K., Chang, C.H., Yang, Z. 2020. Realising advanced risk assessment of vessel traffic flows near offshore wind farms.