IOSUD – „DUNĂREA DE JOS” UNIVERSITY OF GALAȚI

Doctoral School of Mechanical and Industrial Engineering

PhD Thesis

ABSTRACT

RESEARCH ON REDUCING POLLUTION ON MARITIME ROUTES AND COASTAL AREAS IN THE BLACK SEA

PhD Candidate,

Eng. Vasile RAȚĂ

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„Academic excellence and entrepreneurial values - scholarship system to ensure opportunities for training and development of entrepreneurial skills of doctoral and postdoctoral students - ANTREPRENORDOC", Contract no. 36355 / 23.05.2019 POCU / 380/6/13 - SMIS Code: 123847

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Eng.Vasile RAȚĂ

Galați 2022

CONTENTS

(The page numbers correspond to the doctoral thesis)

INTRODUCTION

THE MOTIVATION OF CHOOSING THE TOPIC AND THE OBJECTIVES

Currently, environmental pollution is one of the most major problems globally, but it can have specific aspects for each region. This issue is of significant interest in the highest decision-making forums in the world, in political circles, but also at the individual level. Pollution has various forms of manifestation in the environment. Most pollutants are produced by anthropogenic action and are the result of economic and social activities that people carry out. However, there are also important natural sources of pollution, which are differentiated by the occasional appearance and manifestation. It is proven that these pollutants have an active role in environmental degradation, whether we are talking about: soil, water, or air. Pollutants have a direct impact on the health of humans and animals in the geographically affected area. Finally, the entire planet is affected by a resultant of the action of all present and past polluting factors.

The problem of global warming, which is directly influenced by the volume of greenhouse gas emissions that reach the Earth's atmosphere. Greenhouse gas emissions, which are ultimately a series of pollutants, are in fact the result of natural or anthropogenic actions such as: large vegetation fires, eruptions of volcanoes or industrial activities. Here we can also mention the maritime transport of goods and people, but the list is not limited to these examples.

Clear and fast action is needed to keep any type of pollution under control, applicable to any type of activity. When we refer to the coastal area and the one dedicated to maritime routes, we can take into account the pollution of water, air and last but not least of soil. The studies in this paper are aimed at identifying and proposing solutions to limit pollution resulting from maritime transport activities. It should be noted that ships of a military nature were not taken into account, as they were exempted from the area of regulations requiring operating conditions in accordance with certain pollution limits, at the international and national level.

Thus, several directions of research on greenhouse gas emissions in the field of ship operability have been addressed, both in the port area and at sea. The issue of ballast discharge has also been studied, an operation that may be an active factor in the migration of many invasive species from one marine ecosystem to another.

At the same time, the latest naval accidents in the Black Sea have been studied, to be able to identify first of all whether there is a common context for all these incidents, in order to limit the loss of human lives. This approach also leads to the identification of the potential impact of oil spills resulting from these serious naval incidents.

THESIS STRUCTURE

The doctoral thesis entitled "RESEARCH ON POLLUTION REDUCTION ON NAVIGATION ROUTES AND IN COASTAL AREAS IN THE BLACK SEA" is carried out in the form of 6 chapters, as follows:

Chapter 1 sets out the existing context that motivated the development of this thesis. Initially, the boundaries and peculiarities of the studied geographical area, the Black Sea, were described. This information was supplemented by climate and environmental information, and towards the end of the chapter, a series of historical events on marine pollution resulting from the maritime transport area were presented. In order to create a more accurate context, the characteristics of the ships and the routes on which they are active in the Black Sea were also exposed.

Chapter 2 presents analyze to determine the volume of atmospheric emissions from the shipping industry. These analyzes were carried out in the context of various purposes in the shipping industry, using a method that approached as a study area first a small area, then a larger area, and finally the entire Black Sea basin. In the meantime, the impact on the air quality in the vicinity of the port of Constanța during the state of emergency caused by the SARS-COV-2 virus was analyzed.

Chapter 3 highlights for each serious naval accident in the Black Sea the degree to which the state of the sea, respectively the parameters of wind speed and wave height, contributed or not to the production of each shipwreck. In this regard, the conditions of the past sea state were simulated using a numerical model SWAN forced with the wind fields provided by the U.S. National Centers for Environmental Prediction, Climate Forecast System Reanalysis. The results obtained have a temporal resolution of 3 hours and a spatial resolution of 0,08°. Another approach considered is the fact that the ships involved in these serious naval accidents were designed and built several decades ago. An analysis for the structural collapse was developed, taking into account the action of the metal oxidation process (rusting) over an interval of 40 years. For this, the application *MARS 2000* software solution produced by one of the naval classification companies (Bureau Veritas) was used. The risk of accidental spillage of hydrocarbons as a result of shipwrecks was assessed.

Chapter 4 sets out the effects of the accidental introduction of invasive species into the Black Sea area. The computation of the volume of ballast water with a potential risk of biohazard in the port of Constanța was performed, the study was extended to assess the volume of ballast water with potential risk in the entire Pontic Basin. The volume was determined based on statistical data on the number of ships and the volumes of goods transiting the port of Bosphorus to and from the Black Sea.

Chapter 5 entitled Solutions to Reduce the Impact of Pollution Generated by the Black Sea Maritime Industry sets out practical guidelines that are recommended to be followed by shipowners or the ship's management team. Solutions are presented to reduce fuel emissions from the combustion of fuel in the ship's engine, such as the sizing of an alternative to electricity generation for connection to shore, for berth port activities. Ballast solutions for ballast water treatment have also been dimensioned. An application was developed to calculate the energy coefficient of existing general cargo ships.

Chapter 6 of the thesis presents the conclusions resulting from the research undertaken, the original contributions of the doctoral research topic as well as the future research directions, but also the scientific papers in which the scientific contributions of the paper were disseminated.

The doctoral thesis was carried out with the financial support of the project "Academic excellence and entrepreneurial values - scholarship system to ensure opportunities for training and development of entrepreneurial skills of doctoral and postdoctoral students - ANTREPRENORDOC", Contract no. 36355 / 23.05.2019 POCU / 380/6/13 - SMIS Code: 123847.

NOTATIONS AND ABBREVIATIONS

m	meter
mm	millimeter
µm	micrometer
km	kilometer
m^2	squar meter
ha	hectare
m^3	cubic meter
s	second
h	hour
°	degree
kg	kilogram
mg	milligram
t	tons
GT	gross tonnage
tdw	Deadweight tons
kN	kilonewton
kW	kilowatt
MW	megawatt
SO_x	sulfur oxides
CO_x	carbon oxides
NO_x	nitrogen oxides
PM_x	particulate matter
H_s	significant wave heigh
U_{10}	wind speed measured at 10 meters above the water surface
ρ	water density
S_w	the area of the wet surface of the ship's hull
C_t	the coefficient of total resistance
P_{ME}	main engine power
C_F	dimensionless conversion factor used in the ratio between the amount of fuel consumed and the resulting volume of CO_2
SFC	specific fuel consumption
P_{AE}	auxiliary engine power
P_{PTI}	shaft generator power consumption
P_{AEeff}	reduction of auxiliary power due to the adoption of electrical efficiency solutions on board
P_{eff}	the energy resulting from the use of efficient innovative mechanical technology
V_{ref}	ship speed expressed in knots
f_i	capacity factor for any regulation related to capacity
f_c	volume correction factor (oil and liquefied gas carriers)
f_w	sea state coefficient (wave height, wave length, wind speed)
STD	standard deviation
D_WCC	the capacity of the cargo on board the ship
2D	Two Dimensional
3D	Three Dimensional

4D	Four Dimensional
IPCC	Intergovernmental Panel on Climate Change
BW	Ballast Water
ABS	American Bureau of Shipping
RIM	the main current in Black Sea
SUA	United States of America
SWAN	Simulating Waves Nearshore
DAMWAVE	Data Assimilation Methods for improving the WAVE predictions in the Romanian nearshore of the Black Sea
NCEP-CFSR	U.S. National Centers for Environmental Prediction, Climate Forecast System Reanalysis
DIF	December-January-February
MAM	March-April-May
IIA	June-July-August
SON	September-October-November
S-AIS	Satellite-Automatic Identification Systems
AIS	Automatic Identification Systems
VTS	Vessel Traffic Services
EU-28	European Union (EU)
UN	United Nations
ECAs	Emission Control Areas
UE	European Union
SECA	Sulfur Emission Control Areas
EGR	Exhaust Gas Recirculation
NECA	Nitrogen Emission Control Area
UNESCO	United Nations Educational, Scientific and Cultural Organization
GPS	Global Positioning System
IMO	International Maritime Organization
EGR	Exhaust Gas Recirculation
MARPOL	International Convention for the Prevention of Pollution From Ships
RAMSAR	Convention On Wetlands
OPEC	Organization of the Petroleum Exporting Countries
UAE	United Arab Emirates
PSV	Platform Supply Vessel
ERRV	Emergency Response and Rescue Vessel
EEXI	Energy Efficiency Existing Ship Index
EEDI	Energy Efficiency Design Index
GNL	Liquefied Natural Gas
GPL	Liquefied Petroleum Gas
MDO	Marine Diesel Oil
UTM	Ultrasonic Thickness Measurement
ANR	Romanian Naval Authority
RNR	Romanian Naval Register
FEM	Finite Element Method
CSC	Common Structural Rules
IACS	International Association of Classification Societies
BWT	Ballast Water Treatment
BWTS	Ballast Water Treatment System
UV	Ultraviolet
FPSO	Floating Production Storage and Offloading

BWM	Ballast Water Management
MEPC	Marine Environment Protection Committee
UCS	User Coordinate System
ITTC	International Towing Tank Conference
EPL	Engine Power Limitation

Capitolul 1: HIGHLIGHTS OF POLLUTANTS IN THE BLACK SEA

1.1 Black Sea descriptive notes

The Black Sea belongs to the category of semi-closed seas, having an elliptical shape with east-west development [1], [2]. The Black Sea communicates with the Mediterranean Sea through the two straits that delimit the Marmara Sea from the Black Sea, on the one hand, and from the Mediterranean Sea on the other side. The Bosphorus Strait is the access road to the Marmara Sea [3], and the Dardanelles Strait is the access road between the Marmara Sea and the Mediterranean Sea. Having access to the Mediterranean Sea, we can consider that the Black Sea communicates with the Planetary Ocean through the Strait of Gibraltar which connects the Mediterranean Sea to the North Atlantic Ocean. The Black Sea communicates in the northeast with the Azov Sea, this being possible through the Kerch Strait. At the same time, the Black Sea has a number of six neighboring countries: Romania, Bulgaria, Turkey, Georgia, Russia and Ukraine.

The Black Sea occupies an important place among the European seas, having the largest area compared to the seas that are part of the Mediterranean Sea. The Black Sea basin covers an area of 466,200 km2, this value representing a percentage of 34% of the total Mediterranean Sea [1]. Geographically, the Black Sea is located between two continents (Europe and Asia), with the following geographical coordinates as cardinal boundaries: between 40º55′ and 46º32′ north latitude, and between 27º27′ and 41º42′ east longitude. Given the geographical boundaries of the Black Sea, it is located in the northern hemisphere, east of the Greenwich meridian. This spatial arrangement corresponds to the direct impact of a number of factors: considering the value of 45º northern latitude that crosses the Black Sea, and the value of 43º northern latitude that transits the central area of the Black Sea, we can mention that the presence of the four seasons, characteristic of our country, we also find it in the Black Sea basin.

1.2 Wind and wave characteristics in the Black Sea

The Black Sea has been known since ancient times by seafarers as a sea with many problems shipping related. However, in the new perspective given by the macroclimatic phenomenon called "global warming", accompanied by the related effects that lead to major climate change, it is necessary to analyze how the main factors that characterize the condition of the sea acted. What seemed like a hypothesis years ago is now becoming an increasingly internationally recognized reality, and the latest IPCC reports confirm this [6].

In recent years, extreme weather events have seen a worrying acceleration of their occurrences and their intensity, both on water and on land. Examples include the year 2003, in which the drought affected the entire continent of Europe, with record temperatures [7]. The average amount of damage caused by natural disasters in the United States annually amounts to tens of billions of dollars [8]. We must not forget that these extreme weather events often result in casualties.

1.2.1 The climate of wind and wave in the Black Sea

The sea state is directly influenced by the wind speed and the height of the waves. The sailing conditions themselves are parametric results related to the actual sea state. In order to identify how events, take place at sea, in a geographical area defined by geographical position coordinates, in a certain time interval, it is necessary to use the results obtained from simulations performed with a wave modeling system.

The SWAN model with which the simulations used in this study were performed was calibrated for the Black Sea basin, within the project "Implementation of data assimilation methods to improve wave prediction in the Romanian coastal areas of the Black Sea" (acronym DAMWAVE, https: //www.damwave.ugal.ro/index.htm), in which the parameterization of the model was done with high resolution wind fields provided by U.S. National Centers for Environmental Prediction, Climate Forecast System Reanalysis (NCEP-CFSR). The wind fields have a spatial resolution of 0.312º × 0.312º and a temporal resolution of 3 hours.

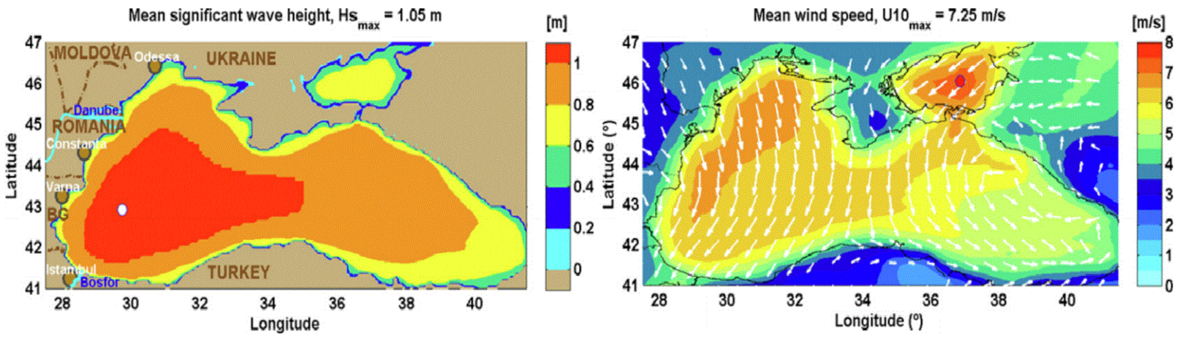

Figure 1.2 Average values of significant wave height (left) and wind speed (right) in the period 1987-2016 [25]

1.2.2 Analysis of extreme events reported in the vicinity of ports in the Romanian coast

In order to identify possible extreme events near the Romanian coast, the data resulting from the simulations with the SWAN model were statistically processed.

To perform the study, seven points were identified, two near each port studied (Figure 1.1). By choosing two geographical points for each of the areas of interest concerned, the resulting data were validated using the comparative verification technique. It was necessary to adopt this geographical point selection strategy in order to increase the capacity to determine possible errors that may occur in the processes of manipulation and processing of input data. At the same time, the use of the geographical points selection approach allows to notice the possible changes of the sea condition resulting from possible bathymetry differences. The sea state and the atmospheric conditions are analyzed near four ports highlighted in the following figures: Mangalia (Figure 1.6a), Constanța (Figure 1.6b), Midia (Figure 1.6c), and Sulina (Figure 1.6d).

Various statistical methods were used to process data on significant wave heights (H_s), such as: samples average, samples maximum, Skewness indicator, samples standard deviation of (STD), 95% confidence interval, and the results are presented in Table 1.1.

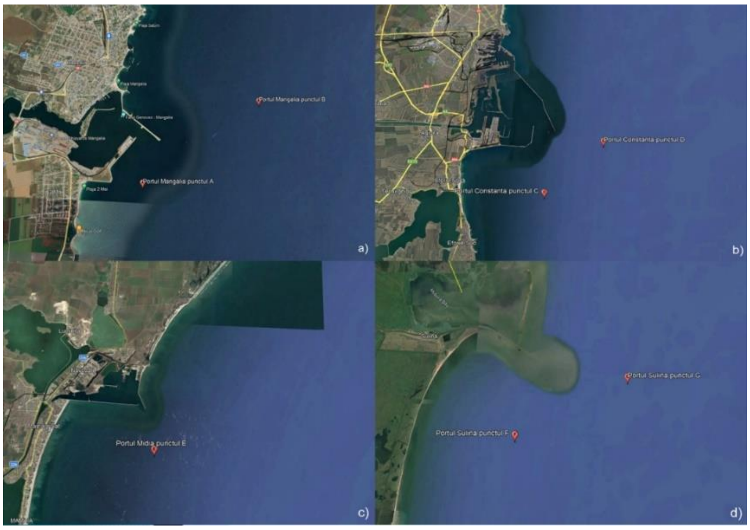

Figure 1.6 Romanian seaports and the position of the points of reference: a) Mangalia (points A and B); b) Constanța (points C and D); c) Midia (point E); d) Sulina (points F and G)

Table 1.1 *The main characteristics of H_s in the reference points*

Points	***A***	***B***	***C***	***D***	***E***	***F***	***G***
Longitude (º)	*28,62*	*28,65*	*28,71*	*28,75*	*28,70*	*29,84*	*29,87*
Latitude (º)	*43,76*	*43,81*	*44,05*	*44,09*	*44,30*	*45,04*	*45,12*
Depth (m)	*14*	*23*	*34*	*32*	*22*	*30*	*27*
Average (m)	*0,59*	*0,66*	*0,72*	*0,74*	*0,50*	*0,77*	*0,77*
Max (m)	*4,39*	*5,41*	*6,14*	*6,19*	*4,70*	*6,12*	*6,01*
Std (m)	*0,47*	*0,50*	*0,53*	*0,55*	*0,39*	*0,56*	*0,56*
95th (m)	*1,51*	*1,66*	*1,76*	*1,82*	*1,26*	*1,88*	*1,88*
Skew	*2,28*	*2,19*	*2,18*	*2,16*	*2,17*	*1,95*	*1,92*

The average wind speed in the seven selected points along the Romanian coast has a value of approximately 5.5 m/s, with the mention that in point E the value drops to a value of 5 m/s. The standard deviation is also in the range of 2.5-3 m/s.

The explanation for the noticeable difference between the values of points A, B, C, D, F, G, and E is that in the case of point E, related to the port of Midia, to the north there are high shore formations. The area between Lake Corbu and the beach is a natural cliff with average altitudes of 20 meters [256]. Thus, at the point 10 meters above sea level, as the wind speed U_{10} is measured, in the present study, the geographical point E is naturally protected from strong winds that are developed predominantly in the N-S direction. See wind rose from point E, Figure 1.8.

To determine the wind action in the four centers of interest studied, four wind roses were made. The wind rose is a graphical representation of the frequency with which the wind acts as a disposition on the four cardinal directions (N-S-E-W) and four sub-cardinal directions (NE-NW-SE-SW). In Table 1.2 can be identified both the geographical position, by GPS coordinates, and the values of the monthly maximums of significant wave height and wind speed, at a height of 10 meters above sea level (U_{10}).

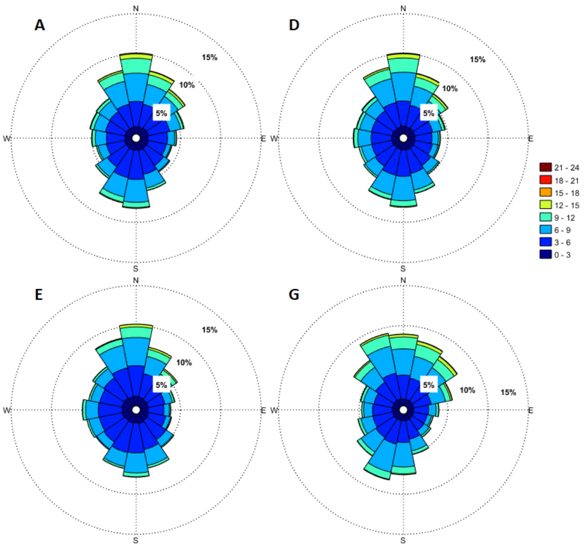

Figure 1.8 Wind diagrams for the studied locations

Table 1.2 *Values and coordinates of the monthly maximums H_s, forecast for the time interval 2021-2050 [31]*

Month	*Date*	*Long (°)*	*Lat (°)*	*H_s (m)*	*U_{10} (m/s)*
January	*2022/01/24*	*36,22*	*44,60*	*7,62*	*21,05*
February	*2042/02/06*	*37,90*	*44,36*	*9,74*	*27,26*
March	*2031/03/31*	*33,10*	*44,04*	*9,84*	*22,28*
April	*2031/4/01*	*34,38*	*43,88*	*9,12*	*21,54*
May	*2050/05/13*	*30,46*	*43,16*	*6,40*	*19,58*
June	*2038/06/25*	*38,30*	*44,04*	*5,80*	*22,79*
July	*2038/07/03*	*37,10*	*44,20*	*6,04*	*22,71*
August	*2033/08/23*	*32,62*	*43,08*	*4,38*	*18,00*
September	*2025/09/27*	*29,50*	*44,12*	*10,93*	*32,70*
October	*2040/10/28*	*38,38*	*44,04*	*11,45*	*30,75*
November	*2047/11/11*	*37,74*	*44,44*	*10,89*	*30,60*
December	*2026/12/11*	*29,34*	*43,64*	*8,36*	*23,33*

1.3 Pollution in the Black Sea, historical data

Anthropogenic activities are generally constant sources of pollution, whether accidental or operational. Through the process of shipping, from one point to another on the planet, new negative effects have emerged: pollution results or effects due to newly created natural imbalances. Whether we are talking about accidental or operational oil spills, the introduction of invasive species from one natural ecosystem to another natural ecosystem, the maritime industry produces certain negative effects on the environment.

Invasive species are those organisms that are anthropically introduced into a new environment, where they manage to adapt, multiply and spread, thus becoming harmful to the natural systems of that host environment. Thus, the consequences of these types of effects may harm the economic interests of the states in the affected region.

In 1982, the sinking of the Romanian oil tanker UNIREA took place. The event took place forty nautical miles southeast of Cape Kaliakra. The explosion affected the structural integrity of the ship, as well as its tightness. The ship sank shortly after. Most likely, the ship did not carry petroleum products in the cargo tanks, so only the fuel necessary for the ship's operability during the voyage was accidentally discharged into the marine environment [42], [43].

In 2019, the cargo ship, QUEEN HIND, tilted to the starboard with sixteen thousand four hundred sheep on board, alive. The ship under the Palau flag was to transport sheep from Romania to Saudi Arabia, but it sank in the Midia-Năvodari port area a short distance from the berth. Subsequently, the ship was rebuffed and removed from the area of the accident, and the remains of the animals that did not survive were removed for incineration [49].

1.4 Characteristics of ships and maritime routes in the Black Sea

Shipping has been certified in the Black Sea area since ancient times. Thus, there is historical evidence attesting to this activity since the early period of the Neolithic era. In the area of Sava, in the region of Varna - Bulgaria, a cult object in the shape of a "boat" was discovered, the artifact being made of red clay [50].

In the area of the Black Sea coast, a series of stones processed with one, two or three holes were also discovered. These stones are supposed to represent ancient anchors, used by the first navigators in the interval between the second millennium BC - the first century BC [50]. In the 7th century BC, the Greek city of Histria was founded in northern Dobrogea. Historians assume that this event was preceded by numerous Greek expeditions to the Black Sea, whether we are talking about the northern coast at the exit of the Bosphorus or the southern coast. After the establishment of the three Dobrogean fortresses on the current surface of Romania: Histria (Istria), Tomis (Constanța), and Callatis (Mangalia), and those on the territory of Bulgaria: Antheia - Apollonia (Sozopol), Mesembria (Nessebar) followed many fortresses on the southern shores of the Black Sea (present-day Turkey): Sinope (Sinop), Trapezunta (Trabzon), Kotyora (Ordu) and Kerasunta (Giresun) [52].

Nowadays, sea routes can be described using huge databases. These databases use data received from satellites (S-AIS) on the location of ships, but especially information received from coastal stations using an automatic identification system (AIS). Automatic identification systems (AIS) use a set of radar-type transmitters and receivers, which are installed on board ships under the name "vessel traffic services" (VTS).

Using the processed data of such a public database, it was possible to highlight a graphical model that reveals the density of maritime traffic. Obviously, this graphic model was applied to the Black Sea region. It should be noted that relatively recent data were used, using the time interval: 2015-2016. Thus, in Figure 1.13 (right side) the main contemporary maritime routes in the Black Sea were highlighted.

The average age value of ships in the port of Constanța is even more worrying. All ships and vessels legally required to use the automatic identification system (AIS) have been taken into account here. Thus, we find many ships of relatively small size, among them even pleasure boats and many ships with duties in the area of port services. An example that can be given is "Bricul Mircea", the school ship of the "Mircea cel Bătrân" Naval Academy, built in 1938 [56]. In Figure 1.16 another characteristic of the active Black Sea fleet can be identified, this is given by the type of ships. A very large number of general cargo ships, bulk carriers, and oil tankers can be seen. These ships generally carry out the export process of products from the Black Sea region. Thus, we can understand that a lot of raw materials are exported: crude oil, cereals, mineral products, timber, etc.

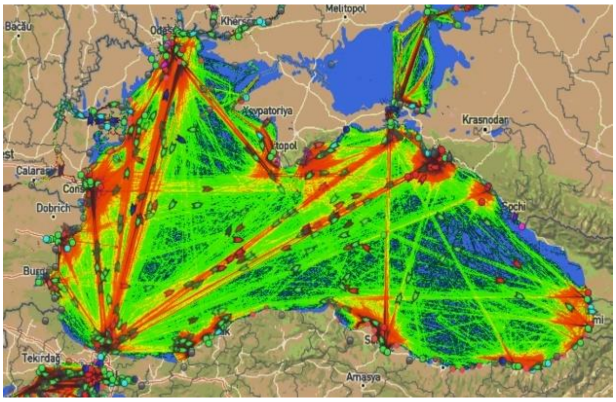

Figure 1.13 Maritime routes in the Black Sea, using traffic density in the period 2015-2016 [56]

Table 1.3 Ships operating in the Black Sea (13.06.2017)

ID	*Flag*	*Name*	*Type*	*L (m)*	*Deadweight*	*Build. y.*
1	*Grecee*	*Providence*	*Chem. tank*	*103*	*6450*	*2009*
2	*S. Leone*	*Princess H*	*General Cargo*	*92*	*2934*	*1985*
3	*Panama*	*Ibrahim Konan*	*General Cargo*	*108*	*8107*	*2006*
4	*Turkiye*	*Nazlim*	*General Cargo*	*146*	*11300*	*1978*
5	*Russia*	*Mekhanik Kharitonov*	*Tanker*	*141*	*5565*	*2011*
6	*Liberia*	*Sea Power*	*Bulkcarrier*	*225*	*74665*	*2001*
7	*Russia*	*Kapitan Barmin*	*Tanker*	*134*	*5742*	*2002*
8	*Russia*	*Mekhanik Paramonov*	*Tanker*	*141*	*5537*	*2011*
9	*Russia*	*Kivach*	*General Cargo*	*105*	*3997*	*1985*
10	*S. Leone*	*Ranyus Sea*	*General Cargo*	*98*	*3732*	*1985*

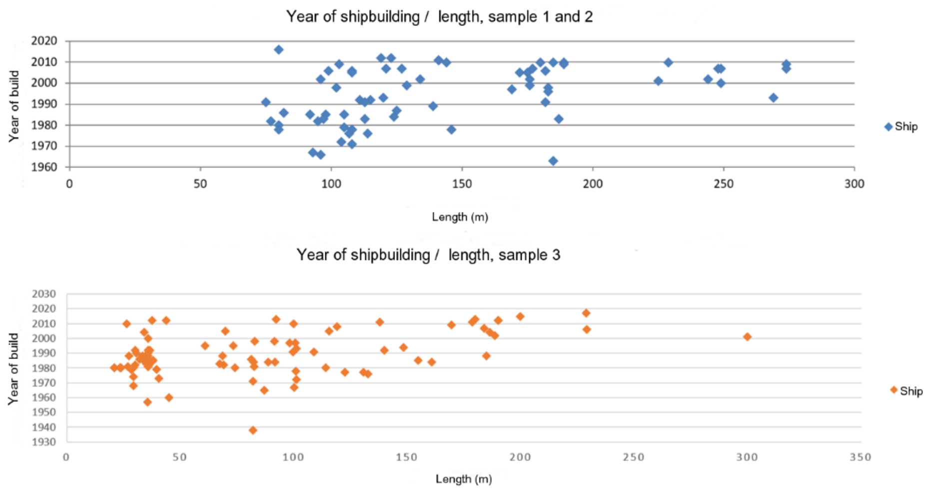

Figure 1.15 Building year of the two fleets's samples corresponding to their length

Large ships, the most newly built, are designated to longer voyages. Smaller and older ships usually travel on shorter sea routes, but this is not a rule [58].

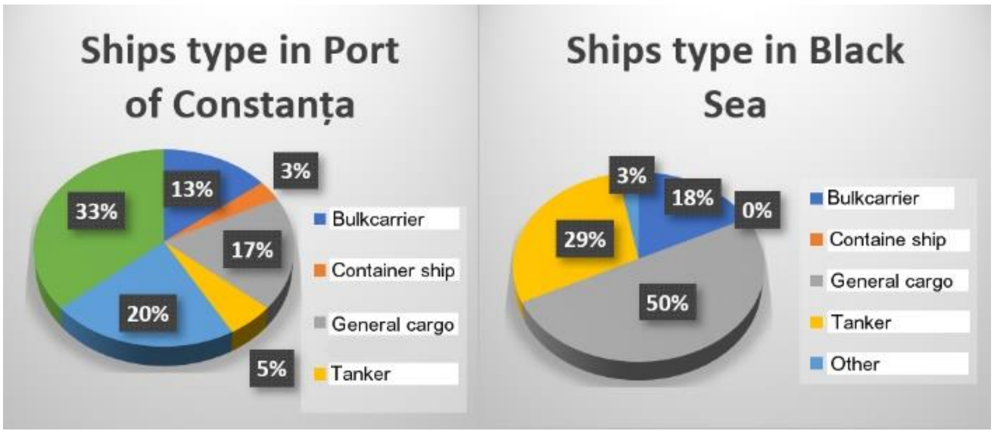

Figure 1.16 Type of vessels in the two samples Port of Constanța / Black Sea

1.5 Conclusions

In the first paragraphs of this chapter highlighted the characteristics and particularities of the studied geographical area, respectively the Black Sea basin. Based on the objectives of the thesis, information on the sea state within the DAMWAVE project was requested, in order to identify the average values of wind speed and significant wave height for the historical period, corresponding to the time period of 30 years, 1987-2016.

Based on these results we can conclude that the Black Sea is a dynamic environment in which the wave energy ratio changes on a seasonal or interannual scale. These variations bring with them a number of factors that negatively influence the safety and productivity of the maritime and offshore sectors [60]. There are also many other studies that confirm the existence of a more pronounced dynamic sea state in the western sector of the Black Sea [59], [61].

It can be concluded that near the Romanian ports, on the Black Sea, can appear a series of extreme natural factors, such as intense winds but also waves with significant wave heights that can adversely affect shipping.

The risk of introducing new species from certain ecosystems into the Black Sea aquarium is an existing and high one. This potential risk is confirmed by historical events in the Black Sea basin, but also by the high probability that ships transport these living beings through untreated ballast water.

Capitolul 2: ANALYSIS OF EMISSIONS GENERATED INTO THE ATMOSPHERE BY COMMERCIAL SHIPS IN THE BLACK SEA

2.1 UNESCO protected natural ecosystems - potentially affected areas

Near the Black Sea there are numerous national nature reserves, delimited and protected by the five neighboring states. However, the three most prominent natural locations that are also included in the UNESCO World Cultural and Natural Heritage are the "Danube Delta Biosphere Reserve", the "West Caucasus Mountains" and the "Srebarna Nature Reserve". The three natural areas, protected under the auspices of UNESCO, are graphically located on the map in

Figure 2.3 in the form of green dots. Near the three green points are associated the names of these locations for easier identification.

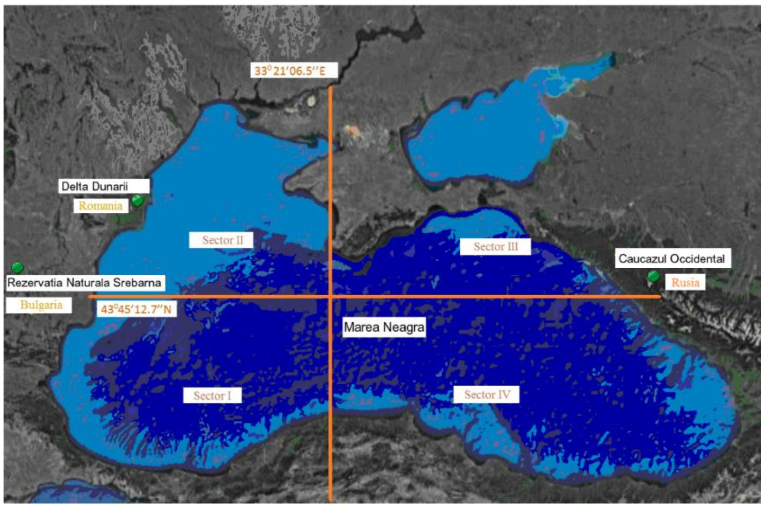

Figure 2.3 The four main sectors of the Black Sea area and UNESCO-protected natural areas [70]

In order to highlight the potential risk in terms of gaseous pollution of these regions, and the possible impact on them, the direction of wind action in the Black Sea basin area was studied. Also, the action of the air masses was evaluated for 7 days, between 05.06.2017-11.06.2017.

The result shows that, in more than half of the studied time, the wind blows towards the protected area "Danube Delta Biosphere Reserve", and these winds have the potential to transport gaseous and suspended emissions (PM_x) from coastal shipping routes. Mainly maritime traffic near the shore should be taken into account..

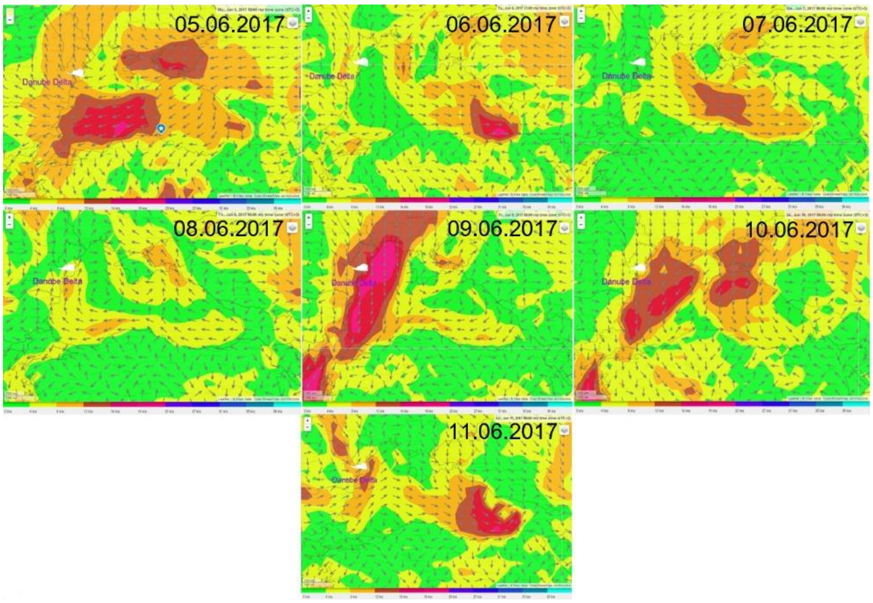

Figure 2.5 Winds direcțion in the Black Sea (05.06.2017)/(06.06.2017)/(07.06.2017)/(08.06.2017)/(09.06.2017)/(10.06.2017)/(11.06.2017) [73]

In Figure 2.6 for the winter and autumn months, we find average values of U_{10} wind speed of 8.44 m / s, respectively 7.59 m / s. Regarding the regime of action of air masses, it is observed that they vary depending on the local geographical characteristics. The predominant wind direction in the case of the Romanian coast is given by the vector N-S [74], [75].

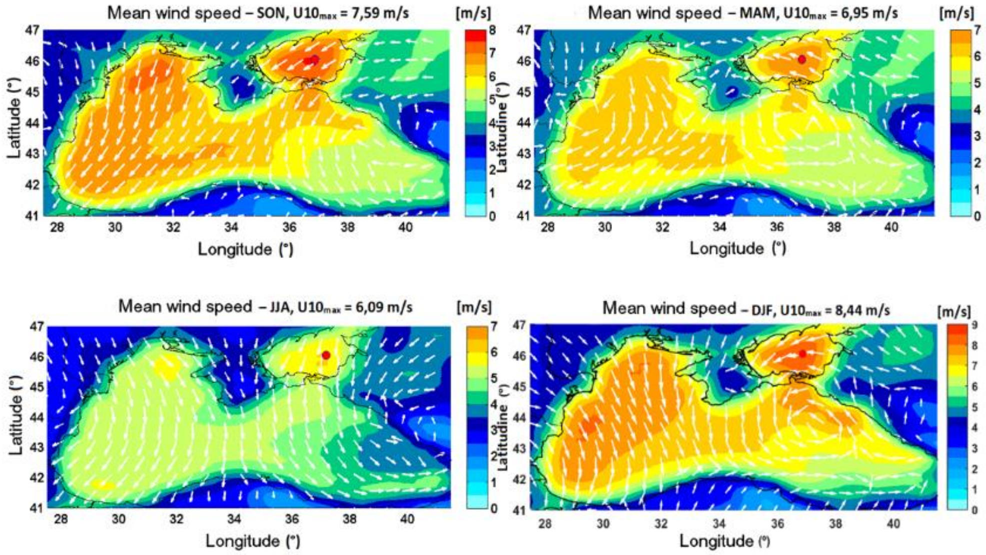

Figure 2.6 Evolution of average wind speed in the Black Sea basin, seasonal [74]

2.2 Case study - Sizing the volume of emissions resulting in the Port of Constanța

The port of Constanța is located near the city of the same name, a city located in the southeastern part of Romania and in the northwestern part of the Black Sea basin. The positioning of the port and the city of Constanța is also shown in Figure 1.6 b). The port of Constanța is for the EU the largest and most important port on the Black Sea. At the same time, it was listed in 2012 as the second most important port in this region, after the Russian port of Novorossiysk [79]. Due to the important position of the port of Constanța in the European Union, the current trend of maritime traffic is one of growth. Taking into account the possibility of increasing maritime activities in the port of Constanța, the largest port in Romania, it is necessary to assess air quality in inhabited areas. The purpose of this chapter is to assess the influence of maritime activities on air quality in areas close to the port.

2.2.1 Ships calling on port services

Annually, the port of Constanța receives a considerable number of port calls. Between 2014 and 2017, the average volume of calls was approximately 14,400 in a single year, see Table 2.1.

Table 2.1. *Port calls in Constanța 2014-2017 [82]*

Year	*Port calls*	*River calls*	*Total ship calls*
2014	*4.771*	*10.053*	*14.824*
2015	*4.605*	*9.765*	*14.370*
2016	*4.331*	*10.203*	*14.534*
2017	*4.093*	*9.272*	*13.365*

300 ships were identified that were inside the port of Constanța in 2019, according to data provided by an international database, which provides public, free of charge and in real time, information on the position of ships [57]. The data processing process led to a 25% percentage

of data that could not be validated, this being motivated by the fact that the necessary data related to the ships in question could not be identified. We continued to work only with validated data that represented 75% of the previously identified information, these values are shown in the graph in Figure 2.9.

From the perspective of the destination of the ships that use the services of the port of Constanța, it can be observed in the following figures certain particularities related to the destination of navigation and dimensions. Thus, we find that the average length of the identified vessels is largely reduced. Thus, 54% of ships have lengths of less than 40 m, and only 4% of ships exceed 200 meters in length. Ships between 40 and 200 meters in length were identified in 42%, as shown in Figure 2.11.

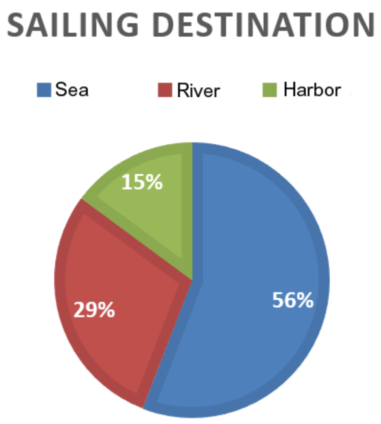

Figure 2.10 Ships distribution by destination

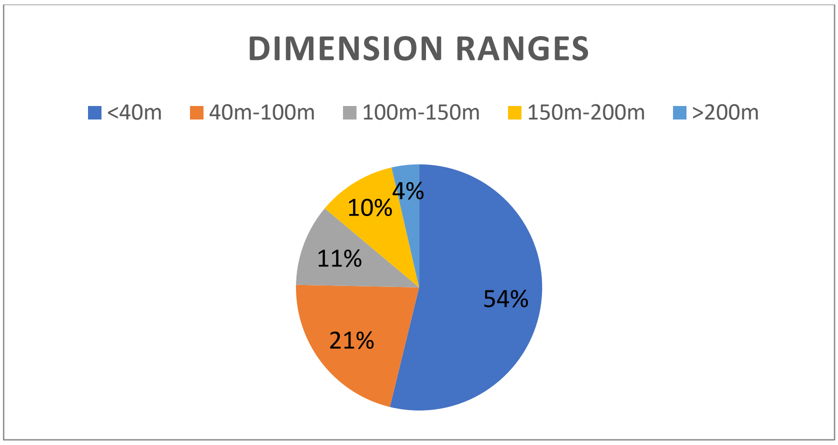

Figure 2.11 Ships distribution by length

2.2.2 Methods

In the initial stage, the entire fleet that benefited from the port services in Constanța was identified. After identifying them, a database was created in tabular format. In Table 2.2, ship identification data and technical characteristics of ships are entered as follows: ID., name, year of construction, length, size range, type of ship, destination, installed capacity, and installed port power.

The information in Table 2.2 is necessary to determine the volume of gaseous pollutants resulting from the combustion of fuels used to ensure the necessary electrical and mechanical power on board ships.

Table 2.2. *Ships identified in the port of Constanța, selection from Annex 1*

ID	*1*	*2*	*3*	*4*
Name	*Neptune KEFALONIA*	*MIRCEA*	*MICHEL A*	*KAMPALA*
Building year	*2009*	*1938*	*2007*	*2001*
L (m)	*169,59*	*82,0*	*183,98*	*299,99*
Lenght	*150<L<200*	*40<L<100*	*150<L<200*	*L>200*
Type	*RO-RO*	*Trainee Ship*	*Container vessel*	*Container vessel*
Destination	*Maritime*	*Maritime*	*Maritime*	*Maritime*
Deadweight (t)	*11361*	*1144*	*22014*	*88700*
Power (kW)	*12000*	*809*	*14000*	*49000*
Harbor Power (kW)	*700*	*809*	*10500*	*36750*

Using the data in Table 2.2 correlated with the information in Figure 2.12, the power installed on board can be determined for each ship. The data provided by the IMO state that for medium-sized oil tankers, the quay power is 400 kW [83].

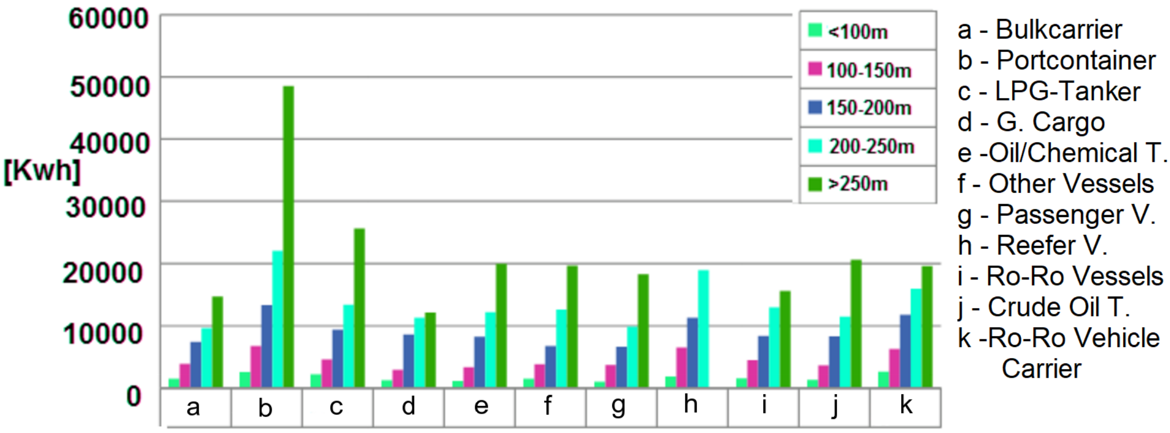

Figure 2.12 Power installed on board the vessel by type and length (kWh) [68]

Most of the time such calculations are made according to relation (2.1), where the emissions are denoted by E, FC represents the fuel consumption and EF is the emission factor. In this case, another approach was adopted to determine the volume of emissions resulting from the operations of ships in the Port of Constanța [84].

$$E=FC \cdot EF \qquad (2.1)$$

Scenarios that took into account different possibilities and regulations were calculated using the relation (2.2). At the same time, individual scenarios were used for each of the SO_x, NO_x and fine particulate matter (PM_x) emissions. The results are quite impressive considering that in one hour of port operations, in Constanța, they are emitted into the atmosphere for the most plausible case: 2 - 2.5 tons of SO_x, between 1 ton and 2.4 tons of NO_x and about 12 kg of PM.

$$E=PN \cdot EC \qquad (2.2)$$

Table 2.3. *The values of gas emissions resulting from port operations in different scenarios, Constanța Port*

Scenario	***Power [kW]***	***Harbor power [kW]***	***The average power for ops. [kW]***	***Volume [g/kWh]***
SO_x 3.5%	*8040*	*1276*	*2011*	*14*
SO_x 4.5%	*10337*	*1640*	*2585*	*18*
Tier II	*4421*	*701*	*1105*	*7,7*
Tier I	*5627*	*893*	*1407*	*9.8*
Îbefore – 2000	*9762*	*1549*	*2441*	*17*
PM_x	*51*	*8*	*12*	*0,09*

2.3 Case study - Sizing the volume of emissions from the offshore industry

The purpose of this section is to assess the risk induced on air quality by offshore exploitation in the Black Sea. It also assesses how potential new offshore operations could affect coastal air quality. The need for such a study is also related to the international quotations of the barrel oil price, which an upward trend in recent years, exceeding the rate of return for the exploitation of offshore deposits for shallow and medium depths.

2.3.1 Oil and gas exploitation

At the local level, in the exclusive economic area of the Romanian coastal marine space (Figure 2.15), the exploration projects of the oil and natural gas fields started at the end of 2014, if we refer to the most recent prospecting.

Figure 2.15 Black Sea oil fields in the Romanian offshore region [96]

2.3.2 Green energy

Another technological trend that will certainly influence the hydrocarbon market is the migration of consumers at all levels, both domestic and industrial, to electricity. Thus, green energy production has migrated to offshore areas. Many studies are trying to assess the opportunity to develop such solutions off the Black Sea along the coast of Romania and the opportunity to install offshore wind farms. At the same time, hybrid solutions are evaluated that are able to transform into electricity: wave, wind and even solar energy [97], [98], [99], [100].

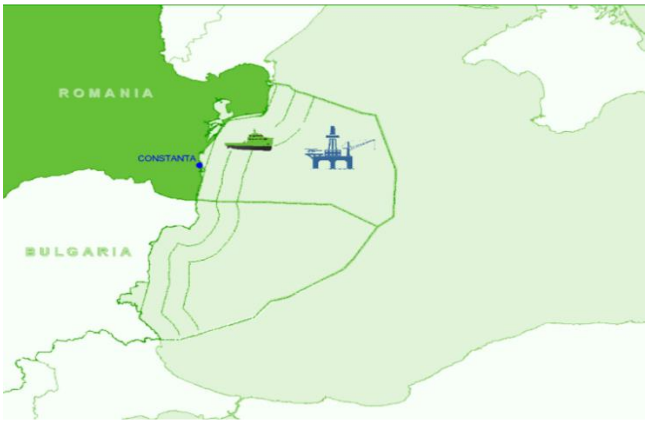

Figure 2.16 Territorial waters of the EU, Romania and Bulgaria [101]

2.3.3 Results and discussions

In Table 2.6, column *a* show the consumption and emissions for the Simon Møkster offshore fleet, values for the year 2018. To perform this study, the comparative method was taken into account. The comparative method was considered Simon Møkster's fleet of standard vessels, and the results of that fleet were processed to be attributed to the offshore fleet in the Black Sea.

***Table 2.6** Consumption / emissions [103], [104], [105]*

Scenario	a	b	c	d	e	Total	S.I.
MDO	30573	6253	360	1170	93,94	7877	t
LNG	1888	N/A	N/A	N/A	N/A	N/A	t
Eq. Energy	391	79,98	4,60	14,96	1,20	100,75	GWh
CO_2	100888	22699	1306	4246	341	28594	t
NO_x	885,9	199,33	11,47	37,29	6,33	254,43	t
SO_x	36,2	8,89	0,51	1,66	0,43	11,49	t
PM	45,9	11,27	0,65	2,11	0,17	14,19	t

2.4 Sizing the volume of emissions resulting in the Black Sea basin

Air quality has become a real concern from two major perspectives: firstly because of the high health risk to the entire population [106], and secondly, because of the direct connection it has in the growing trend of global warming effects. Recent studies estimate that approximately 3% of all cardiopulmonary diseases and 5% of all deaths from lung cancer are the result of the effects of $PM_{2.5}$ and PM_{10} globally [107]. In the two scenarios presented, this environmental issue must be addressed by decision-makers [108], [109], who can implement concrete measures and are responsible for them. Currently, air pollution is one of the most important and analyzed scientific issues.

2.4.1 Black Sea ports

There are a large number of ports on the Black Sea coast. At the same time, these ports belong to the different countries bordering the Black Sea. The neighboring countries of the Black Sea are six in number: Romania, Bulgaria, Turkey, Georgia, Russia and Ukraine. Table 2.8 shows the volume of port calls, for each port concerned, first

Table 2.8 *Port calls in Black Sea ports on 15 July 2020 [57]*

Port	***Constanța***	***Burgas***	***Varna***	***Samsun***	***Trabzon***	***Batumi***	***Poti***	***Novorossiyssk***	***Sevastopol***	***Odessa***
Ship calls	*162*	*33*	*67*	*38*	*8*	*2*	*18*	*134*	*69*	*51*
Expected arrival	*58*	*11*	*15*	*18*	*3*	*7*	*9*	*36*	*2*	*15*
Total	*299*	*69*	*184*	*73*	*17*	*35*	*53*	*259*	*413*	*109*

2.4.2 Description of the method used to determine the volume of atmospheric emissions

In order to determine the volume of pollutants resulting from port activities, characteristics related to port activities were taken into account, as shown in Figure 2.13. After an estimation was made, taking into account the literature, some adjustments were made. In the case of maximum power, it has been adjusted by 25%.

Table 2.9 *Estimation of installed power on board ships in Black Sea ports*

Port	***Constanța***	***Burgas***	***Varna***	***Samsun***	***Trabzon***	***Batumi***	***Poti***	***Novorossiyssk***	***Sevastopol***	***Odessa***
ME power [Mw/h]	*1000,4*	*203,8*	*413,7*	*234,7*	*49,4*	*12,4*	*111,2*	*827,5*	*426,1*	*314,9*
Gen. power [Mw/h]	*119,1*	*24,3*	*49,2*	*27,9*	*5,9*	*1,5*	*13,2*	*98,5*	*50,7*	*37,5*

At the same time, using the information from the diagram presented in Figure 2.13, a hypothesis was assumed by which the periods related to port activities were clearly delimited, between the berthing time and the rest of the port activities. These values were adjusted as follows: the power used was reduced by 25%, representing a percentage of the maximum power installed on board the ships. As time periods, 75% of the total time spent by the ship in the port area and for berthing time was allocated. Based on the hypotheses presented, an "Average Power of Port Operations" was developed.

The percentages of scenarios that are included in the current average value are as follows: 20% for ships complying with TIER2 regulations, 40% for ships complying with TIER1 regulations, the remaining 40% ships that do not meet the requirements for TIER regulations and are related to ships built before 2000.

Table 2.10 *One hour of port operations volume of emissions resulted, Black Sea ports*

Port	***Constanța***	***Burgas***	***Varna***	***Samsun***	***Trabzon***	***Batumi***	***Poti***	***Novorossiysk***	***Sevastopol***	***Odessa***
PM_x (kg)	*24,9*	*5,1*	*10,3*	*5,8*	*1,2*	*0,3*	*2,8*	*20,6*	*10,6*	*7,8*
CO_2 (t)	*247,5*	*50,4*	*102,4*	*58,1*	*12,2*	*3,1*	*27,5*	*204,7*	*105,4*	*77,9*
NO_x (t)	*3,4*	*0,7*	*1,4*	*0,8*	*0,2*	*0,04*	*0,4*	*2,8*	*1,4*	*1,1*
SO_x (t)	*4,8*	*1,0*	*2,0*	*1,1*	*0,2*	*0,1*	*0,5*	*3,9*	*2,0*	*1,5*

2.5 The influence of gaseous emissions from port activities and air quality in coastal areas

This chapter aims to determine the impact of maritime transport on air quality in the area adjacent to the port of Constanța, regarding the measures imposed by the Romanian government to reduce the spread of the SARS-CoV-2 virus in Romania. In Romania, the state of emergency was officially declared by the Military Ordinance issued by the Ministry of Internal Affairs, which was implemented starting March 18, 2020. In the period between the beginning and the end of the state of emergency, several military ordinances issued by the Ministry were applied. Home Affairs, which described a series of restrictions and procedures that had to be followed by all those within the air and sea borders to prevent the spread of SARS-CoV-2. These measures have been applied even to the shipping industry. The state emergency was concluded by a similar military ordinance, which announced the state of alert in Romania starting with May 14, 2020 [117].

2.5.1 The Northwest coast of the Black Sea

Every day, the region is transited by over 300 ships, due to a considerable number of ports on the Romanian coast, of which we can mention: the port of Constanța - (Agigea), Mangalia, Midia-Năvodari, Sulina. Ships traveling to the Ukrainian region of Odessa and originating from Bulgaria or transiting the Bosphorus Strait also travel through the round perimeter shown in Figure 2.21. This number represents about 40% of the total volume of daily maritime traffic in the entire Black Sea area.

2.5.2 Atmospheric pollutants

On the territory of Constanța county, there are seven locations where the air quality is evaluated from the perspective of different parameters. All seven locations are located within the grid bounded in Figure 2.22 a). Only six locations are close to the sea coast and also close to Romanian ports. These six locations are shown in Table 2.12. In Tulcea County, there are no fixed stations located close to the coast.

***Table 2.12** Fixed air quality monitoring stations located on the Romanian coast - Figure 2.22 b)*

ID	Name of the fixed air quality control station	Location
1	CT1	Constanța
2	CT2	Constanța
3	CT3	Năvodari
4	CT4	Mangalia
5	CT5	Constanța
6	CT6	Năvodari

CO_x emissions

Carbon oxides result from the burning of fossil fuels such as petroleum products and LNG. CO emissions are directly proportional to fuel consumption.

NO_x emissions

Nitrogen oxides are the result of the reaction between two common chemical compounds, oxygen and nitrogen, in a high temperature environment. The most common mode of production is by burning fuels, such as burning fuel inside combustion engines. Massive naval engines are a significant source of emissions.

SO_x emissions

Sulfur oxides are formed during the combustion process in naval engines, and occur due to the presence of sulfur in the fuel. It is recognized as an emission that contributes to pollution and harms all living things.

Particle matter

PMs are associated with gas emission processes due to the burning of fossil fuels and lubricating oils. These residual combustion products are an international problem that threatens human health [122].

After analyzing the data available in each location, presented in Table 2.12, in the last six years (from October 2014 to October 2019), only two locations (CT4 and CT5) were chosen.

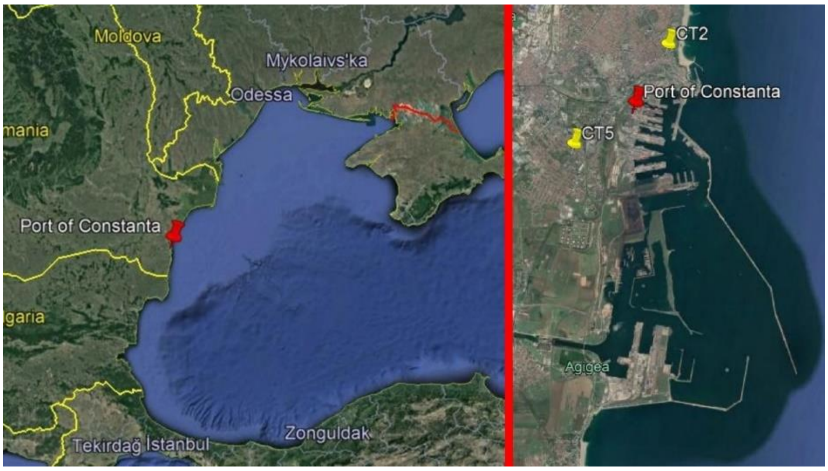

Figure 2.23 Location of fixed air monitoring stations, Constanța port (CT2, CT5) [70]

From Figure 2.24 it can be seen that only PM_{10} emissions values often reached critical values in 2017 and in the first two quarters of 2019.

Figure 2.24 Daily variation of PM_{10} in fixed air quality measuring stations 2017/2019

Referring to Table 2.13 and taking into account the trend of expanding the global fleet, which leads to higher fuel consumption, the reduction of emissions is supported only by the global approach to strict regulations and their imposition to regulate shipping activity.

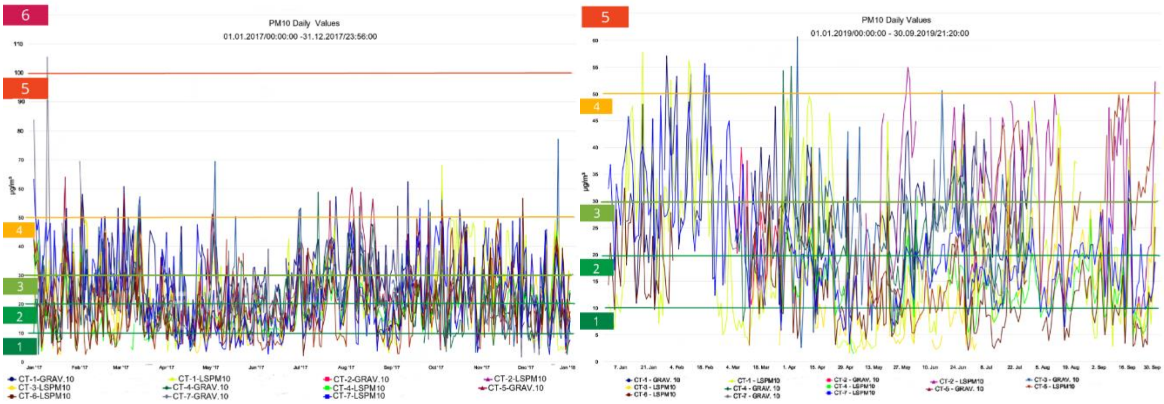

Table 2.13 *Mediterranean and the Black Sea emissions 2009 and 2030*

Mediteraneean Sea and Black Sea					
Annualy\Emissions (kilotonnes)	*NO_x*	*SO_2*	*CO*	*$PM_{2.5}$*	*PM_{10}*
2009	*1701*	*1194*	*188*	*137*	*144*
2030	*1735*	*264*	*188*	*31*	*33*

2.5.3 The impact generated by the SARS-COV-2 virus on the air quality in the Constanța port area

In the new global context generated by the spread of the SARS-CoV-2 virus, the economy has been affected. Due to the measures taken by most states to limit the spread of this virus among humans, production activity has been stopped in many economic sectors and, consequently, the shipping industry has also been affected. The measures that were taken in the shipping sector in Romania are known, similarly it happened worldwide. In the perspective of reducing the number of ships in ports, the evolution of some parameters of air quality in the area of Constanța County will be followed. This evolution will be correlated with the evolution of the volume of port calls, of international ships, to the port services from Constanța and presented in this chapter.

2.5.4 Parameters considered in the assessment of air quality

The parameters of the air quality data were provided by the public platform provided by the National Air Quality Monitoring Network, subordinated to the Romanian Ministry of Environment [116].

The state of emergency in Romania was officially declared by the Romanian government between March 18 and May 14. These two data are shown in Figure 2.27, with a vertical black line for each of the two. Thus, it was chosen as the investigation period March 1 - May 31, 2020 [117]. In order to be able to detect more easily if something completely different happened during the state of emergency.

The red dotted line represents the daily values of SO_2 for the period 2020. At the same time, the blue line represents the daily values of SO_2 for a similar period in 2019. For a better understanding, a polynomial curve has been created, which has as a role to show the trend for each period. It can be observed that in Figure 2.27 the light green curve, having a decreasing tendency, is dedicated to the values from 2020 of the selected period. The curve dedicated to

2020 shows for May 31, compared to March 1, of the same year, a 30% decrease in sulfur dioxide emissions.

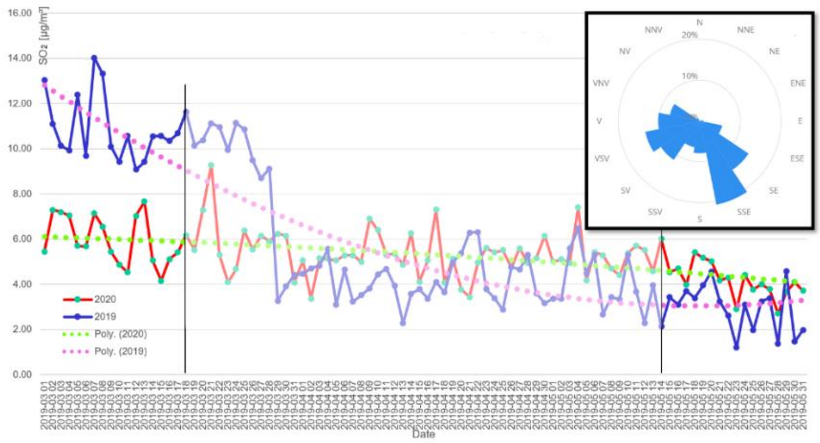

Figure 2.27 SO_2 in CT2 in period 1 March – 31 May (2020 și 2019)

In the first phase, we could have attributed this favorable difference to the information that the Chinese factories had ceased operations. This would have led to a major transposition effect in the delivery of goods to Europe with long delays. Hence this presumption by which we could have believed that the traffic decreased in volume in the Port of Constanța. It would have been a wrong hypothesis, the statistics closest to the period studied showed an increase of 3.31% in the first four months of 2020, for the port of Constanța. These differences arose by comparison with the previous year, the tonnage of goods operated. On the other hand, the number of ships that resorted to port services was 4450 in the first four months of 2020 (+ 6.7%), compared to 4152 in 2019 [129].

2.6 Conclusions

There are several measures to combat these effects which can be taken into account:

- Use in ports of solutions such as electrical connection to port facilities. These facilities could be complemented by power stations using LNG.
- „SLOW STREAMING”.
- Use of quality fuels (with a low percentage of sulfur) / change of fuel type.
- Technical solutions for reducing emissions by filtration (Scrubber).

Capitolul 3: ASSESSMENT OF THE CAUSATION OF THE ACCIDENT IN THE BLACK SEA ACCIDENTS IN THE LAST THREE DECADES

3.1 Identification, evaluation, and analysis of sea state parameters at the time of the accident

The Black Sea is known by the shipping industry, even in history, to be an area with many problems for navigation. Thus, serious naval accidents occur periodically in the Black Sea basin.

Given that from 2001 to the present, no less than twenty ships have sunk in the Black Sea and five of them in 2017, a general analysis of the causes that led to these unwanted events is needed. Thus, for a series of accidents identified in time and space, the wave and wind characteristics were analyzed based on the results obtained from simulations with numerical models. In order to identify as accurately as possible the external factors that affected the ships involved in these accidents, the main parameters of the waves are evaluated. Thus the waves were simulated using a numerical wave modeling system implemented in the Black Sea. In this way, in the entire Black Sea basin, but also for the known location of the ship involved in a major incident, several sets of information on the state of the sea are identified a few days/hours before the event, during the event, as well as after the catastrophe.

3.1.1 Black Sea naval incidents

To carry out this study, all serious naval incidents in the geographical area of the Black Sea were identified, which ended in shipwrecks. Table 3.1 identified 21 records [56], [136], [137], [138], [139]. All these incidents were verified from different sources, to confirm the facts for each ship and incident separately, Annex 2.

3.1.2 Geographic positioning of events

Geographical locations were identified according to the reports of each event. Thus, the approximate locations where the events took place are graphically represented on the Black Sea map, Figure 3.1. The numbering in the first column of Table 3.1 was used to identify each event.

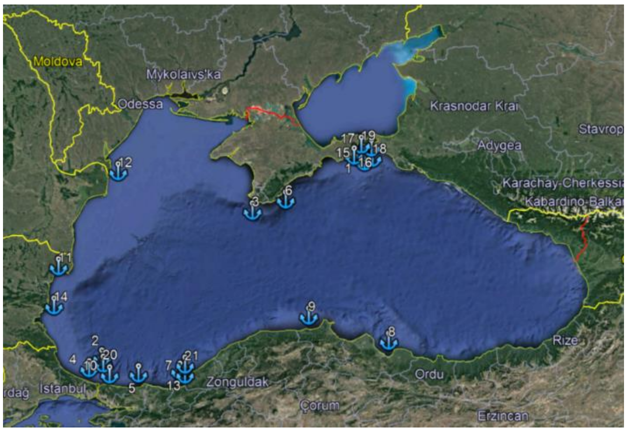

Figure 3.1 Representation on the map of naval incidents in the Black Sea from 2001-2017

3.1.3 Characteristics of the active Black Sea fleet

The results show that this causality is closely related to the time of shipbuilding. Even the percentages, by the size of their values, clearly show the influence of the age of the ship on the possibility or high risk of involving certain ships, from clear intervals, in a severe naval event.

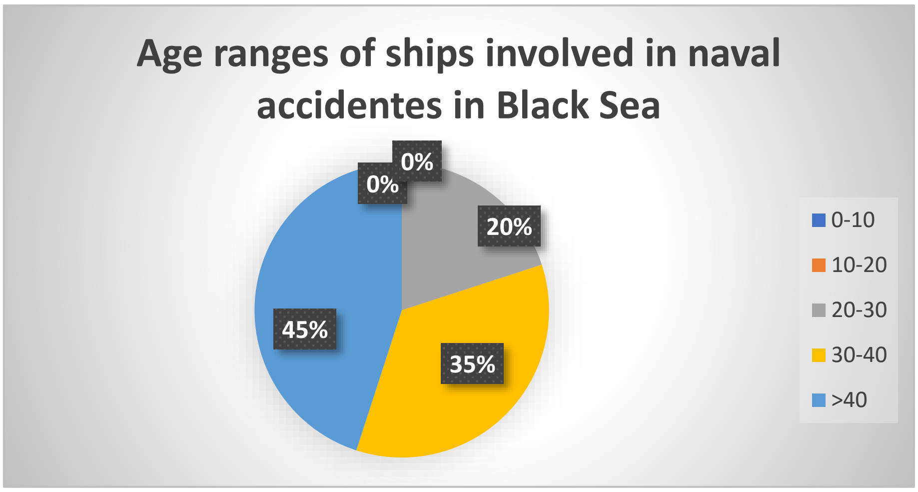

Figure 3.2 Age ranges of ships involved in naval accidents 2001-2017, Black Sea

Figure 3.4 shows the evolution of the age of ships involved in serious naval events over time and the incidence of these unwanted events, it can be seen that an increasing number of ships are starting to go out of use.

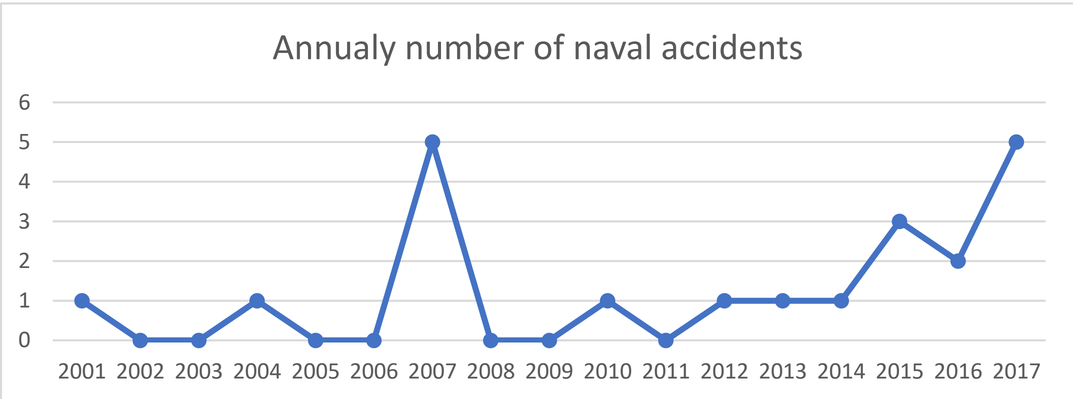

Figure 3.4 Evolution of the annual volume of naval accidents 2001-2017, Black Sea

General cargo ships take first place. More than 80% of accidents in 2001-2017 involved a general cargo ship. Bulk carriers are in second place in terms of incidence, with a percentage of less than 9%.

3.1.4 Natural factors leading to naval accidents in the Black Sea

For each incident, wind and wave conditions were simulated for 48 hours with a time resolution of 3 hours. The wind speed is at an altitude of ten meters above sea level and is denoted by U_{10} (m / s). The other parameter of interest for this study is the significant wave height, being denoted by H_s (m). Due to the historical database, the simulations could only be performed in the period 2001-2016, so that of the twenty-one incidents mentioned in Table 3.1, only sixteen events were checked for sea state, those that can be identified both in Table 3.1 and in Table 3.2 with numerical values between 6 and 21. The results of the numerical simulation system were analyzed for each case, resulting in a series of graphical representations depending on the parameter chosen for the indicated time coordinate, as in Figures 3.7 and 3.8.

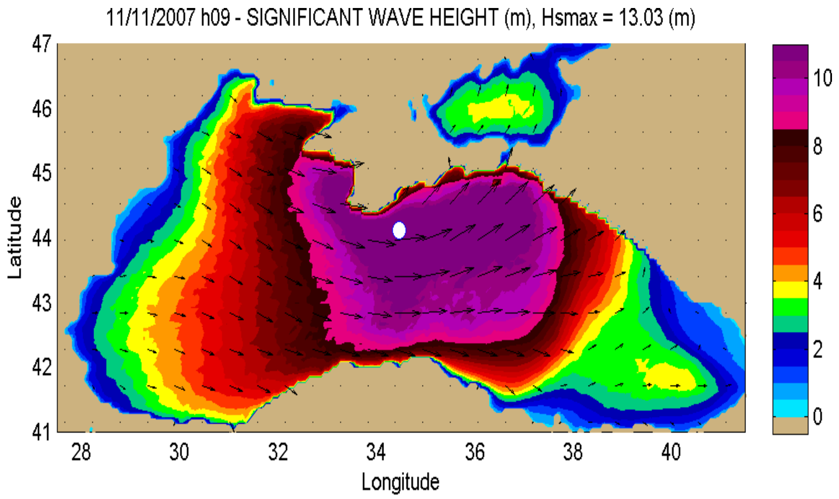

Figure 3.7 Spatial distribution of significant mean fields of significant wave height and mean wave direction in the Black Sea basin (11.11.2017)

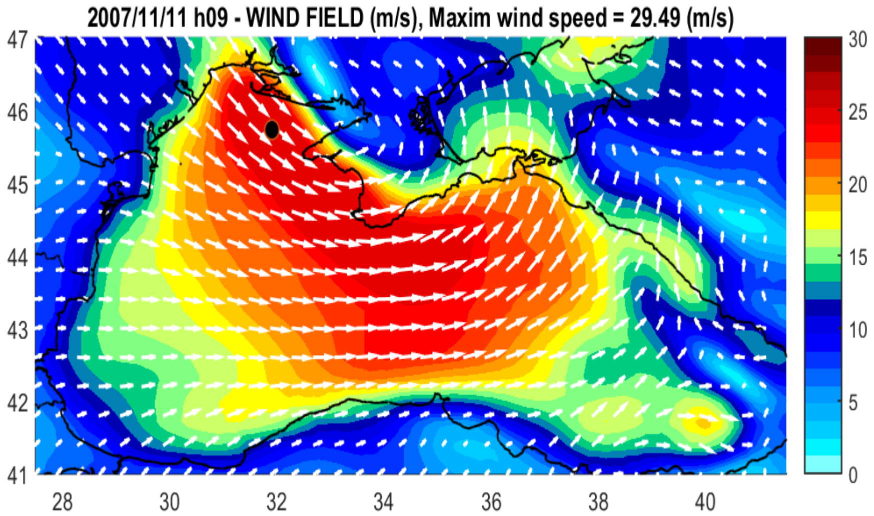

Figure 3.8 Spatial distribution of winds and the direction of their action in the Black Sea (11.11.2017)

The maximum value of the significant wave height was identified and noted on the first row of the table, and the second row is intended for the maximum value of wind speed. The maximum values of these parameters were identified because the most unfavorable scenario was taken into account. The corresponding accidents being identified in Table 3.2 with values between 15 and 19.

Table 3.2 *Wave and wind parameters in the Black Sea at the time of naval accidents, 2001-2016*

ID	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*
H_s *[m]*	*1,5*	*1,5*	*1,5*	*3,5*	*5,5*	*5*	*2,5*	*5*	*3*	*13*	*13*	*13*	*13*	*13*	*8,5*	*6*
U_{10} *[m/s]*	*10*	*9*	*7,5*	*15*	*18*	*15*	*12*	*17*	*15*	*29*	*29*	*29*	*29*	*29*	*22*	*20*

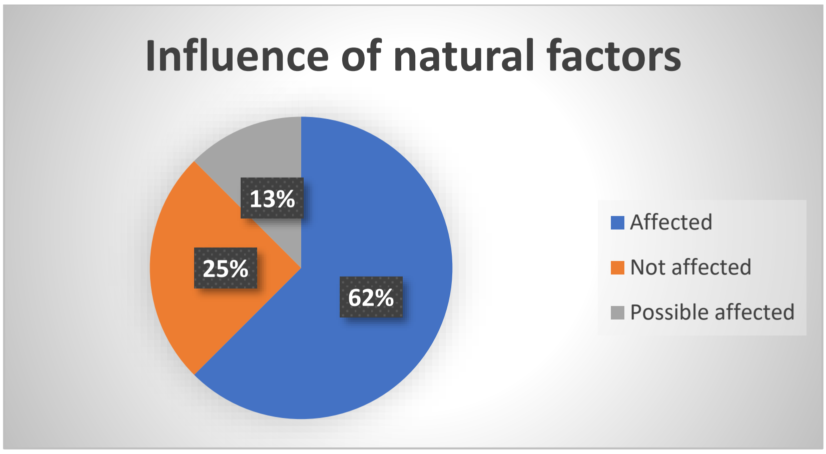

Figure 3.9 The influence of natural factors on maritime accidents 2001-2017, Black Sea

The main objective of the international maritime field, composed of the three complementary industries: ship design, shipbuilding and ship operation (maritime transport), is safety at sea [23]. In this direction, the factors that lead to the development of events that can endanger human lives, the transported goods, but also the integrity of the ship itself are evaluated [28]. The three main factors that can lead to a naval accident are: the state of the sea, the technical condition of the ship, and the actions of the crew. Continuing in-depth the study in this chapter [9] shows that for a number of naval events, the sea state and atmospheric conditions played a significant role in the unfolding in a negative direction of the events presented.

3.1.5 Methods and results

The fields of significant wave height (H_s) and wind speed (U_{10}) were identified for each event. In the case of the first event indicated in Table 3.3 (which took place in December 2014), they are illustrated in Figure 3.11, every three hours. Significant wave heights and wind speeds can be found in Table 3.4

It is obvious that violent storms can occur in the Black Sea area from time to time, which can reach a local intensity comparable to that of a hurricane. This statement emerges from the results of wind speeds greater than 20 m/s. At the same time, in the cases studied in the Black Sea basin, significant wave heights of over 11 m have been identified.

3.2 Structural assessment of General Cargo ships involved in pollution risk accidents

This chapter aims to conduct a study to help create a safer environment for the marine ecosystem and for the safety and security of crew members operating on Black Sea vessels. The need to assess the risks of structural fatigue stems from the fact that various ships that have been involved in serious maritime accidents have not withstood from a structural point of view, with ships even breaking into two pieces. Twenty-one major shipwrecks occurred between 2001 and 2017, of which five occurred in 2017. Some of the ships were wrecked or sunk due to structural damage caused by extreme storms. It can also be mentioned here that the average age of the ships involved was over thirty-seven years.

***Table 3.4** Results of H_s and U_{10} of each event took place in the Black Sea*

Period of time/ID		I		II		III		IV		V	
		H_s	U_{10}	H_s	U_{10}	H_s	U_{10}	H_s	U_{10}	H_s	U_{10}
DB	00:00:00	2	10.5	1	8	7	16	1	11	4	17
	03:00:00	2	10.5	1	8	6.5	21	1	12	4	19.5
	06:00:00	2	10.5	1	8	8	19	1	12	3	15
	09:00:00	2	10.5	1.5	8	11	22	2	8	2.5	12
	12:00:00	2.5	11	1.5	9.5	10.5	23	3.5	6	2	12
	15:00:00	2.5	11	1.5	9.5	8	20	4.5	15	2	8
	18:00:00	3	14	1.5	8	4.5	14	5	17	2.5	6
	21:00:00	3.5	14.5	1.5	7	3	9	7	18	2	14
D	00:00:00	4	14.5	1.5	6	2.5	5	7.5	19.5	1.5	14
	03:00:00	4.5	15	2	13	2	7	8	20	1.5	14
	06:00:00	4.5	14.5	2.5	12	2	7	8.5	22	1.5	10
	09:00:00	4	13	2.5	11.5	2	9	7.5	21	1.5	9
	12:00:00	3.5	14	2.5	9	3	9	6	19	1.5	14
	15:00:00	4	14.5	2.5	8	3	16	5.5	18	1.5	11
	18:00:00	4	10	2.5	7	2.5	12	4.5	15	1.5	8
	21:00:00	3	10	2.5	11.5	2.5	13	4	14	1.5	10
	00:00:00	2.5	9	2.5	11.5	3.5	10	3.5	13	1.5	12

3.2.1 Working hypotheses

Of the 21 ships identified in Figure 3.1, a total of 17 general cargo ships suffered one of the following three incidents: shipwreck, sinking or propulsion loss because of engine problems. As a result of this operation, in Table 3.1 we can identify: ship identification number, ship name, incident type, accident year, ship construction year, ship flag, length (L), and ship type. In this study, the ship type is represented exclusively by general cargo ships. The exact date (day.month.year) of the event exists as the date of entry, but could not be presented due to lack of space in Table 3.1. However, this information can be found in ANNEX 2. After arithmetic mediation of the general construction dimensions (length and width) of the 16 vessels, for which these data are known, the following characteristics resulted: Length = 103.43 m, beam = 13 m.

3.2.2 Methods

In the initial phase, the general characteristics of the vessels were identified. Then, they consulted existing databases/archives of naval design companies to find a ship with similar characteristics. The identified vessel has the following characteristics, General Cargo 5000 Tdw, maximum length 101.5m, beam 16.4m, draft 7m, speed 14knots. Significantly similar characteristics can be observed, which confirmed the possibility of validating the working hypothesis involving a series of operations that will be presented in the following paragraphs. After identifying the working hypotheses and validating the model of the ship identified for the analysis of the resistance of the beam-ship, the modeling of the cross section of the ship to the “Midship section” was performed. This was done in the MARS 2000 software [155].

The second step is to use the "scantling" module, or the ship's own stiffening system, faithfully reproducing the section from the midship section. In the first phase, the nodes for the sheet metal sheets were determined, they are presented in Figure 3.16. Then, their thicknesses were added. In the second phase, the longitudinal and transverse stiffening elements were introduced, part of the structure of the ship's beam [159].

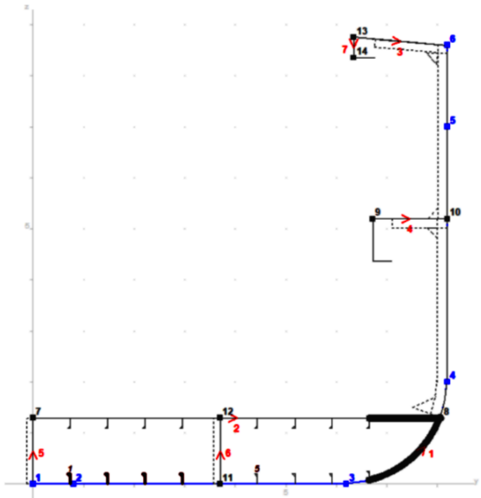

Figure 3.16 Midship section of a cargo ship designed in the 70s and 80s

The values in Table 3.6 are theoretical and represent the most unfavorable value in the calculation, given the corrosion models adopted by naval classification societies, based on empirical methods, but practically validated. These assumptions only complement the impact of uniform corrosion applied globally on this ship, but in real cases, corrosion may have a different development in time and space, as in the examples shown in Figure 3.18. This depends on how the ship is used, if and how the maintenance and repair processes are performed.

Table 3.6 *Corrosion action on the structural elements of the general cargo ship (25 years, 50 years)*

Area	*Decks*	*Keel*	*Bottom*	*Bilge*	*Sidej*	*Sheer str.*	*C. girder*	*L. girder*
Initial design (mm)	*20*	*15*	*12*	*13*	*12*	*17*	*13*	*11*
25 y (mm)	*19*	*13.5*	*10.5*	*11.5*	*11*	*16*	*11*	*9*
50 y (mm)	*18*	*12*	*9*	*10*	*10*	*15*	*9*	*7.2*
% (I design – 50 y)	*10%*	*20%*	*25%*	*23.08%*	*16.67%*	*11.76%*	*30.77%*	*34.55%*

Figure 3.18 Ship in advance stage of corrosion, the resistance structure being severely affected

3.2.3 Results and discussions

From the results, following the algorithm for calculating the structural collapse in the application developed by Bureau Veritas, we can identify acceptable values for the Hogging effect for the ship designed to be used for 25 years (N25, H25). The note "N" is used to represent the situation of the ship in the case of navigation and 25 means the period of 25 years of operation. The notation "H" is used if the calculation is made for the ship in calm water, in port. For the favorable case, in which the state of the sea is similar to that in the port harbor, the Hogging value does not exceed 50% of the maximum allowable limit. The result is valid both for the hypothesis of 25 years of operation and for the second hypothesis used in the study.

Table 3.7 *Ultimate strength check for 25- and 50-year Cargo vessel in operation*

Conditions	*Bending momentum (kN·m)*	*Mu*	*Maxim*	*Applied*	*%*
N25	*Hogging*	*472 328*	*449 579*	*318 152*	*70,77*
	Sagging	*-319 381*	*-303 999*	*-323 466*	*106,4*
H25	*Hogging*	*472 328*	*449 579*	*217 211*	*48,31*
	Sagging	*-319 381*	*-303 999*	*-219 743*	*72,28*
N50	*Hogging*	*435 413*	*414 442*	*318 152*	*76,77*
	Sagging	*-296 841*	*-282 544*	*-323 466*	*114,48*
H50	*Hogging*	*435 413*	*414 442*	*205 221*	*49,52*
	Sagging	*-296 841*	*-282 544*	*-207 752*	*73,53*

For the less favorable case, when the ship is in real sea conditions, under the action of waves, the hogging effect shall not exceed 77% of the maximum accepted value for such cases. The curve in Figure 3.19, top right, represents the influence of the hogging effect on the ship's beam, when calculated for the second hypothesis, for 50 years.

The appearance of the moment shown in Figure 3.21 results largely from the use of a simple framing system in the curb area. The transverse framing system used for these ships designed and built in the 1970s and 1980s was an easy-to-use technical solution. This problem has been solved over time by applying the IACS CSR rules (common structural rules) [162], [163], using a double edging system and a mixed framing system.

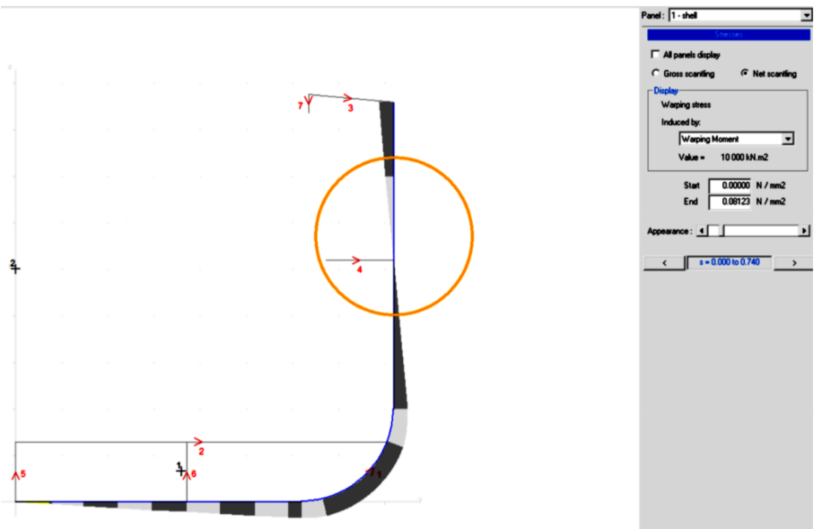

Figure 3.21 Warping Moment of a 50 years Cargo Vessel old

3.3 Evaluation of the volume of hydrocarbons spilled following the studied naval accidents

The biggest impact and probably the fastest, in terms of media impact but also real that considers the immediate effects on the marine environment, is attributed to hydrocarbon pollution. Taking into account, in the same measure, the fact that one liter of vegetable oil (3.1) used can contaminate one million liters of water [164], we can deduce that hydrocarbons have a very high dispersion potential.

$$CH_3(CH_2)_{16}COOH \tag{3.1}$$

Various studies show that over 100,000 tons of hydrocarbons reach the Black Sea [23]. There are estimates that the volume in the mainland is considerably larger than in the area of maritime exploitation. However, there is a percentage in the volume of hydrocarbons mentioned, also dedicated to the exploitation area of floating structures. Around 12,000 tons of hydrocarbons are discharged annually into the Black Sea as a result of ship operations [40].

3.4 The volume of hydrocarbons on board a general cargo ship

Taking into account the significant percentage of cargo ships involved in naval accidents [166], the same example in subchapter 3.2.2 was considered as a reference ship in the Black Sea.

Thus, in the presented context, the volume of hydrocarbons on board the ship can vary from a possible maximum of 595.3 m3. The way in which the volume of hydrocarbons, dedicated to the operability area varies, clearly depends on the moment when the event takes place during the trip. In the calculations we can consider 85% of the maximum possible volume of hydrocarbons that can be accommodated on board the ship. Taking into account the ships in Table 3.1, we find that in the period of time studied a volume of 11000 m3 of hydrocarbons most likely arrived in the aquatic environment of the Black Sea

Table 3.8 *Volume of hydrocarbons in the "Tank List" of an existing General Cargo ship*

Lub oil tanks		***HFO***		***MDO***	
Tank name.	*cm*	*Tank name.*	*cm*	*Tank name.*	*cm*
ME store tank Ps	*6,5*	*Store tank central*	*198,5*	*Deep tank Ps*	*54*
ME store tank Ps	*6,5*	*Deep tank Bb*	*59,5*	*Deep tank Sb*	*54*
DG store tank Sb	*8*	*Deep tank Tb*	*59,5*	*Store tank Ps*	*36,7*
Reductor store tk Ps	*3,1*	*Slop tank*	*8,4*	*Store tank Sb*	*48,8*
DG waste oil tank Ps	*4,9*	*Service tank MP*	*8,4*	*Slop tank*	*6,5*
Af. Lubrication tank	*2,6*	*Overflowing tank central*	*3,8*	*Service tank*	*6,5*
ME circulation tank	*7,8*			*Overflow tank Ps*	*2,6*
ME waste oil tank	*8,7*				
Total lub oil	*48,1*	*Total HFO*	*338,1*	*Total MDO*	*209,1*

3.5 Conclusions

There has been a growing trend in the number of maritime accidents in recent years. The new navigation conditions are an important factor in the context in which they are constantly changing, in terms of climate change. Ships interact on classic sea routes with the new navigation conditions, an effect of climate change. In the last 30-40 years, in the studied geographical area, storms occur more often and are more pronounced, both in duration and intensity, developing both locally and on significant areas in the Black Sea [18], [167].

It is true that extreme storms, comparable to a hurricane, can occur in the Black Sea, taking into account the wind speed and the significant height of the waves, data obtained for the studied cases. In this context, there may be a risk that certain vessels will be prone to involvement in incidents of the nature of those studied in this chapter, for example, those with a coastal navigation destination, those with very poor maintenance from a structural point of view, those with a non-professional crew who failed to comply with the cargo loading plan on board the ship.

It is also clear that the structural strength is affected over time, and the case presented for the calculation of the sagging effect values only takes into account a different factor for the case where the ship has been operating for 50 years, compared to the 25 years for which the ship was originally designed.

Accidental oil spills have historically occurred in the Black Sea, however, commercial vessels not intended for the transport of petroleum or chemical products do not have significant volumes of pollutants on board. An incident involving a small ship like a general cargo can largely be handled by the authorities in terms of accidental oil spills into the marine environment.

Capitolul 4: ASSESSMENT OF THE IMPACT OF UNTREATED BALLAST WATERS IN THE BLACK SEA

4.1 The effects of untreated ballast water discharges into the Black Sea

According to studies conducted so far [33], [34], [35], [36], [37], [38] it turned out that over 29 species accidentally arrived in the Black Sea, from different other geographical areas. Two of these had a considerable impact in the 1980s and 1990s on the Black Sea marine ecosystem. In the 1980s, the Black Sea was confronted with an invasive species, the jellyfish "Mnemiopsis leidyi". Originally from the west coast of the Atlantic, this jellyfish found a suitable environment in the Black Sea and, not having a natural predator, it experienced an explosive development of the number of flocks. It managed to multiply and spread in a relatively short time throughout the studied area, affecting the entire food chain in this marine ecosystem. The implications of this episode had consequences on the number of plankton-feeding fish species, with the disappearance of plankton leading to a chain reaction [37]. First, the number of fish feeding on those plankton-feeding fish species, which disappeared due to lack of food, was affected. The effect has been perpetuated in the Black Sea food chain, eventually leading to an increase in the number of marine mammals [168], with the number of dolphins in the Black Sea being significantly affected over the past 40 years.

4.2 Case study - volume sizing of potentially discharged ballast water in Port of Constanța

Shipping in the Black Sea has increased in volume in recent years. For this reason, appropriate measures are needed for the safety of navigation and the protection of the environment. Maritime operations are usually very dynamic in coastal areas. All ships must have adequate stability at sea. The ballast is used to control the stability of the ship and also to maintain a proper draft. Ballast is not a desired element, but for the efficiency of maritime transport and the need to operate the ship safely, its use is required.

The demand for shipping exists. This is presented in Table 4.3 (data processed from studies [182], [183], [184], [185], where we can see the need for maritime transport services according to the volume of exported goods, expressed in tons. important ports in the Black Sea, the export demand for 2016 was about 110 million tons of cargo.In general, the capacity of ballast water, as a preliminary design of the ship, follows the following calculation formulas [187], [188]:

$$BW = \frac{37.72}{100} D_W \ , \tag{4.1}$$

$$D_W CC = \frac{94}{100} D_W \ , \tag{4.2}$$

$$BW = \frac{37.72}{94} D_W CC \ . \tag{4.3}$$

Table 4.3 *Annual report of tonnage exports from Black Sea ports*

Port / Export*1000 tonnes	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***
Constanța	*16195*	*16260,8*	*21176,3*	*21782,4*	*19439,4*	*21631,8*
Odessa					*19020,88*	*18999,06*
Novorossiysk				*64137,6*	*66259,8*	*68460,6*
Samsun	*553,52*	*725,78*	*770*		*790*	*800*
				TOTAL	***105510,1***	***109891,5***

Thus, ballast water (BW) is water transported in ships' tanks to improve the stability of ships in real sea conditions, trim, or structural stresses. Deadweight (DW) indicates the ship's carrying capacity, which does not include the weight of the ship itself. The ship's cargo capacity (DWCC) indicates the amount of pure cargo that can be loaded without supplies, lubricants and fuels for the ship, etc.

Table 4.5 *The ballast water treatment capacity of the ships from the port of Constanța*

Port of Constanța	***Ballast water (*10^6 tonnes/annually)***	***Ballast water (*10^3 tonnes/daily)***
Ballast water	*7,60*	*20,82*
Ships with BWTS in 2017 (15%)	*1,14*	*3,12*
Ships with BWTS in 2020 (40%)	*3,04*	*8,33*
Ships with BWTS in 2022 (80%)	*6,08*	*16,66*

4.3 Sizing the volume of ballast water potentially discharged into the Black Sea

Geographically, the main route of entry for potentially endangered species into the Black Sea marine ecosystem is the Bosphorus Strait [191].

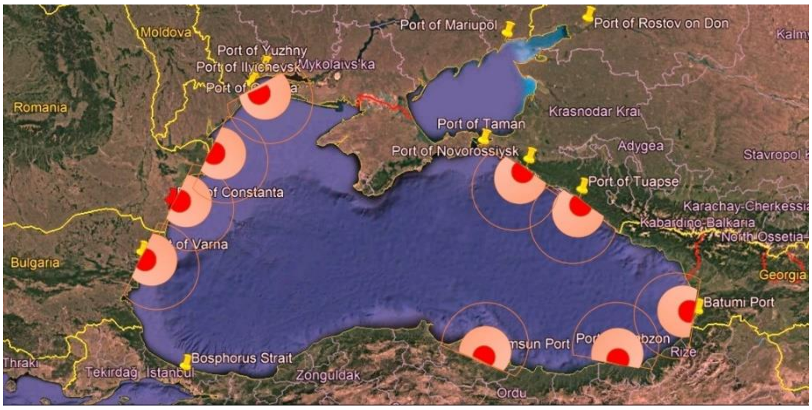

Figure 4.5 Potential impact of invasive species in Black Sea ports [70]

The Black Sea area mainly exports: hydrocarbons, cereals, chemicals (fertilizers), coal, scrap metal and others.

The value resulting, for the volume of ballast water passing through the Bosphorus Strait into and from the Black Sea, from the application of equation (3) is 262.5M m3. In order to calculate the volume of ballast water that presents a potential risk for the Black Sea, the hypothesis was adopted in which the percentage between imports and exports in 2019 is given at the regional level by the most important port in the studied area. In this sense, the public statistics of the port of Constanța for 2019 were taken into account [115]. The estimation of the potential risk of ballast water in the Black Sea in 2019, results from the reporting of the value of 262.5M m3 to the ratio between exported goods and imported goods 50.8%. The final value of the volume of ballast water with high-risk potential is 133.35M m3 (where M represents millions).

4.4 Conclusions

It is necessary to adopt unanimously, by all the states bordering the Black Sea, policies against uncontrolled discharges of ballast water into the Black Sea basin. The calculation model presented can be applied to all Black Sea ports as well as other ports in the world. There are historical incidents with huge impact related to invasive species in the Black Sea in the last 50 years, which have been documented and studied. The problem of ballast water is also known internationally and there are concrete measures that have been implemented.

Capitolul 5: SOLUTIONS FOR REDUCING THE IMPACT OF POLLUTION GENERATED BY THE MARITIME INDUSTRY IN THE BLACK SEA

The increase in the standard of living globally has produced changes in the lifestyle of each individual, and this can be directly observed by increasing the consumption of goods and services. This has directly affected maritime freight and cruise activities.

5.1 Directions for limiting atmospheric emissions from maritime activities

In order to make up for the additional power required for the consumption of berthed ships, a non-polluting or as low-polluting approach as possible is needed. Cruise ships and container vessels have been taken as examples because the specific electricity consumption of each of the two is sensitive, being higher than in the case of other types of merchant ships. The high electricity consumption in the case of cruise ships is given by the energy needs of the hotel area, intended for passengers, but also of the considerably larger number of crew members [201]. In the other case, the container vessels have a high energy requirement due to the service of the refrigerated containers. Thus, the context of a scenario for the dimensioning of a terrestrial or floating power plant that uses liquefied natural gas (LNG), within the port of Constanța, in Romania, can be described.

5.1.1 The scenario considered

Scenario A assumes that the new ships, found in the order book, are intended for navigation on established routes, most likely. The Black Sea is not part of the offer of any classic cruise operator as a tourist destination. However, due to the pandemic situation that started worldwide at the end of 2019, and which continues today in an easier form but which can induce the fear of traveling, cruise ship operators have sent many ships to Black Sea. However, these ships did not arrive in the Black Sea to operate economic activities, but to be "scrapped" in shipyards of this type on the northern coast of Turkey.

Scenario B considers that the new ships are being built to raise new standards in the field of cruise services. Thus, by increasing competition and offering much more attractive packages for the general public, ships of older generations will also remain active for highly sought-after and established destinations and routes. This can be supported by much more competitive / lower prices than at present.

The scenarios presented related to a forecast that did not take into account the geopolitical tensions and even the armed actions in the North Black Sea area, which began in February 2022, taking into account their maritime and/or terrestrial nature. To stop the military actions taking place, there is no reasonable timeframe forecast at this time, nor for the recovery of conditions to reach parameters similar to the period of time preceding these military events.

5.1.2 Results

Taking into account the possibility of building an LNG-type power plant for the port of Constanța, for its sizing to meet the requirements, it is necessary to estimate the energy requirements for port operations. For this purpose, data from the literature were analyzed to identify potential consumers.

A "dummy" ship was parameterized, using the main features of a number of six different cruise ships. All six ships were scheduled to dock during the time studied in the Port of Constanța. Through the mediation of the obtained values, it was identified that the type ship was 35 years old, an installed onboard power of 16 MW and an auxiliary power supply system of 13.5 MW. All these values resulted from the mediation of the values of the ships mentioned above and present in Table 5.2.

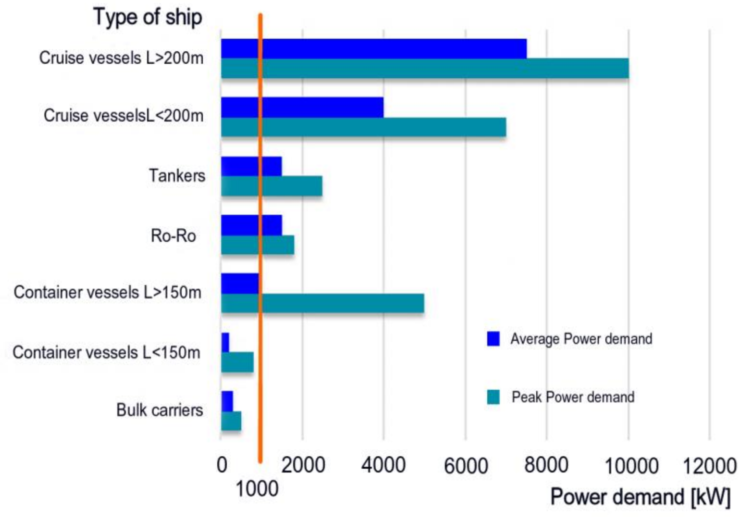

Figure 5.4 Required power [kW], depending on ship type [203]

According to the annual statistics from the Port of Constanța, daily we can identify two container vessels at the berths dedicated to the containerized freight transport area [82]. Given that one ship is stationed for container loading and unloading operations for an average of two days, it results those 4 ships are in port daily for container handling operations.

Therefore, the classic approach to port operations has the effect of producing and dispersing into the atmosphere a significant volume of greenhouse gas emissions. This is a direct consequence of the use of auxiliary generators on board the ship. An example is presented in Table 5.3 (data processed from [205]). These values represent a mediation for 6 empirical measurements performed on board ships in port operating conditions.

For the dimensioning of its own LNG power plant, in the port of Constanța, the scenario in which two cruise ships with a length of more than 150 meters, such as the ships in Table 5.2 whose average length tends to 200 m. Thus, the average power required to be supplied by the new plant is 20 MW. In order to be able to cope with the highest levels of demand, also taking into account the forecast for the growing volume of container vessels, a 30 MW power plant is recommended.

Table 5.3 *Volume of emissions from measurements*

Pel (kW)	***NO_x (kg/h)***	***SO_x (kg/h)***	***CO (kg/h)***	***CO_2 (kg/h)***
1000	*14,1*	*6,7*	*1,2*	*794,3*

5.2 Implementation of ballast water treatment systems in ports and onboard ships

Currently, on the market, dozens of technical solutions can be implemented to solve the problem of biological pollution, by preventing the migration of marine organisms from one geographical area to another. All these solutions are at an advanced stage of research and development. The technical solutions agreed by the authorities and institutions capable of taking such decisions or granting approvals can be found in Figure 5.5. Thus, there are multiple solutions that filter, treat and disinfect the water that arrives and is discharged into/from the ballast tanks. Ballast water treatment can be performed: mechanical, chemical or physical. Most of the times the technical solutions approach hybrid solutions such as: filtration + UV, filtration + electro chlorination, etc.

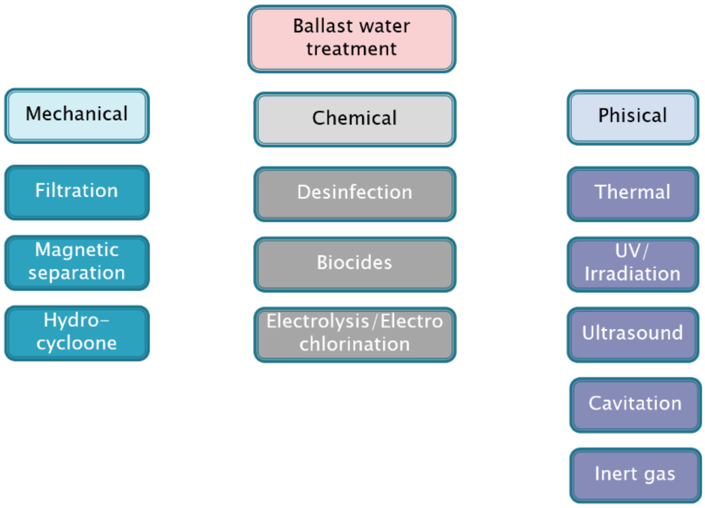

Figure 5.5 Technical solutions available on the market

On the other hand, the solution agreed by the shipowners would be to develop the port infrastructure as in the left column of Figure 5.6. This type of approach can be found in the North Sea and Baltic Sea area [176].

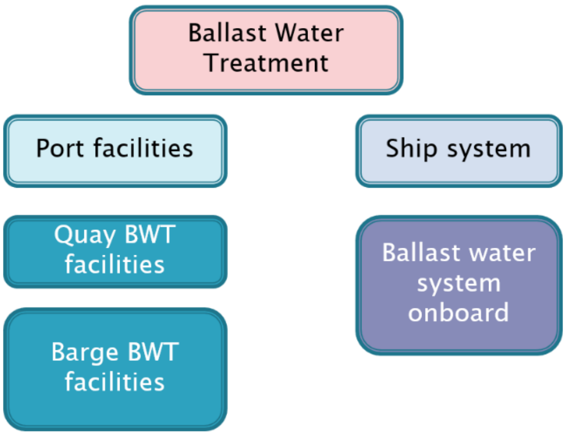

Figure 5.6 Facilities options for combating invasive species

This issue has been actively debated over the last ten years globally, within the IMO, within its departments of competence [179]. The International Convention on Ballast Water Management entered into force on 8 September 2017 [32]. As a conclusion to this requirement, all ships must implement a ballast water management plan in accordance with the D-2 discharge standard by 8 September 2024 [206].

According to Figure 5.7, it is easy to understand that, by creating port facilities, shipping will increase in these areas, or at least not decrease. Assuming that not all shipowners will succeed or be able to bring their entire fleet of ships up to IMO standards, ports in the Black Sea region should come to their aid. Achieving a modernization of the entire fleet, described in Figure 5.6, implies a fairly high financial availability. In view of the financial effort mentioned, it can be stated that most shipowners of such vessels will seek to avoid or delay such investment as much as possible.

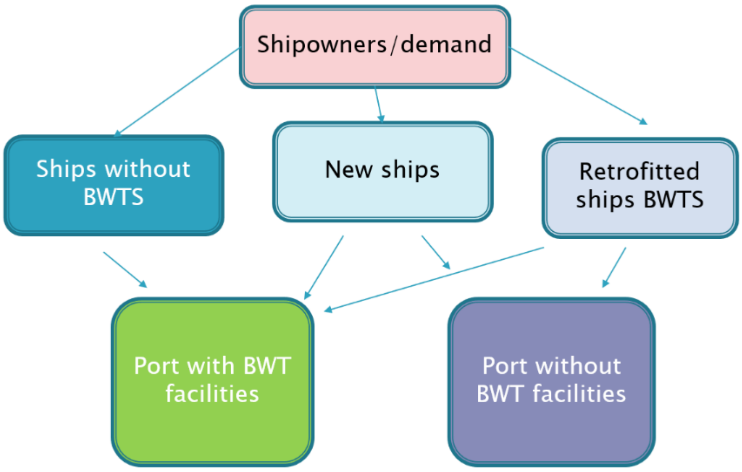

Figure 5.7 BWT port strategy

Ballast water treatment devices should be included in future investment plans, as there are solutions on the market. Only an assessment/forecast of the requirements for this type of service needs to be made, which the port can offer to arriving ships to be loaded with cargo. Once a possible scenario for the requirements of the installation has been established, the type of vessels that will have access to these ballast water treatment devices will be established.

It is possible to purchase modular ballast water treatment systems, container type, which can be transported on a quay trailer. This solution involves a flexible external connection to the ship, which can be connected to a set of dedicated flanges on the main deck of the ship, shown schematically in Figure 5.8. The advantage of this method is that it has a low take-off in terms of moving the device and even works without causing additional pollution, as it will be connected to the port's power resources. Of course, the initial purchase price is much lower than other solutions. The disadvantage would be the time - the possibility to condition the cargo operations in a timely manner. This disadvantage arises in the context in which the number of modular devices would not be one that would serve all applicants at a given time.

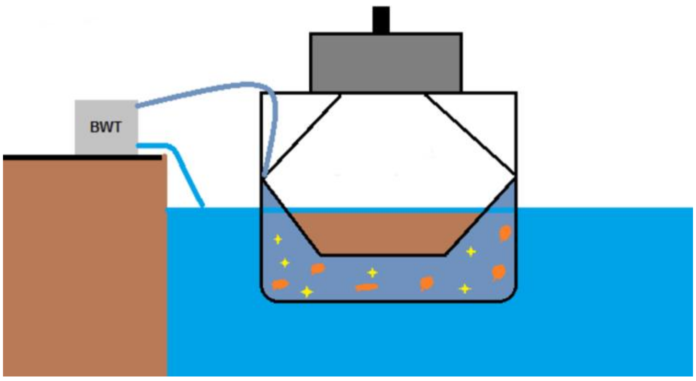

Figure 5.8 Port Facility - Ballast Water Treatment Equipment (BWT) [32]

The second solution presents a barge dedicated to the treatment of ballast water, as shown in Figure 5.9. The main advantage of this choice is the ability to save time. This is done within the timeframe for port maneuvers, until the beginning of the actual handling of the cargo in the port, because the barge can accompany the ship outside the port. The barge can operate outside the port only in favorable weather conditions for this operation. It is known that the Black Sea is a rough sea, at least in the winter season, recent studies have shown that this feature will be even more pronounced in the near future [207].

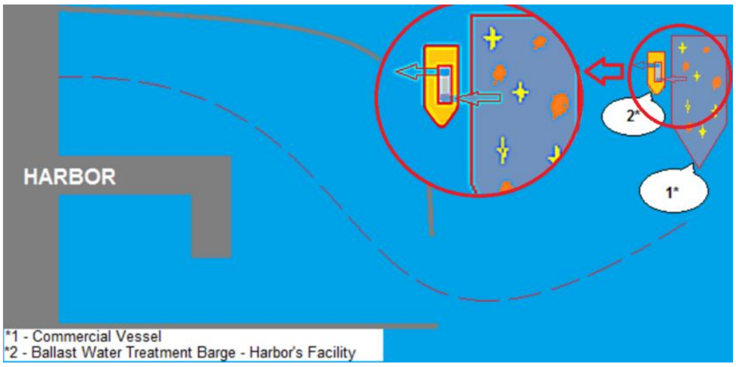

Figure 5.9 Port facility - ballast water treatment barge [32]

One of the disadvantages is the relatively long time until port services can take possession of such a barge. This is because it involves the construction stages of a ship: concept design, supply, design, and construction. There are also higher costs of maintaining, operating and purchasing the solution.

5.3 Digitization of the field of ship repairs and modernizations - impact in reducing the polluting footprint

This chapter describes the 3D laser scanning technology and compares the budget expressed in hours with the time allocated to the classical practice of collecting input data in order to design new systems, designed to reduce the impact of ships on the environment. Thus, the input information is obtained by inspections on board ships in a classic way or by the activity of 3D laser scanning. The comparison is made based on the evaluation of the records from several classic and scanned projects and the subsequent stages of design and execution.

Complex teams of inspectors were mobilized to identify this information in the past. Currently, the technology allows a process of digitization of the existing environment and its faithful reproduction in the form of "point clouds", Figure 5.10.

Figure 5.10 Digitally reproduced commercial vessel based on "point clouds"

The process of making "point clouds" involves, first of all, the 3D laser scanning technique. After identifying the primary data, they are processed in software applications dedicated to pointing cloud processing. This technology benefits from the total time spent on board the ship for inspection and by increasing the accuracy of the design process. The design process is substantially improved by adapting the new information to the existing information on the ship "as it is built". Nowadays, the classic process of data acquisition is increasingly being replaced by the use of 3D laser scanning technology in areas of interest, generating input data called "point clouds".

5.3.1 3D laser scanning technology

This technology is oriented towards physical objects, as can be seen in the approach in Figure 5.11, which is in the field of view of the scanner. To scan the object, a field of dots is created, very close to each other, produced by the laser beam emitted by the device. The position of each point, in three-dimensional space, is determined by the polar coordinate system. As a result of this scanning process, a "dot cloud" results, which renders the scanned physical object with high accuracy in a digitized format. The "point cloud" contains real information, for a single scan it can contain from a few thousand points to tens of millions of individual points. Each point has its own information in a two-dimensional polar coordinate system, which after processing is transformed into a three-dimensional coordinate system [212].

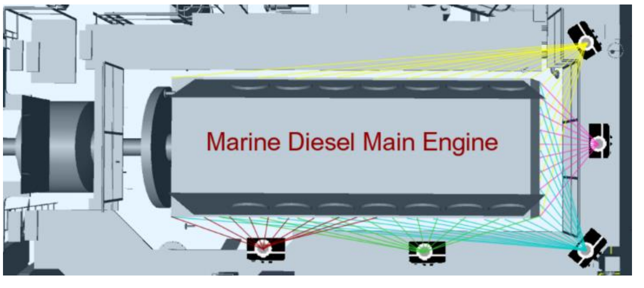

Figure 5.11 Subject-oriented scanning [211]

5.3.2 Case study

The graphical digital environment obtained after post-processing a number of laser scans depending on the size of the project looks like in Figure 5.13. The total number of scans varies depending on the requirements of the project and represents a compromise between the desire to collect as much information as possible and the limitations imposed by: costs, time of access on board the ship, date of delivery, etc.

Figure 5.13 Engine Room point cloud processed [212]

Figure 5.14 presents the budgets, calculated in “working hours”, comparable for a series of modernization projects for different ships carried out in a naval design company. The inspection processes, both classic and with the help of 3D laser scanning techniques are: Preparation, Inspection, Processing of scanned data, Modification design process, Ship assembly process, Cost of materials.

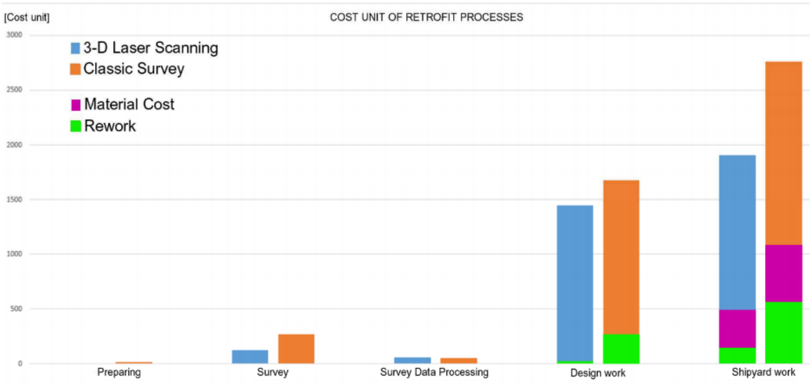

Figure 5.14 Relative cost example for a ship upgrade project [212]

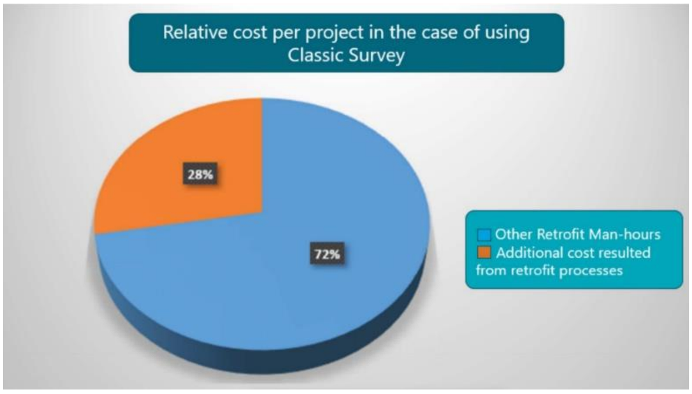

Figure 5.15 Allocated budget to classical inspection from the total project budget [212]

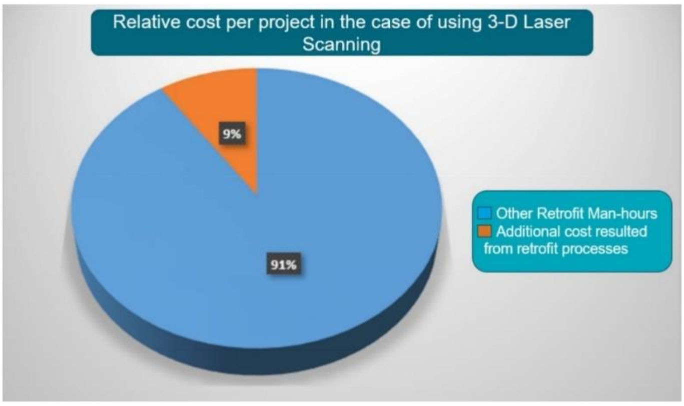

Figure 5.16 Allocated budget for the use of 3D laser scanning from the total project budget [212]

As can be seen from Figures 5.15 and 5.16, the use of laser scanning can significantly reduce the effort in the case of an inspection, as part of the total working hours involved in a ship modernization project. This ultimately leads to a reduction in the total project budget.

5.3.3 Results and discussions

Unfortunately, 3D laser scanning is not commonly used in the construction of new ships, probably because decision-makers are not well informed about the information capabilities resulting from such processes. A possible cause may be the additional cost; however, this cost comes with advantages such as:

- The use of the “point cloud” as a tool to verify the quality of the works delivered by the shipyard (for the benefit of the shipowner).
- Use of the point cloud as evidence in case of incidents that occur during the warranty period (for the benefit of the shipowner).
- Use of the point cloud for easier maintenance, including the installation of new equipment/systems on board the ship, at a later stage.
- Use of “point cloud” information and photographs to perform 360 ° virtual tours on board ships for crew training and instruction procedures.

5.4 Determination of the energy efficiency index, EEXI, for General Cargo ships and corrective measures

The reduction of pollution from maritime activities can only be achieved by adopting a set of concrete and widely applicable measures. This is necessary to reduce the impact that the maritime industry has on the environment [64], [65], [101].

The final target is similar to the targets set in the European Union, namely neutrality in terms of greenhouse gas emissions, in 2050 [77]. In order to be able to implement the requirements of the International Maritime Organization [113], a number of measures need to be implemented on board existing ships. The results of these solutions must be, and are, quantifiable. In this regard, the IMO has also prepared a series of calculation models, especially applicable to classic merchant ships.

Considering that the general cargo ship, having the main characteristics listed in Table 5.4, is a ship representative of the studied area [146], respectively the Black Sea basin.

Table 5.4 *EEXI Characteristics of the vessel for which the EEXI calculation was performed*

Type	***General cargo***
Building year	*1998*
L (m)	*107.6*
Lpp (m)	*103*
B (m)	*18.2*
D (m)	*9*
T (m)	*5.5*
DWD (t)	*6750*
v (knotsi)	*12*

In order to determine the energy coefficient of an existing ship, a series of information is needed regarding the studied ship: ship type, ship length, ship width, ship draft, year of construction, ship speed, construction height, deadweight, etc. [220]. This information is necessary and must be provided by the ship's legal representative, whether it is the shipowner or the company managing the ship. The energy efficiency coefficient of a ship may be expressed as the ratio of carbon emissions from the carriage of a quantity of cargo, formula (5.1) [221]:

$$EEXI=\frac{CO_2\ \text{emissions}}{\text{Transportation work}} \qquad (5.1)$$

Formula (5.1) poate fi dezvoltată ca relație matematică exprimată mai jos în relația (5.2).

$$EEXI=\frac{\left(\prod_{j=1}^{M} \int i\right)\left(\sum_{i1}^{nME} P_{ME(i)}\cdot C_{FME(i)}\cdot SFC_{ME(i)}\right)+\left(P_{AE}\cdot C_{AE}\cdot SFC_{AE}\right)}{f_i\cdot f_c\cdot Capacity\cdot f_w\cdot v_{ref}}$$

$$+$$

$$\frac{\left(\left(\prod_{j=1}^{M} \int i\cdot \sum_{i=1}^{nPT} P_{PTI(i)} - \sum_{i=1}^{nef} f_{eff(i)}\cdot P_{AEeff(i)}\right)C_{FAE}\cdot SFC_{AE}\right)-\left(\sum_{i=1}^{nef} f_{eff(i)}\cdot P_{eff(i)}\cdot C_{FME}\cdot SFC_{ME}\right)}{f_i\cdot f_c\cdot Capacity\cdot f_w\cdot v_{ref}}$$

Relation (5.3) describes much more simply and generally the constitutive elements of relation (5.2) presented above.

$$EEXI=\frac{Main\ engine\ emissions+Auxiliary\ engine\ emissions}{\text{Transportation work}*\text{speed}}$$

$$+$$

$$\frac{(PTI-Innovative\ electrical\ energy\ technologies)-Innovative\ propulsion\ energy\ technologies}{\text{Transportation work}*\text{speed}}$$

(5.3)

In order to be able to improve the value of the energy efficiency index, which is calculated using information from the design and not from the actual operability of the ship [223], [224], a first approach is the one that involves the lowest costs of implementing the solution and can be achieved by reducing the speed [225]. The power required on board the ship is a function that depends exponentially on the value of the speed that the ship can develop [226]. Thus, the described effective power expressed in relation (5.4) is related to the density of water (ρ), the area of the wet surface of the hull (S_w), the coefficient of total resistance to advance (C_t) and the cube of the speed of the ship (V^3):

$$P_E = \frac{1}{2}\cdot \rho S_W C_t V^3 \qquad [227]\ (5.4)$$

All IMO-approved formulas for determining the required power are based on the 1978 ITTC Ship Performance Prediction Method presented at the International Towing Tank Conference (ITTC).

The ship's energy efficiency index is ultimately the amount of greenhouse gas emissions that are produced, a first approach would be to limit the ship's speed [228]. In order to identify the optimal speed compatible with the new energy efficiency requirements of the ship, a power determination was made for the given design speed. Then determinations were made for +1 node, using an increment of ½ node and -5 nodes, using the same increment up to -3 nodes, after which the increment of 1 node up to -5 nodes of the given design speed was used.

In parallel, the reference values for the vessel concerned were identified, namely the EEDI index and the EEXI index in Table 5.6, for the vessel type, gauge and other characteristics. For the reference EEDI index, the value of 16,003 g / t * node was obtained. The EEDI index was processed with the new EEXI requirements for vessel type and unique characteristics and resulted in a reference EEXI index of 14,503 g / t * node.

Table 5.6 *Values resulting from EEXI calculation for General Cargo ship*

	speed (knots)	EEXI index	Percent (%)
Base calc. EEDI	12	16.00	100.00
EEXI req.	12	14.50	90.63
EEXI of ship	11	14.37	99.10

It is obvious that for each of the cases, at higher speeds the values for the forward resistance of the ship, the Effective Power, and the Installed Power increase several times, at the difference of even two nodes. Indications have been determined for the different speeds of the ship mentioned above and it has been found that the reduction in speed from 12 knots to 11 knots meets the new energy efficiency requirements at least until new regulations from the decision makers.

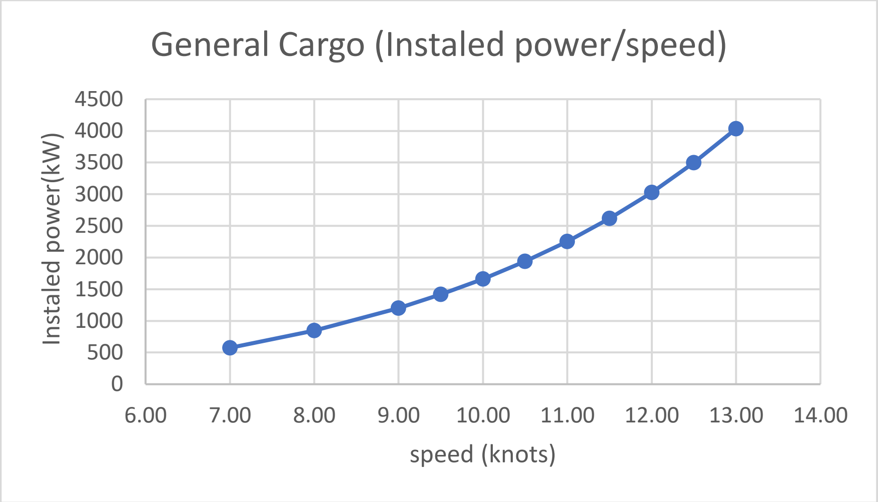

Figure 5.20 Installed power of the General Cargo ship function of speed

Other approaches to meet the new IMO requirements would be to improve the efficiency of the propeller, introduce a new section that would increase the volume of cargo that can be operated by the ship, or even identify the additional input of a sailing system. which helps to capture the force of the wind.

5.5 Conclusions

It is recommended to follow examples of good practices that already have effects, such as measures taken by the Baltic and the North Sea states, where emission control zones (RCTs) are in place [229]. The location of the Port of Constanța near the city [230] raises serious concerns about the health of citizens from the perspective of air quality in this area in the long term.

As a future direction of study, an economic analysis must be performed to determine what type of LNG installation is feasible to be implemented in the Port of Constanța, because in terms of efficiency, many calculations show that there are no differences between a power plant Terrestrial LNG and a floating plant [231]. Also, to resize the energy needs of the LNG plant, a potential input from the renewable energy area should be considered, which could result from a wind farm installed offshore.

Reverse engineering [232], combined with the benefits of 3D laser scanning technology and post-processing of field information, is ideal for processes such as design, control or measurement, in order to adapt new systems or equipment within existing structures in the shipbuilding industry. [233]. Considering the experience gained in several dozen scanning projects, it can be said that laser scanning technology makes a valuable contribution to the projects in which it is used. This statement is also reinforced by a large number of engineering projects in which "point cloud" data were used.

Regarding the obtaining of the energy efficiency index of a General Cargo ship, by reducing the speed of the ship with 1 knot as a limitation, it is a solution that can be agreed in the current conditions. As a percentage, the speed difference varies by 8.34%, which is a significant value. However, although General cargo ships have a wide range of uses, they are still ships with a significant number of years in operation but still have some weaknesses in terms of design and construction rules.

The implementation of an EPL software is a viable solution due to the low impact on the ship's operability, time, and low implementation costs compared to other agreed technical solutions. The result is at the same time predictable, quantifiable and real, unlike other directions that can have a dubious impact on the desired result.

Capitolul 6: CONCLUSIONS

6.1 General conclusions

The Black Sea Basin is a geographical area with a spatially delimited area in which, for any increment as a temporal dimensioning, maritime commercial activities take place. Maritime transport, port activities, "offshore" commercial activities have an important role for society and for daily activity from countless points of view, but they bring with them directly a considerable contribution on water, air, soil pollution, air pollution. the type of noise emissions and even makes a considerable contribution to the creation of biological imbalances. From the studies carried out in the thesis, as well as from the consulted bibliography, it was found that pollution resulting from the operation of seagoing vessels has two main causes that are influenced by the operability of ships and shipwrecks resulting in shipwrecks.

Numerous studies indicate that the western sector of the Black Sea is characterized as a very dynamic one, frequently presenting extreme conditions characterized by the presence of waves with significant high altitudes. These manifestations of the state of the sea in the Pontic basin are strongly influenced by the periodicity of the seasons.

The volume of active vessels in the Black Sea varies according to the season, between 700 and 1000. Of this volume of active vessels, a significant proportion is represented by vessels built before 2010. At the same time, a majority of the total is represented by general cargo ship. Of this volume of active vessels, some are intended for port operations, others operate in inland navigation, but almost all have a direct or indirect impact on the spread of invasive species, if not provided with filtration, purification, and treatment systems. ballast water. The same area also includes the transport of species attached to the outer hull of the ship known as "fouling". During the thesis, an assessment was made of the volume of ballast water with potential risk regarding the migration of invasive species, resulting from the operations of cargo ships in the ports of the Black Sea.

Greenhouse gas emissions from the maritime industry are a real and quantifiable fact. An extremely accurate sizing is indeed quite difficult to achieve due to a very large number of factors that must be taken into account in the calculation. The impact of the maritime industry on coastal air quality could be traced mainly during the "SARS-VOC-2 state of emergency", as the resulting emissions in the naval area contain significant concentrations of sulfur compared to emissions from cars, whose activity was limited.

The active Black Sea fleet consists of vessels that have long exceeded the operating period for which they were designed. Some of these ships do not constructively meet current requirements. This results in numerous naval accidents in the Black Sea basin, resulting in shipwrecks. For all recent accidents, the period studied being 2001-2017, simulations were performed on sea conditions using a numerical model for wave simulation, respectively the SWAN model. The results of the simulations were analyzed and it was found that for several accidents the external factors acting on the ships had a high percentage in terms of the causality of the event. Following these studies, sea characteristics were highlighted: H_s = 11m and U_{10} = 20 m / s, characteristics specific to a storm comparable to a small to medium class hurricane.

It was identified that a significant percentage (81%) of ships involved in serious naval accidents were of the general cargo type, ships designed and built in a certain period of time, respectively the period 1955-1991. Following the evolution and frequency of accidents, it was found that the study should focus on the type of general cargo ship. The analysis of the structural collapse concluded that general cargo ships, designed before 1990, present a high risk when used in maritime transport.

Also, a feasibility study was carried out for the sizing of a liquefied natural gas LNG plant for electricity production, intended for port operations in the port of Constanța.

The opportunity was presented to digitize the data acquisition processes from the ship, through inspection processes using 3D laser scanning technology, in order to implement on board the systems to reduce the impact of ships on the environment from several perspectives: air, water and soil pollution, migration of harmful organisms, limitation of energy consumption on board ships, limitation of noise and vibration transmitted to the marine environment, etc.

In order to obtain an energy efficiency index of a general cargo ship, an analysis was carried out which found that by reducing the running speed by 1 knot, the ship complies with the new requirements on energy efficiency and pollution rules. This approach was chosen to have as main constraints the desire of the shipowner to obtain maximum efficiency with a minimum impact in terms of costs, but also the age of the ship.

6.2 Personal contributions

With the aim of identifying ways to reduce pollution on the Black Sea shipping routes, in the context of an accelerated increase in commercial navigation, the own contributions resulting from the studies will be briefly presented below.

1. Analysis of maritime traffic in the Black Sea is characterized by the volume of ships conducting operations in the study area. The analysis showed that there is a seasonal variation, the number of vessels varies between 700 and 900 vessels active daily in the Black Sea Basin.
2. Analysis of the characteristics of the active fleet in the Black Sea basin. In order to perform various calculations, it was necessary to create a database for active ships in the Black Sea/port of Constanța. This analysis showed that most of the ships operating in the Black Sea were built before 2000. At the same time, a significant number of ships are represented by the general cargo ship type.
3. Identification of the main shipping routes used for commercial purposes in the Black Sea. Using the public databases of marinetraffic.com [56] we highlighted the main sea routes in the Black Sea. Except the coastal area, which is probably the most heavily used for maritime transport, there are a number of other routes, most of which leave for the Bosphorus Strait.
4. Sizing of the volume of greenhouse gas emissions from maritime activities. Based on the data on the number of ships, their characteristics and areas of action, as well as their mode of operation, a series of calculations were made on the power installed on board ships, a value directly proportional to the volume of emissions into the atmosphere.
5. Sizing of the volume of ballast water resulting from maritime activities. Using the database

created, as well as information from the literature, calculations were performed to assess the volume of ballast water that is not neutralized and presents a potential pathological risk in the Black Sea ecosystem.

6. Identification of all naval accidents resulting from sinking or shipwreck. Serious naval accidents have been identified over a limited period of time and relatively recently. These events were detailed according to the type of ship and geographically positioned according to the location reported for the accident.
7. Sizing of the volume of hydrocarbons resulting from serious naval accidents. A basic assessment was performed that identified the volume of hydrocarbons resulting from serious naval accidents identified in the Black Sea during the study period.
8. Identification of areas sensitive to pollutants. The UNESCO protected natural areas in the vicinity of the Black Sea basin have been identified and a primary assessment of the potential risk to external factors created by the Black Sea maritime industry has been carried out.
9. A structural analysis of a type of ship was carried out, most often involved in serious naval accidents in the Black Sea. The study identified that the general cargo ship was involved in most serious naval events. This led to the need to carry out a study on the structural integrity of the ship which had been in operation for about 40 years. A software application belonging to one of the most prestigious classification companies in the field of naval design was used to perform the calculation.
10. Analysis of the state of the sea within a reasonable period of time for each naval accident in the Black Sea (generally at least 48 hours before the event). This analysis was performed to identify the possibility of a direct causality between external factors (wind, waves, etc.) and serious naval accidents that occurred in the Black Sea. The study showed that, for a number of events, this hypothesis was validated.

6.3 Perspectives on future studies

This paper opens up new research perspectives on reducing pollution from commercial maritime activities, and among those identified are the following:

1. Carrying out a complex structural strength study in order to determine and validate the previous analysis, which aimed to assess the causes of the main shipwrecks produced in the Black Sea, in the period 2001-2018, of general cargo ships.
2. Carrying out measurements on board ships in order to sample them in a new database on the volume of emissions from the use of fossil fuels.
3. Carrying out analyzes on the behavior of merchant ships on existing shipping routes, in the perspective of climate change.
4. Implementation of a study on the analysis of future shipping routes, in terms of climate change that affects the parameters that act on ships in the real sea (wind, wave, etc.).
5. Identify the contribution of a wind farm off the Black Sea, in the port area, in order to supply the energy needed for port activities.
6. Analysis of the opportunity to implement hydrogen fuel cell technology on board merchant ships.

6.4 Dissemination of results

Some of the research presented in the doctoral thesis have been capitalized and disseminated through the publication of scientific articles:

Papers published in indexed journals Web of Science (ISI)

1. **V. Raţă**, C. Gasparotti, L. Rusu, 2018. *Ballast water management in the Black Sea's ports*, Journal of Marine Science and Engineering, 6(2), 69; **IF2020 – 2.458 (Q2)**. https://doi.org/10.3390/jmse6020069
2. **V. Raţă**, L. Rusu, 2020. *Impact on air quality of the offshore-ships which are operațing in the Black Sea maritime borders of Romania,* Journal of Environmental Protection and Ecology, 21 (1), 19-27. **IF2020 – 0.577**.

Papers presented at international conferences and published in indexed volumes Web of Science (ISI)

3. **V. Raţă**, A. Hobjilă, L. Rusu, 2019. *LNG to power in the Romanian port of Constanta,* Proceeding of the 4th International Conference on Advances on Clean Energy Research (ICACER2019), 5-7 April 2019, Coimbra, Portugal, E3S Web of Conferences, Volume 103, Article 01007 https://doi.org/10.1051/e3sconf/201910301007
4. **V. Raţă**, L. Rusu, 2018. *Assessing the traffic risk along the main Black Sea maritime routes*, International Conference on Traffic and Transport Engineering ICTTE, 27-28 Septembe, Belgrad, Serbia, pp. 290-297. http://ijtte.com/article/102/ICTTE_Belgrade_2018.html

Papers presented at international conferences and published in indexed volumes Scopus

5. **V. Rață,** E. Rusu, 2020. *Evaluation of entire volume of resulted emissions from the harbours activities in the Black Sea*, Proceeding of the 20th International Multidisciplinary Scientific GeoConference (SGEM 2020), 18 - 24 August, Albena, Bulgaria, Vol. 20, pp. 433-440. https://doi.org/10.5593/sgem2020/4.1/s19.054
6. **V. Rață**, L. Rusu, 2020. *Analysis of the sea state parameters of the time interval that preceded a series of naval accidents in the Black Sea*, Proceeding of the 20th International Multidisciplinary Scientific GeoConference (SGEM 2020), 18 - 24 August, Albena, Bulgaria, Vol. 20, pp. 801-806, https://doi.org/10.5593/sgem2020/3.1/s15.103
7. **V. Raţă,** L. Rusu, 2019. *Air pollutant products resulting from port activity of ships in Constanta harbour*, Proceeding of the 19th International Multidisciplinary Scientific Geoconference (SGEM2019), 30 June - 6 July, Albena, Bulgaria, Volume 19, Issue 4.1, pp. 821-828. https://doi.org/10.5593/sgem2019/4.1/S19.104
8. **V. Raţă**, L. Rusu, C. Gasparotti, 2018. *Analisys of the extreme events reported in the proximity of the Romanian harbours areas*, 18th International Multidisciplinary Scientific GeoConference (SGEM 2018), 02 June - 08 July, Albena, Bulgaria, Vol. 18, pp. 1071-1078. https://doi.org/10.5593/sgem2018/3.2/S15.136
9. A. Hobjila, **V. Rață**, L. Rusu, 2019. *Benefit of combined renewable energy farms in western Black Sea*, Proceeding of the 19th International Multidisciplinary Scientific Geoconference (SGEM2019), 30 June - 6 July, Albena, Bulgaria, Vol. 19, Issue 4.1, 2, pp. 51-58. https://doi.org/10.5593/sgem2019/4.1/S17.007

List of papers published in journals BDI

10. **V. Rață**, A. Ivan, L. Rusu, 2020. *The impact generated by SARS-CoV-2 virus on the air quality in the Constanta port area*, Journal of Mechanical Testing and Diagnosis, Volume

3, pp. 26-30, https://www.mtd.ugal.ro/download/2020-3/5_MTD_Rata%20V,%20Rusu%20L,%20A%20Ivan_2020%20rev.pdf

11. **V. Rață**, L. Rusu, 2020. *Ballast water pollution risk assessment in the Black Sea*, Journal of Mechanical Testing and Diagnosis, Volume 4, pp. 29-34, https://www.mtd.ugal.ro/download/2020-4/5_MTD_Volume%204_Rata_DL%20xx.pdf
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List of papers presented at international conferences

15. **V. Rață,** 2018**.** *The influence of shipping to the air quality in the North-West Black Sea*, presented at 6th International Conference on Environment Pollution and Prevention (ICEPP 2018), 6-8 December, Brisbane, Australia.
16. **V. Rață**, 2017. *Black Sea sustainability - Ballast water treatment facilities in harbors*, presented at 4th International Conference on Environmental Systems Research (ICESR 2017), 14-16 December, Singapore.

List of papers presented at national conferences

17. **V. Raţă**, L. Rusu, 2022. *Existing General Cargo Ship - EEXI Determination and Compensation Measures to Reduce Carbon Emissions*, presented at 10th edition of the Scientific Conference organized by the Doctoral Schools of "Dunărea de Jos" University of Galati (SCDS-UDJG), 9-10 June, Galati, Romania
18. **V. Raţă,** L. Rusu, 2019. *Offshore operațions effects on the Romanian coast air quality*, poster presentation at 7th edition of the Scientific Conference organized by the Doctoral Schools of "Dunărea de Jos" University of Galati (SCDS-UDJG), 13-14 June, Galati, Romania.
19. **V. Raţă**, L. Rusu, 2018. *Evaluating the navigation of pleasure and fishery boats in the Black Sea coastal area în Romania*, presented at 6th edition of the Scientific Conference organized by the Doctoral Schools of "Dunărea de Jos" University of Galati (SCDS-UDJG), 7-8 June, Galati, Romania.

Participation in research projects

2018-2019 Membru în echipa proiectului de cercetare exploratorie 'Evaluarea efectelor produse de schimbarile climatice asupra condițiilor de val din Marea Neagră – ACCWA', cod proiect PN-III-P4-IDPCE-2016-0028, director proiect Prof. Liliana Rusu, https://accwa.ugal.ro/index.php

2019-2020 Membru tânăr cercetător în proiectul Excelentă, performanta si competitivitate în activităti CDI a Universitatea Dunarea de Jos din Galati, contract nr 14PFE/17.10.2018, https://www.expert.ugal.ro/managementul-activitatilor-cdi

Participation in the POCU project

2019-2020 Membru al grupului țintă în cadrul proiectului ANTREPRENORDOC Cod Proiect: SMIS 123847

Participation in mobility projects obtained through national competition, financed by UEFISCDI

2019 Proiect de Mobilitate depus la UEFISCDI pentru finanțare participare la conferință internațională, cod PN-III-P1-1.1-MC-2019-0132, suma 8,943 RON.

2018 Proiect de Mobilitate finanțat de UEFISCDI pentru participare la conferință internațională, cod PN-III-P1-1.1-MC-2018-2973, suma 20,844 RON.

2017 Proiect de Mobilitate finanțat de UEFISCDI pentru participare la conferință internațională, cod PN-III-P1-1.1-MC-2017-1146, suma 18,590 RON.

Awards and international recognition

2019 Locul al II-lea pentru prezentarea de poster la Scientific Conference of the Doctoral Schools Seventh Edition, organizată de Universitatea „Dunărea de Jos" din Galați, pentru lucrarea intitulată: "Offshore operation effects on the Romanian coast air quality".

2018 Moderator la două sesiuni ale conferinței internaționale: 18th International Multidisciplinary Scientific GeoConference (SGEM 2018), 2018, 30 June - 9 July, Albena, Bulgaria, Secțiunile 15. Marine and Ocean Ecosystems și 18. Recycling.

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