THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI
FASCICLE XI – SHIPBUILDING. ISSN 1221-4620, e-ISSN 2668-3156
DOI: https://doi.org/10.35219/AnnUgalShipBuilding/2025.48.03
2025

OFFSHORE PLATFORM ADAPTATION TO CLIMATE CHANGE THROUGH TECHNOLOGICAL OPTIMIZATION AND ADVANCED MONITORING: LITERATURE REVIEW

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ABSTRACT

Climate change is one of the major challenges of the 21st century for the offshore oil industry, generating fundamental changes in operating conditions and requiring complex technological adaptations. This paper investigates the vulnerability of offshore oil infrastructures to the effects of climate change, analysing the impact of temperature increases, sea level changes and the intensification of extreme weather events on offshore platforms. By analysing the specialized literature and evaluating the data, the study identifies the main risks to which these infrastructures are exposed and proposes integrated optimization and adaptation strategies. The results highlight the need to implement advanced structural monitoring technologies, develop multi-criteria optimization methods and integrate renewable energy solutions to increase the resilience of offshore platforms. The analysis shows that infrastructure in Arctic regions is exposed to risks caused by permafrost instability, and many major European terminals are vulnerable to sea level rise. Our paper proposes a unified conceptual model that integrates structural optimization technologies, continuous monitoring solutions, and modern risk management approaches to maintain the safety and sustainability of offshore operations under conditions of intensifying climate change.

Keywords: offshore platforms, structural optimization, risk management, oil infrastructure.

1. INTRODUCTION

Climate change is causing profound changes in marine and coastal ecosystems. These are manifested in rising sea levels, warming ocean waters, increased ocean acidity, storms, reduced oxygen in the water, changes in weather patterns, and changes in atmospheric and ocean circulation. These global effects are often amplified by pressures that are generated by human activities. In recent decades, scientific knowledge about these phenomena has considerablyexpanded, and evidence regarding their impact is increasingly clear [1,2].

The study carried out in this paper, based on data obtained from the literature, aims to identify and implement solutions for the optimization of marine platforms. The cause of this study is the need to respond to the impacts of climate change, such as sea level rise and extreme weather events, to ensure their safety, efficiency, and sustainability in the long term.

The article is structured as follows: Section 2 includes a brief literature review; Section 3 describes the data collected and the research methodology; and Section 4 presents the research results and conclusions.

2. LITERATURE REVIEW

The key factor in maintaining offshore platforms is to prioritize, strengthen the structure, identify necessary modifications, and develop repair plans for both old and new platforms.Another relevant example is a study conducted by Samarakoon and coworkers in 2015 that implemented a multi-criteria analysis (MCA) using an analytic hierarchical process (AHP) for structural integrity control (SIC) [20, 21].Also, for extending the service life of offshore platforms in the North Danish Sea, structural monitoring systems (SMS) have been proposed, which include equipment such as accelerometers, GPS, strain sensors, and wave radar [3].

2.1 Impact of climate change

Climate change has been shown to increase risks to infrastructure located in coastal and offshore areas [4,5,6].

The increase in ground-level air temperature (LSAT) indicates a consistent pattern of global warming between 1901 and 2014 [7]. Studies show that global warming is more pronounced in northern regions compared to southern ones. Fifteen of the warmest twenty years on record occurred in the 21st century [28].Between 1979 and 2014, high-latitude areas in the Northern Hemisphere experienced significantly higher temperature increases compared to other regions [8]. As the oceans store more heat, the increase in sea surface temperature affects ocean circulation, which regulates the movement of warm and cold water around the globe.

Table 1. Optimization techniques for platforms

Year	Technique	Results	Author
2017	Metaheuristic algorithm (CPA)	Reduction of jacket platform weights	Hosseini and Zolghadr [9]
2018	Multi-objective optimization for TLP	Maximization of dynamic tension and weight reduction	Zhang et al. [10]
2019	Automated topology optimization	Safe structure, minimal weight in case of an earthquake	El-Makarem et al. [11]
2019	Topology optimization	Increase in structural stiffness	Tian et al. [12]
2020	Topology optimization (wind, waves, ice)	Increase in stiffness	Deng et al. [13]
2021	Probabilistic seismic demand analysis	Evaluation of engineering requirements	Babaei et al. [14]

3. DATA AND METHOD

The data presented in this study were collected from scientific articles and studies available on various platforms, which are recognized for the diversity and relevance of research in the field of marine platforms and climate change, including studies on the impact that climate change has on marine infrastructure, as well as adaptation solutions.

The analysis carried out in the study was based on a selection of relevant works that discuss both the adaptation of marine infrastructures to new climatic conditions and the technological optimization strategies to reduce their impact. The information collected from the literature provides a solid basis for understanding the current challenges and developing resilient solutions for offshore platforms.

4. FINDINGS

In Arctic regions, accelerated warming causes the melting of permafrost, which compromises the stability of offshore installation foundations, generating the need to implement complex adaptive technical solutions.

Global precipitation variability is an important topic for the scientific community in the context of climate change, impacting the environment and society [15]. Adler et al. [16] analyzed precipitation trends between 1979 and 2014, noting that the average precipitation for oceans and land was 2.89 and 2.24 mm/day, respectively. Although there was no significant increasing trend at the global scale, regional analysis shows significant variations. Between the 1950s and 2018, precipitation increased in North America, Eurasia, south-eastern South America, and northwestern Australia, but decreased in eastern Australia, Africa, the Middle East, and parts of East Asia and South America [17].

The frequency of intense precipitation events also varied significantly between regions and seasons. Since the second half of the 20th century, increases in daily maximum precipitation maxima and average intensities have been observed [18,19]. The frequency of global land precipitation has increased by 2.54 mm per decade [16].

Global mean sea level rise (GMSL) has increased by 18 cm since 1880, as a result of melting glaciers and thermal expansion due to warming oceans. Statistics show that by 2020, GMSL was 9.1 cm higher than the 1993 average [20]. Since the 1960s, the rate of sea level rise has intensified, particularly as a result of sea level changes in the South Atlantic and Indo-Pacific [21]. Annual sea level rise has climbed from 2.2 mm in 1993 to 3.3 mm in 2014 [22]. Sea level has fluctuated considerably regionally due to additional factors [23]. For example, in the last decade, the rate of rise has been different in the Pacific Basin, with higher values in the west compared to the east. In addition, on the northeast coast of North America, sea level rise has exceeded the global average in recent decades, culminating in an extreme sea level rise event in 2009-2010 [24].

Research shows that about 70% of the infrastructure located in these regions is at major risk due to ground instability caused by thawing, which could lead to serious damage to buildings. Rapid climate warming also delays the formation of coastal ice, accelerates its melting, and reduces the thickness of sea ice [30].Extreme temperature changes can lead to problems in maintaining infrastructure such as roads, railways, and buildings by accelerating the degradation of building materials [27].

Changes in rainfall patterns and water runoff regimes can affect oil refining, storage and transportation, as well as related buildings. Drought can cause reduced soil volume and reduced water resources, which can greatly affect oil and gas pipelines as well as drilling, production and refining processes [28].

Table 2 presents different types of impacts produced by climate change on marine platforms.

Table 2. Impact of climate change

Climate Change	Infrastructuri afectate	Impacts	Author
Temperatures	Transport infrastructure	- Reduction of ice transport accessibility and instability of buildings built on permafrost. - Decrease in load-bearing capacity of structures - Accelerated wear of construction materials.	[25–27]
Sea level rise	Oil and gas platforms Oil refineries Gas processing stations Oil and gas pipelines	- Oil and gas platforms are vulnerable to damage and disruptions. - Oil refineries and gas processing stations are exposed to coastal erosion and the risk of saltwater flooding.	[27-29]
Extreme storms	Oil and gas platforms Oil and gas pipelines Oil refineries Gas stations	- Capsizing and damage of platforms, rigs, offshore pipelines, and mobile offshore drilling units	[26-30]

Intense rainfall and increased humidity can cause unplanned disruption of refining processes and overloading of air filters, damaging downstream equipment. Such conditions can compromise the strength of structures and facilitate mould growth [29]. Furthermore, higher risks of damage to pipelines and electrical equipment are observed [31]. Heavy rains and extreme storms, and thunderstorms can affect refineries and oil storage tanks, being a possible trigger for spills of oil and other toxic substances [32].

Brown et al [33] also analysed the risks to which the energy infrastructure on the European coastline could be exposed. The study identified 158 major terminals for oil, gas, and tanker transportation in coastal Europe. Comparable research by Dismukes and Narra [34] studied the possible risks to coastal energy infrastructure under different sea level rise scenarios. In the context of a 1.83 m sea level rise scenario, more than 37 oil refining facilities could be at risk, given that they are located within 2 km of the coast [34]. Approximately 8.9 million barrels per day (MMbpd) of refining capacity could be impacted by this change [34]. As mentioned, increased storm activity has been observed in various regions.

To design offshore platforms to be resilient to climate change, an approach based on several key principles is required [6], [9], [11], [13]:

-Future climatic conditions must be incorporated into the loading calculations to ensure the resistance of these platforms to increased wind, wave, and current conditions;

-Platform foundations must be robust to withstand erosion and other climatic factors;

-To ensure the functionality of marine platforms, when component failures occur, it is necessary to incorporate redundancy in critical systems;

-Materials used must be resistant to corrosion;

-Using advanced concrete technologies to give it increased durability and resistance to degradation;

-The construction must be modular, so that components can be built on land to reduce the risk of offshore installation.

-Using advanced technologies to increase the resilience of marine platforms (Predictive Maintenance, allowing for the prediction and prevention of maintenance needs; Simulation and Testing, allowing virtual testing of structures for different climate scenarios, without the creation of physical prototypes; Monitoring of structural condition and environmental conditions in real time, through the use of advanced sensors and monitoring systems).

Fossil fuels account for 81.79% of the total energy produced globally, while low-carbon sources, including nuclear energy (3.99%)

and renewable energy (14.21%), cover the rest of the energy requirements [35]. Solar and wind energy are cost-effective and efficient in terms of cost and capacity [36]. The progress of renewable energy is influenced by international regulations such as the Kyoto Protocol and the Paris Agreement on climate change [37]. It is believed that these strategies, applied globally, will support international efforts, particularly in Europe, to achieve the ambitious targets set by policies to combat climate change [38].

Since ancient times, wind has been used for various purposes, such as pumping water, grinding grain, and propelling sails, being at the same time a natural phenomenon determined by the uneven heating of the Earth and its rotation [39,40].

Due to the constraints of onshore locations and land use concerns, the offshore wind industry has experienced significant growth [41-44].

Stronger and constant winds in offshore regions help to increase energy production [45,46]. Despite offshore projects having similar goals, the challenging marine environment makes their implementation technologically more complex, requiring large financial investments [47-49]. The development of the offshore wind industry has been hampered by its complexity, the limited number of investors, and the need for substantial funds [52,54].

For more than two decades, the oil industry has focused on reducing greenhouse gas emissions, ignoring measures to prevent climate change damage to the oil sector [57-59]. In order to reduce the effects of oil spills, numerous initiatives have been undertaken over time using various intervention techniques [75, 56-58. Clean-up measures include natural attenuation, physical and mechanical recovery (such as booms, collection devices, and pressure washers), the use of spill treatment agents (such as dispersants, solidifiers, clean-up agents), direct on-site burning and bioremediation [59-63].

5.CONCLUSION

The development of oil and gas infrastructure in offshore and coastal environments is influenced by climate change in all stages of the operational cycle, from exploration to processing and transportation of hydrocarbons.

Phenomena such as sea level rise, changes in the physicochemical properties of the marine environment (increasing water temperature and ocean acidification), and the increase in the frequency and intensity of extreme weather events negatively affect the performance of underwater equipment and the durability of pipelines, and the implications for safety and operational continuity are significant.

Due to the multidimensional and interdependent nature of these impacts, there is an urgent need to adopt rigorous methods for risk assessment that integrate climatic, operational, and socio-economic variables. Therefore, interdisciplinary research is needed in the future, which includes updated climate scenarios and supports the development of sustainable technological solutions for the protection of marine infrastructure.

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Paper received on October 1st, 2025

