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Safety of Logistics Processes in the Supply of Liquid Natural Gas (LNG)

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Abstract:

Purpose: *The purpose of this article is to analyse and assess the threats and risks associated with the logistics of LNG supplies at various stages of this complex process. In addition, the technologies and security procedures that are used to minimise these risks will be discussed, as well as the best practices and legal regulations that aim to improve the overall level of safety in LNG logistics*
Design/Methodology/Approach: *This article presents issues related to the security of logistics processes in the supply of liquefied petroleum gas (LNG). In the paper, the author used the diagnostic interview method, which focused on obtaining answers to questions related to the safety of logistics processes in the supply of liquefied petroleum gas (LNG). The results of the research were presented using descriptive and graphic methods.*
Findings: *The greatest threat is terrorism and new technologies are improving safety.*
Practical Implications: *Liquefied petroleum gas (Liquefied Natural Gas) plays a key role in global energy supply, being one of the most important fuels of the 21st century. However, its transport and logistics require specific safety measures, as LNG is a liquefied natural gas, stored and transported at a temperature of around -162°C. Effective safety management in LNG logistics processes is therefore crucial both to protect people and the environment and to ensure continuity of supply.*
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1. Introduction

The commonly used and popular name LNG is an abbreviation of the English term liquefied natural gas, which means "liquefied natural gas" in Polish. Natural gas is a natural fuel extracted from deposits in the Earth's crust, consisting mainly of methane, as well as other flammable gases and non-flammable compounds. To liquefy natural gas, it must first be thoroughly dried and clean of all contaminants.

To obtain liquefied natural gas (LNG), its temperature is reduced to -162 °C[2]. Due to this solution, one cubic metre of liquefied natural gas corresponds to as much as 600 cubic meters of gas in the gaseous state, which significantly increases the efficiency of its transport[3]. For this reason, the transport of LNG over distances of more than 1100 km by sea and over 4000 km on land is economically viable[4]. The transport of LNG by sea increases the efficiency of gas markets around the world.

The technology of liquefying natural gas began in the 19th century, when the British chemist Michael Faraday was the first to liquefy gas[5]. In 1883, Polish scientists liquefied oxygen and nitrogen from the air, and in 1896 Karl von Linde patented the technology of liquefaction of gases[6]. The first installation was built in the USA in 1917, and a commercial one in Cleveland in 1941. The breakthrough occurred in 1959, when the Methane Pioneer carrier transported 5,000 m³ of LNG across the Atlantic.

In 1965, the first industrial gas liquefaction plant was built in Algeria[7] and gas began to be imported from Algeria, which was made possible by new terminals in Africa. After the discovery of gas deposits in the North Sea, supplies to Europe decreased. In the 1970s and 1980s, Japan and South Korea began to invest in LNG by building gas-fired power plants. Japan began importing LNG from Alaska in 1969 and recognised it as a strategic resource in 1973, reducing its dependence on oil from the Middle East[8]. Liquefied gas is a safe and environmentally friendly energy carrier, especially compared to other fuels[9]. This is a significant advantage over other alternative fuels. This feature of LNG makes it a more stable and secure solution compared to other energy options[10].

LNG is playing an increasingly important role in the global energy economy,

[2] *Adamkiewicz A., Anczykowska A., (2018)*
[3] *Tuchowicki J., (2019)*
[4] *Banaszkiewicz T., Chorowski M., (2020,)*
[5] *Liuhto K., (2012)*
[6] *Bralewski A.(2019)*
[7] *Skarżyński M.,(2019)*
[8] *Bąk M., (6), (2016)*
[9] *Chłopińska E., Bajko A., Autzen A. (2019)*
[10] *Brodacki D.(2017)*

especially in the context of current geopolitical events, such as the war in Ukraine, tensions in the Middle East and changes in global energy markets. The increase in demand for stable, safe, and environmentally friendly energy sources makes LNG a strategically important raw material for many countries, including Poland. The current popularity of LNG is due to several factors, including increased environmental awareness, the search for alternatives to oil and natural reserves, and efforts to become independent of energy suppliers, such as Russia.

LNG is of particular strategic importance for Poland. Due to the geopolitical location of the country and its long-term dependence on Russian gas supplies, Poland is actively developing the infrastructure that allows LNG imports, which increases its energy security. The LNG terminal in Świnoujście plays a key role in the diversification of energy sources, which is even more important in the face of the conflict in Ukraine and the suspension of gas supplies from Russia.

2. LNG Logistics Process

In the entire LNG logistics process, including order, liquefaction, bunkering, shipping, spot purchasing, unloading, regasification, distribution and sales, safety is a key element that requires strict control and advanced technologies.

The LNG logistics process begins with the order and purchase of the raw material. Spot purchases, i.e. one-off transactions for the purchase of LNG on the open market, allow for a flexible response to changing market demand. In the context of security, it is crucial to properly plan and assess the risks associated with the spot market, where prices and availability can fluctuate rapidly. Reliable supplier partnerships and thorough market analysis are necessary to minimise the risks associated with supply unpredictability.

Liquefaction of natural gas is a process in which the gas is cooled to a temperature of approximately -162 ° C, which reduces its volume by up to 600 times. This process requires advanced technologies and extremely precise supervision. Small deviations under controlled conditions can lead to major failures. Therefore, LNG liquefaction plants are equipped with numerous safety systems, such as pressure and temperature sensors and emergency shutdown systems in the event of irregularities.

After liquefaction at the export terminal, the gas is transported by sea to a regasification terminal, for example in Świnoujście, where it is again converted into a gaseous state. Before reaching its destination, LNG travels a long route on board tanker ships, called methane carriers[11]. Bunkering refers to the loading of LNG onto ships or other means of transport. This is one of the more risky stages because LNG has to be reloaded from one tank to another, increasing the risk of leaks and fires. To minimise these risks, the bunkering process must be carried out in accordance with

[11] *Poznań M. (2019)*.

strict procedures, including the use of specialised fittings and regular monitoring of the entire process. LNG carriers are designed with safety in mind, with multiple layers of security to prevent leaks.

LNG maritime transport requires the highest standards of safety. LNG transport vessels, known as methane carriers, are specially designed to carry this raw material. They have double hulls and advanced monitoring systems that allow for immediate detection of irregularities. In addition, sea routes are carefully planned to avoid high-risk areas, such as areas with heavy traffic by boats or waters with a high risk of piracy. In emergency situations, LNG ships are equipped with emergency cargo dumping systems that can immediately disconnect the gas supply and reduce the risk of explosion.

The offshore LNG supply system consists of three main stages: activities carried out by the gas exporter, maritime transport using methane carriers, and operations carried out by the importer. After the gas is extracted from deposits on the shelf or on land, the exporter delivers the raw material to offshore terminals via pipelines. At these terminals, the gas is purified, dried, then liquefied, and loaded onto a methane tank. The second stage involves sea transport using specially designed vessels. After reaching the port in the importer's country, the gas is unloaded, stored in LNG tanks, and then regasified and sent to the distribution network[12].

After reaching the port, the LNG is unloaded and regasified, i.e. the process of restoring the gas to a gaseous state. This process takes place in LNG terminals, which are equipped with advanced monitoring and control technologies to ensure the safe course of regasification. These terminals are designed with the highest safety standards in mind, including pressure and temperature monitoring systems and failure prevention systems. After regasification, LNG is injected into the pipeline network or distributed directly to end users[13]. Distribution networks are regularly inspected for leaks and other potential hazards. Additionally, operators must ensure that end users are aware and trained in the safe use of LNG.

3. The Aim and Methodology of the Research

The main objective of this article is to analyse and assess threats and risks related to the security of logistics processes in the supply of liquefied petroleum gas (LNG). The main research problem was included in the question: What are the key challenges and solutions to ensure the security of logistics processes in the supply of liquefied natural gas (LNG)?

A research problem should be expressed as a question that refers to a specific lack of knowledge on a given topic. Therefore, it is worth formulating the following detailed

[12] *Gromada A., Wysokiński M.(2017)*.
[13] *Gabryś A., Baj K., Abramczyk B.(op. cit., p. 25)*.

research problems:

1. What are the threats and risks associated with the logistics of LNG deliveries at different stages of the process (transport, transshipment, storage)?
2. What safety technologies and procedures are currently in place to minimise risk in LNG supply logistics?
3. What are the best practices and legal regulations to improve safety in LNG logistics processes?

The study used the diagnostic interview method, which focused on obtaining answers to questions related to the safety of logistics processes in the supply of liquefied petroleum gas (LNG). The results of the research were presented using descriptive and graphic methods.

Twenty employees of the President Lech Kaczyński LNG Terminal in Świnoujście (also known as the Gas Terminal) participated in the survey. The characteristics of the study group were described using a metric included in the questionnaire, which contains information such as position and professional experience in LNG logistics. Among the respondents, 65% were security specialists and the remaining 35% were logistics managers and logistics employees. Furthermore, 96% of those surveyed have more than 5 years of experience in LNG logistics.

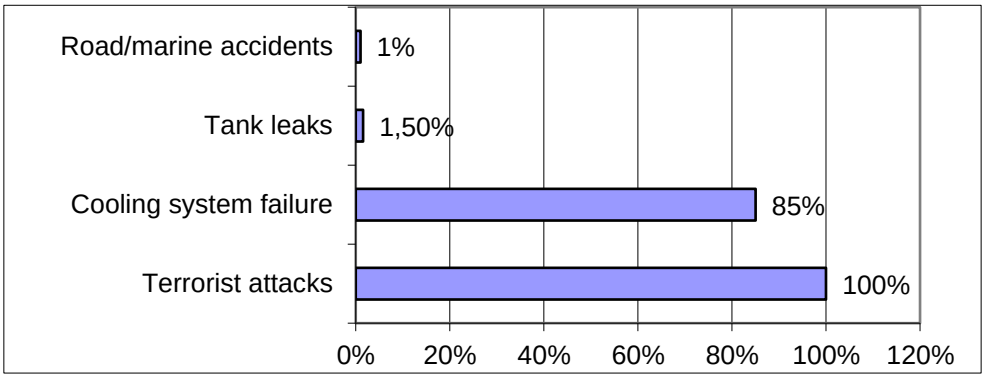
4. Results

The first question was what threats do the respondents think are the most important in the stage of LNG transport? It was a question with the possibility of choosing several answers. The most important types of hazards at the LNG transport stage are presented in Figure 1. The results of the survey showed that terrorist attacks were indicated as the greatest threat, with 100% responses. This suggests that all respondents consider this aspect to be a key issue that requires special attention and countermeasures in LNG transport.

Failure of cooling systems was also rated a very significant threat, receiving 85% of the votes. The loss of tank tightness was indicated by 1.5% of the respondents. Road/maritime accidents received only 1% of the responses, which may mean that respondents consider current road and maritime safety systems to be sufficiently effective or that these risks are perceived as less relevant in the context of LNG transport.

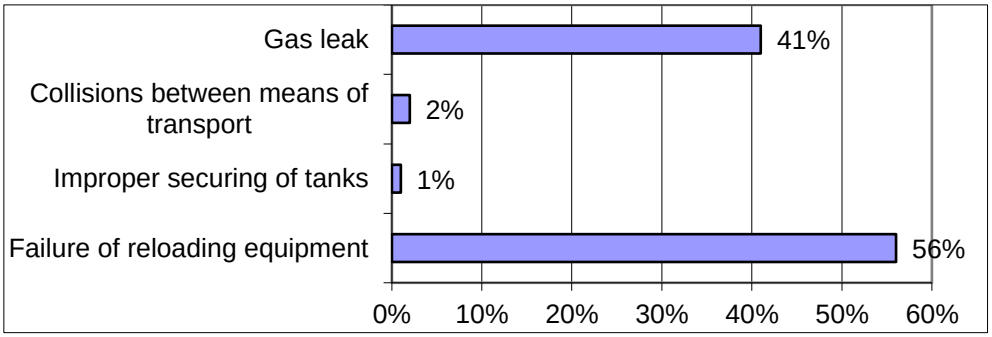
Then, the risks related to LNG transshipment were examined by the respondents as the most important. The responses of the respondents are presented in Figure 2. The failure of the handling equipment received the highest response rate of 56%. Gas leakage was rated another significant risk, with a score of 41%. Collisions between means of transport received only 2% of the indications.

Figure 1. *Types of hazards most relevant at the stage of LNG transport*



Source: *Own work based on a survey.*

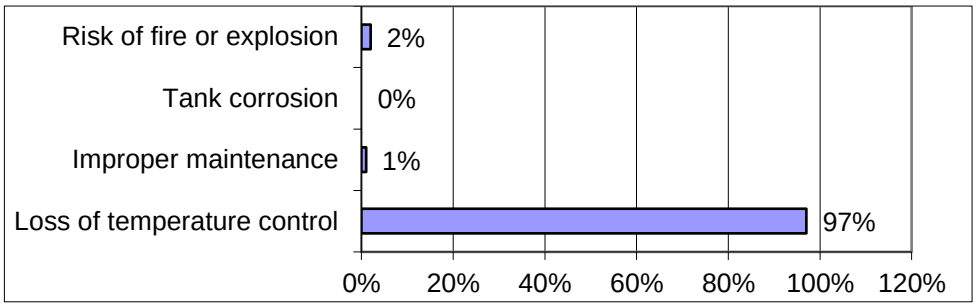
Figure 2. *Risks related to LNG transshipment*



Source: *Own work based on a survey.*

Impairment of tank protection was assessed as the least significant risk, with a score of 1%. The respondents were asked what threats they considered the most important in LNG storage. According to the respondents, the most important threats in LNG storage are presented in Figure 3.

Figure 1. *Risks in LNG storage*



Source: *Own work based on a survey.*

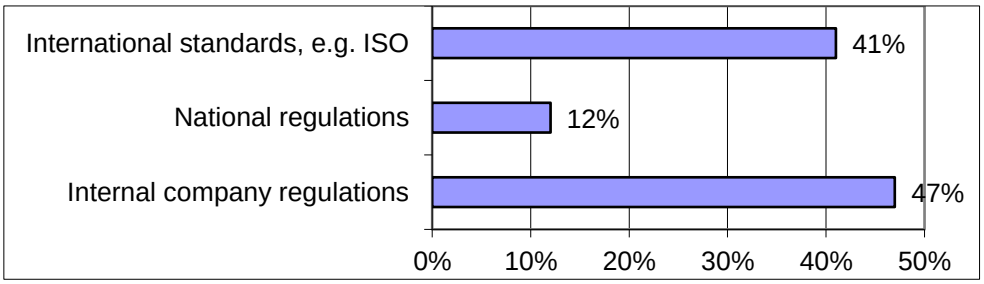
The analysis of the results shows the strong beliefs of the respondents about the most important risks. The loss of control over temperature was indicated by 97% of the respondents as the most important threat in LNG storage. The risk of fire or explosion was assessed as significant by 2% of the respondents. Improper maintenance received only 1% of the votes. Tank corrosion was not perceived as a significant threat, which is reflected in the 0% result.

An analysis was also carried out to determine what solutions are used to monitor LNG-related risks. As part of the multiple choice question, all respondents indicated the following technologies: leak detection systems, pressure and temperature monitoring, GPS systems for transport tracking, and automatic fire extinguishing systems. These tools are crucial to ensuring safety when working with LNG.

To assess the respondents' knowledge of safety procedures, they were asked what safety procedures are regularly used during LNG transport. (with the possibility of choosing more than one answer). The highest value was recorded for real-time monitoring, which was indicated by 100% of respondents. 94% of the respondents cited emergency procedure training as a regular practice. 57% of the respondents confirmed that regular vehicle or tanker inspections are standard safety procedures.

Only 17% of the respondents indicated that securing cargo against theft is a regularly used procedure. It was also analysed whether the respondents assessed existing legal regulations on LNG logistics as sufficient. All study participants responded that they are only partially adequate. The respondents were also asked which legal regulations have the greatest impact on improving safety in LNG logistics processes. The responses of the respondents are presented in Figure 4.

Figure 2. *Types of legal regulations that have the greatest impact on safety in LNG logistics processes*

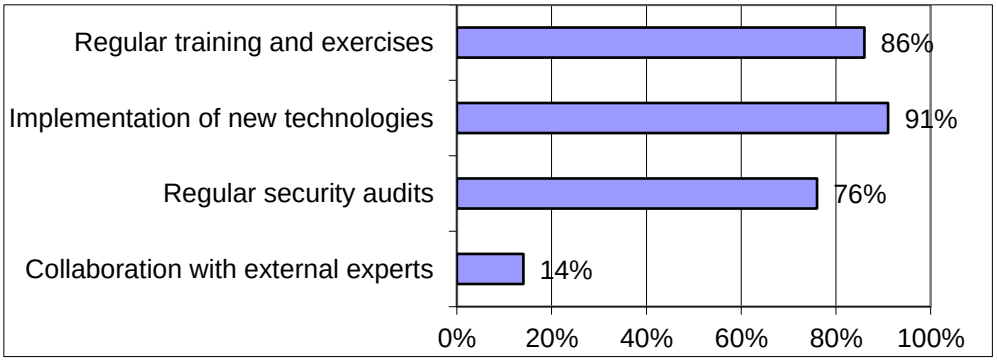


Source: *Own work based on a survey.*

The largest number of respondents, 47%, indicated that internal company regulations have the greatest impact on improving safety. 41% of the respondents considered international standards, such as ISO, to have a significant impact on improving safety. Only 12% of the respondents rated national regulations as having the greatest impact on safety. The low percentage indicates that national regulations may be

perceived as less relevant compared to internal company regulations and international standards. The respondents were asked what best practices are used to minimise the risk associated with LNG. It was a question with the possibility of choosing several answers. The responses of the respondents are shown in Figure 5.

Figure 3. *Practices to minimise LNG risks*



Source: *Own work based on a survey.*

The highest percentage of responses (91%) is related to the implementation of new technologies as a key practice in minimising risk. 86% of the respondents indicated that regular training and exercises are important to minimise risk. 76% of the respondents identified regular security audits as a key practice. Only 14% of the respondents cited working with external experts as an important practice.

Summary and Conclusion

Research on safety in the logistics of LNG supplies provides valuable information on the risks, technologies used, safety procedures, and legal regulations in this area.

Safety in LNG logistics is becoming an increasingly important topic in the literature on engineering, risk management and energy logistics. The results of the conducted research unanimously confirm the existing conclusions in this area. Ozowe C., Ukato A. and others point out that due to the highly flammable nature of LNG and the potentially serious effects of accidents, safety plays a key role in LNG operations. Strengthening safety measures in LNG operations is necessary to protect personnel, infrastructure and the environment[14].

In the LNG transport stage, the respondents rated the risk of terrorist attacks and failure of the cooling system as the highest, suggesting that these areas require the greatest attention and investment in security. Accidents and tightness loss, on the other hand, were perceived as less important threats.

In the field of LNG transshipment, the highest risk is the failure of the handling

[14] *Ozowe C., Ukato A., (2024).*

equipment. These problems can lead to serious incidents, so it is essential to ensure the high quality and regular maintenance of the equipment. Gas leakage is another significant risk, which highlights the need for effective monitoring and detection systems. Ozowe and Ukato (2024) emphasise that leak detection systems play a key role in identifying and eliminating leaks in LNG infrastructure.

With advanced technologies such as fibre optic sensors, leak detection has been significantly improved, offering extremely high sensitivity and precision monitoring. These sensors can identify even the smallest leaks in pipelines and storage tanks, allowing operators to quickly detect and neutralise potential safety hazards[15].

At the storage stage, the results clearly indicate that *loss of temperature control* is by far the most important risk associated with LNG storage, suggesting the need for continued attention and monitoring in this regard. Other threats, while still relevant, are seen as less likely or better controlled. To ensure complete storage safety, all procedures and systems must focus on precise thermal management.

The respondents showed a great knowledge of real-time monitoring and emergency procedure training, suggesting that these are key and well-understood aspects of security. However, lower levels of awareness regarding regular inspections and the security of cargo against theft indicate potential gaps in knowledge or application of these procedures, which may require further education.

Real-time monitoring capabilities greatly improve leak detection systems, giving operators instant access to key data. This allows for a quick response to leaks, minimising the risk of accidents and increasing safety. Emergency shutdown systems are crucial to preventing accidents. They use automated controls and sensors to detect abnormalities and automatically shut down operations, reducing the risk of human error and ensuring a quick response in emergency situations[16].

The respondents considered that the internal company regulations are the most influential in improving safety in LNG logistics processes, which may indicate the importance of specific, tailored internal procedures. International standards are also important, pointing to global standards as an important element of safety. National regulations were evaluated as less impactful, suggesting the need to adapt or strengthen them to better respond to the challenges of LNG logistics.

Respondents considered the implementation of new technologies and regular training to be the most important practices in minimising the risks associated with LNG, which emphasises the importance of innovation and continuous education in ensuring safety. The authors of Adeleke, Oyebode, Adebayo, and Olowe et al. also confirm that effective training and emergency drills are crucial to preparing staff to

[15] *Ibid., (p. 1913).*
[16] *Ibid., (p. 1913).*

act quickly and efficiently in LNG emergencies.

Training programmes should cover various emergency scenarios such as leaks, fires, and equipment failures, while offering hands-on experience with procedures and equipment operation. Regular exercise reinforces training by ensuring that staff can respond calmly and effectively in high stress situations[17].

Regular security audits are also important, highlighting the need for systematic monitoring and evaluation. A low rating for cooperation with external experts may suggest that many companies rely primarily on internal resources and procedures.

Overall, the results of the study point to important areas that require attention in LNG security management, highlighting the importance of advanced technologies and effective procedures and regulations tailored to the specificities of the sector. They also point to the need for further analysis and possible updating of legal regulations and internal procedures to better respond to the challenges related to the transport, transshipment, and storage of LNG.

Security in the logistics processes of LNG supplies requires the integration of advanced technologies, rigorous procedures, and strict supervision at every stage – from ordering, through transport, to distribution and sales.

Each of these stages has unique risks that must be effectively managed to minimise risk and ensure uninterrupted supply of this key energy resource. Investing in monitoring technologies, employee training, and strict compliance with regulations is essential to maintain a high level of safety throughout the LNG supply chain.

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[17] *Ibid., (p. 1914.)*

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