„Polityka i Społeczeństwo" 1(21) / 2023
DOI: 10.15584/polispol.2023.1.13

Piotr Narloch[*], **Tomasz Skrzyński**[**]

METHANE EMISSIONS FROM ELEMENTS OF GAS DISTRIBUTION NETWORKS AND THE ENERGY SECURITY OF EU COUNTRIES IN TIME OF GAS WARS

Abstract

The scale of methane emissions from gas distribution systems has serious consequences for energy security, ensuring the security of natural gas transmission and reducing gas losses in transport. That is why it is important to determine the scale of such emissions from individual elements of the infrastructure. It has been confirmed that such emissions have a significant effect on the military security of EU countries. The emission factor (EF) is affected by many other causes. The best method of calculating the EF is one that takes into account the most variables. A theoretical method of determining the EF has been developed, taking into consideration the age of the equipment as well as pressure, temperature and speed. When comparing the methods in the literature to date, one has to bear in mind that none of them describes the variables that affect the magnitude of the EF. To map an actual emission, it is crucial to have data that describe the gas infrastructure component under analysis, along with the most precise information available to characterise the operating conditions.

Keywords: energy security**,** military security, methane emission factors, gas distribution network, natural gas

Introduction

The 21st century has seen a growing significance of the energy dimension of war activities, including the dependence of military operations on the civilian energy infrastructure. From the military point of view, the flexibility of energy supply chains to units in combat is crucial.

---

[*] Akademia Górniczo-Hutnicza w Krakowie, e-mail: piotr.narloch@psgaz.pl, ORCID: 0000-0002-3464-2883.

[**] Uniwersytet Pedagogiczny im. Komisji Edukacji Narodowej w Krakowie, e-mail: tomasz.skrzynski@up.krakow.pl, ORCID 0000-0003-2063-4396.

Armed forces strive for energy supply chains to be able to be moved quickly as required by operational needs[1].

This article deals with the military significance of methane emissions from the distribution network in the territory of the EU as well as theoretical aspects of attempts at determining the emission factor (EF) from the gas distribution infrastructure. According to a definition applicable in Poland since September 1, the gas security of the state is a condition allowing covering Polish consumers' demand for that commodity "in a specific amount and time, in an economically and technically justified manner, at a level allowing proper functioning of the economy"[2]. Under the above-mentioned definition, methane is in practice used as a synonym of natural gas. However, many EU countries use a broader definition, which encompasses not only natural gas, but also biogas, LNG, synthetic gas, etc. In Western Europe, the term "natural gas" includes not only natural gas, but also methane obtained from other sources. Also taken into account is the quality and parameters (physiochemical properties) of transmitted gas.

An attack on a distribution or transmission infrastructure increases risks to the supply of gas and (in winter in particular) electricity for the military. This affects the ability to move as well as the logistics of military units on the front line.

At the same time, it is very important to ensure the continuity of supply of specific volumes to plants and facilities crucial for ensuring the defence of a state. Thus, it is not surprising that states are increasingly often sponsoring cyber attacks on distribution systems transmitting energy or energy raw materials in the territory of countries deemed hostile or competitive[3].

In the EU, it is particularly relevant in terms of natural gas. With volumes of gas production in the EU decreasing for decades, specialists estimate that in the medium term the EU will remain the world's largest importer of natural gas[4]. At the same time, the current international conflict significantly increases the probability of a serious and imminent

---

[1] J. Gryz [et al.], *Mobile Nuclear-Hydrogen Synergy in NATO Operations* „Energies”, 2021, no 14, 7955. doi.org/10.3390/en14237955.

[2] Ustawa z dnia 5 sierpnia 2022 r. o zmianie niektórych ustaw w celu wzmocnienia bezpieczeństwa gazowego państwa w związku z sytuacją na rynku gazu (Dz.U. 2022, poz. 1723).

[3] *Recommendations on the importance of critical energy infrastructure (CEI) stakeholder engagement, coordination and understanding of responsibilities in order to improve security EXECUTIVE SUMMARY,* Vilnus 2018, p. 10.

[4] M. Kõrts, *Liquefied Natural Gas (LNG) as an alternative propellant in the naval field,* Vilnus 2021, p. 41.

armed conflict unfolding in the EU, in which the armed forces of EU states will be directly involved.

On 20 July, the European Commission published guidelines on securing natural gas for EU member states. It estimates that due to the aggressive foreign and energy policy of the Russian Federation as well as its invasion of Ukraine, the shortage of this commodity in the upcoming winter period may reach from 30 to 45 billion m^3, and gas storage facilities may be emptied by March 2023. The situation will be even more hazardous in extremely low temperatures in the 2022/23 heating season or in case of particularly high demand for gas in other parts of the world. This would result in a 1% drop in the EU's GDP. Possible solutions include, among others, reducing the consumption of gas and updating national contingency plans in the scope of the security of gas supplies.

The challenges connected with methane emissions caused by activities taken as part of hybrid warfare in the territory of the EU have been addressed multiple times in the publications of NATO Energy Security Centre Of Excellence Among Polish researchers, certain aspects have been raised by e.g. Mariusz Ruszel[5].

Russia's aggression against Ukraine has created an entirely new situation in this respect, which requires an analysis regarding distribution networks[6]. Even more so, as the existing literature concerning military issues has been wrongly treating distribution networks as clearly secondary issues and always in conjunction with other energy networks.

The determination of CH emission values in peaceful conditions has been the topic of a larger number of publications. It has already been analysed mainly in relation to the places of extraction and storage of gas as well as gas transmission pipelines[7].

---

[5] M. Ruszel, *Bezpieczeństwo energetyczne w kontekście współczesnych wyzwań wywołanych wojną w Ukrainie w 2022 roku*, [in:] *Bezpieczeństwo Wybrane zagadnienia*, ed. A. Wiącek, M. Ruszel, J. Stec-Rusiecka, Rzeszów 2022; *idem*, *NATO and energy security in European Union,* [in:] *A Transatlantic or European Perspective of World Affairs: NATO and the European Union Towards Problems of International Security in the 21st Century,* ed. A. Podraza; Madrid 2018.

[6] More on the significance of its gas pipelines, e.g.: M. Ruszel, *Znaczenie gazociągów tranzytowych Ukrainy dla bezpieczeństwa energetycznego Europy*, [in:] *Energetyka w czasach politycznej niestabilności*, ed. P. Kwiatkiewicz, R. Szczerbowski, Poznań 2015, pp. 583-592.

[7] A.M.Robertson [et al.], *Variation in methane emission rates from well pads in four oil and gas basins with contrasting production volumes and compositions,* "Environmental Science & Technology", 2017, t. 51. DOI: 10.1021/acs.est.7b00571; I.M. Boothroyd [et al.], *Assessing fugitive emissions of CH_4 from high-pressure gas pipelines in the UK.* "Science of the Total Environment", 2018, no 631-632, pp. 1638-1648. DOI: 10.1016/j.scitotenv.2018.02.240; D.R. Lyon [et al.], *Aerial surveys of elevated hydrocar-*

Methods of practical measurements in the scope of gas pipelines have been determined in relation to Norway and Poland[8]. A geochemical characteristic of methane emissions from the distribution network as well as their distribution on land in the United Kingdom has been presented[9]. A number of valuable remarks can be found in a work on the Italian distribution network[10].

Our deliberations will focus on the less studied theoretical aspects of a more accurate determination of the values of CH_4 emissions from the infrastructure of the distribution network. They vary significantly more in terms of used pipes, materials and diameters, and thus the data set will be much smaller than in the case of distribution networks.

It is difficult to find analyses in the literature that address the impact of external factors on the magnitude/change of the emissivity factor for a component. Research is usually limited to the analysis of a set of data (measurements).

The scale of methane emissions and their consequences

Methane is classified as the second most potent greenhouse gas. Its potential to generate the greenhouse effect is 28-36 times greater than that of CO_2. Compared to carbon dioxide, it remains in the atmosphere

---

bon emissions from oil and gas production sites. “Environmental Science & Technology”, 2016, v. 50, pp. 4877–4886. DOI: 10.1021/acs.est.6b00705; E. Dyakowska, A. Przybył, *Metody wykrywania i pomiaru wielkości niezorganizowanej emisji metanu z elementów infrastruktury przesyłowej – wyniki projektu GERG Detection and Measurement of Fugitive Emissions of Natural Gas from the Transmission Systems*, “Nafta-Gaz”, 2021, v. 2; B. Uliasz-Misiak, J. Lewandowska-Śmierzchalska, R. Matuła, *Emisja ditlenku węgla i metanu związana z poszukiwaniem i wydobyciem węglowodorów w Polsce*, “Przemysł Chemiczny”, 2019, no 98; E. Dyakowska, M. Pęgielska, *Porównanie dokładności dwóch metod pomiaru emisji lotnych – według normy EN 15446 oraz z zastosowaniem urządzenia Hi Flow Sampler – wyniki projektu GERG (The European Gas Research Group)*, „Nafta-Gaz”, 2016, v. 72. DOI: 10.18668/NG.2016.08.11.

[8] T. Log, W.B. Pedersen, *A Common Risk Classification Concept for Safety Related Gas Leaks and Fugitive Emissions?,* “Energies”, 2019, v. 12, 4063. DOI: 10.3390/en12214063; J. Holewa-Rataj, E. Kukulska-Zając, *Przegląd metod pomiaru emisji metanu wraz z analizą możliwości ich zastosowania do pomiaru emisji metanu z gazociągów*, “NAFTA-GAZ”, 2018, 74, pp. 37-43 DOI: 10.18668/NG.2018.01.04.

[9] D. Lowry [et al.], *Fugitive methane emissions from UK onshore gas distribution: geochemical characterization and inventory verification,* Harvard University, https://ui.adsabs.harvard.edu (14.07.2022).

[10] M. Dell’isola, G. Ficco, F. Zuena, *Analisi del delta in-out nelle reti di distribuzione del gas naturale in Italia,* researchgate.net/publication/353644728. DOI: 10.13140/RG.2.2.13943.96164 08.2021 (15.08.2022).

for a relatively short time. The emission of CH_4 together with other greenhouse gases leads to an increase of the global average surface temperature on Earth by 3-4°C by the year 2100[11]. The process of emission results in a significant increase of methane concentration in the atmosphere (fig. 1).

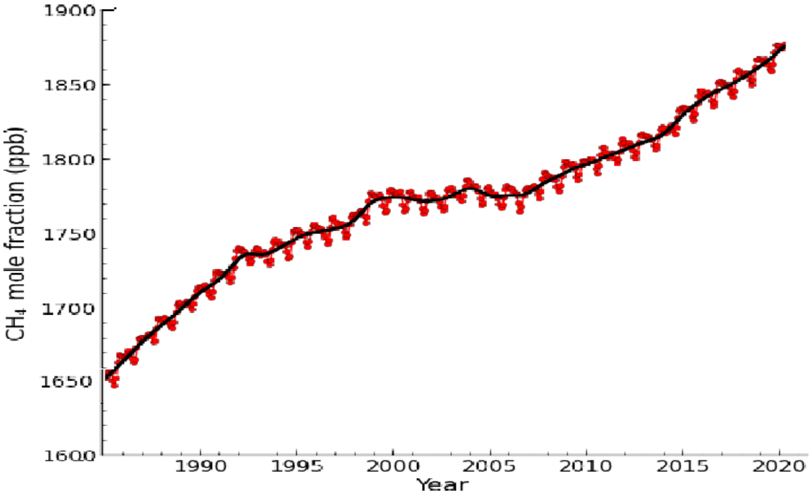

Fig. 1. Estimated increase of global concentration of CH_4 in the Earth's atmosphere in the years 1985-2020

Source: *Global Methane Budget shows methane emissions heading in the wrong direction with fossil fuel and agriculture sources leading the way*, Climate & Clean Air Coalition, https://www.ccacoalition.org, 15.07.2020 (20.08.2022).

The oil and natural gas industry accounts for approx. 1/7 of the overall emissions of CH_4 world-wide. Globally, methane emissions alone are estimated at 0.2%-10% of all CH_4 produced[12]. In 2015 in the USA, they were estimated at 2.3% of the gross gas production[13] .

High losses often occur in the distribution system. There is a view that e.g. in the EU they make up over a half of the overall natural gas losses from the chain of supply of this commodity (Fig. 2).

---

[11] *Global Methane Budget shows methane emissions heading in the wrong direction with fossil fuel and agriculture sources leading the way*, Climate & Clean Air Coalition, https://www.ccacoalition.org, 15.07.2020 (20.08.2022).

[12] P. Balcombe [et al.], *The Natural Gas Supply Chain: The Importance of Methane and Carbon Dioxide Emissions,* "ACS Sustainable Chemistry & Engineering", 2017, no. 5, pp. 3–20. DOI: 10.1021/acssuschemeng.6b00144.

[13] R.A. Alvarez [et al.], *Assessment of methane emissions from the U.S. oil and gas supply chain,* "Science", 2018, no 361, pp. 186-188. DOI: 10.1126/science.aar7204.

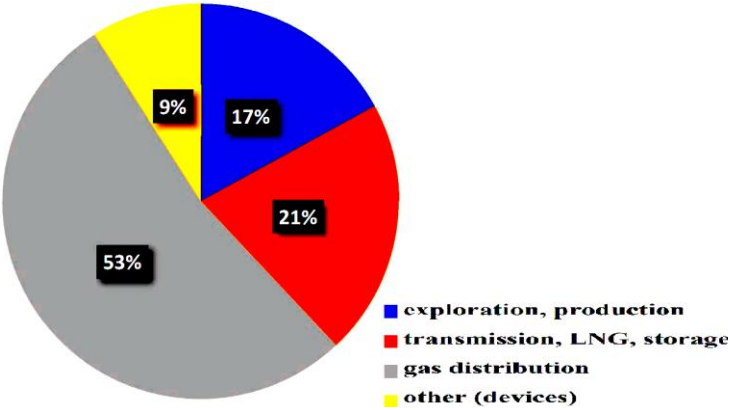

Fig. 2. Methane emissions in Europe from the natural gas supply chain in 2016

Source: E. Dyakowska, A. Przybył, *Metody wykrywania i pomiaru wielkości niezorganizowanej emisji metanu z elementów infrastruktury przesyłowej – wyniki projektu GERG Detection and Measurement of Fugitive Emissions of Natural Gas from the Transmission Systems*, „Nafta-Gaz", 2021, v. 2, p. 119.

In a gas distribution network, gas emissions pertain to infrastructure elements, such as valve stations, elements of gas stations, gas pipelines or output connections.

The UN Framework Convention on Climate Change officially states that it is possible to reduce CH_4 emissions by 45% in the coming decade. Considering this aspect from the military perspective, the consequences of climate change may lower the energy resilience of countries that rely on importing natural gas for industrial purposes[14]. One of the reasons are uncontrolled methane emissions connected with natural disasters, especially in the process of extraction and transmission of this commodity. Their scale is affected by transformations –connected with climate changes –of some factors increasing methane emissions from distribution networks.

The scale of losses of the commodity and the repair time is affected by corrosion and related leakages. Their occurrence is intensified by decisions made during peace times to extend the period use of facilities. The intensification of corrosion and leakages is also affected by the di-

---

[14] *Web conferences on Climate change and Energy Security for NATO Nations 8 April – 22 April – 6 May – 27 May 2021*, 8 April – 22 April – 6 May – 27 May 2021: Climate Change and Energy Security for NATO Nations, NATO OTAN, https://enseccoe.org, pp. 20-21 (5.08.2022).

rections of gas transmission, rate of transmission, pressure changes and composition of transmitted gas.

In the 21st century, the amount of fuel and energy used in military operations has been markedly increasing. Currently, the armed forces in the EU deem energy "a system-wide strategic leverage"[15]. It satisfies the needs of the permanent military infrastructure and field operational activities[16]. It is no coincidence that for over 10 years most EU countries have been striving for reducing the amounts of energy consumed by their armed forces[17].

Attacks on the gas sector are intended to contribute to creating military as well as socio-economic conditions favourable to the aggressor. Intentional attacks e.g. on distribution networks are no exception here. The tools used for this purpose in the case of this part of the gas sector will include, among others:

– disruption or interruption of supply to civilian elements of the infrastructure used by the military directly or indirectly (including individual plants with strategic significance for the armed forces);
– using a cascade effect to hinder or prevent the functioning of other infrastructure facilities crucial not only in the part of the state that has been attacked[18];
– disrupting or interrupting supply meant for municipal consumers.

The failure rate of the distribution infrastructure caused by attacks allows the aggressor to stimulate citizens' discontent with state authorities in the affected area. In extreme cases, this can lead to a political and economic chaos. The use of cyber attacks for this purpose is facilitated by difficulties in proving that the country ordering such attacks is actually responsible for them.

As illustrated by Russia's hybrid war against Ukraine in 2014-2017[19], the said feature of cyber-attacks makes it easier for the aggressor

---

[15] W.J. Nuttall, C. Samaras, M. Bazilian, *Energy and the Military: Convergence of Security, Economic, and Environmental Decision-Making*, Cambridge Working Paper in Economics 2019, 1752, University of Cambridge, https://www.eprg.group.cam.ac.uk (15.07.2022).

[16] J. Gryz [et al.], *op.cit.*, p. 2.

[17] V. Keršiulis, *Strategy Options For Installation of Modern Energy Technologies into Military Bases Vytautas Keršiulis*, „Energy Security: Operational Highlights", 2013, v 2, p. 8; J. Grubliauskas, M. Rühle, *Energy security: a critical concern for Allies and partners*, NATO, https://www.nato.int, 26.07.2018 (10.06.2022).

[18] V. Butrimas [et al.], *op.cit.*, pp. 29-31.

[19] More on the topic: *Ibidem*, p. 23. In a full context on Russia's hybrid war waged at that time: O. Wasiuta, S. Wasiuta, *Wojna hybrydowa Rosji przeciwko Ukrainie*, Kraków 2017.

to carry out information campaigns. They are meant to convince the citizens of the defending country that it is their government, not the other country, that is to blame for the lack of a stable gas distribution system. In the scope of the above-mentioned disinformation campaigns, the attacking country can make use of some rights to which the citizens of democratic EU countries are entitled. A wide-spread attack on a gas infrastructure may also be used as a demonstration of the aggressor's devastating potential in order to exert pressure or undermine the credibility of the state as a country acting as an intermediary in gas transmission, being a hub or having gas storage facilities in its territory.

As is well known, preventing or limiting the volumes of gas supply is not the only factor helping the aggressor achieve the above-mentioned goals. Also important is the threat of significant methane emissions or causing a threat of methane emissions on a scale posing a serious danger to citizens, adjacent infrastructure and –in case the gas supply is not shut off and damage is not repaired –significant and definite losses of the commodity.

Therefore, military planning and preparations for negotiations with the enemy should take into account threats for the distribution network. One example is readiness to carry out similar attacks on the enemy's infrastructure, which has a deterring effect. It is worth considering placing additional security measures or improved monitoring in key points along the distribution network.

Due to the EU's dependence on imports, creating an infrastructure that would ensure swift and significant production increase is unrealistic. At the same time, an aggressor, as part of hybrid warfare, may target gas transmission pipelines, gas storage facilities and extraction installations; in the case of a few EU countries, port blockades could also be possible. Thus, in order for gas to be able to reach the distribution network in some EU countries, it will be necessary to continue expanding a diversified import infrastructure of an appropriate size that would allow gas transmission of required volumes between EU countries. An extreme example are the meagre capabilities of gas transmission by land between Spain and France.

Attacks on the natural gas distribution network can be divided into:

–collateral damage alongside main military activity (e.g. through the use of conventional weapons) as well as attacks aimed at damaging, destroying or temporary shut-down of distribution networks in an entire country or its part. Attacks aimed at distribution networks are intended to force the defending country to incur significant costs connected with regaining control, securing and repairing the damaged and often leaking infrastructure, thus indirectly limiting financial resources which the country could directly allocate to military activities.

As Russo–Ukrainian conflict, lasting since 2014 has shown, deliberate attacks on distribution networks can be subdivided. The most important sub-groups are: efficient external interference in monitoring and control systems of distribution network (cyberattacks), physical taking-over of facilities (e.g. gas compressor stations), deliberate destruction of said networks during hostilities, blowing-up of particular facilities, particularly pipelines, gas stations or massive-scale dismantle of gas infrastructure. Russian actions against the Turkmenistan gas pipeline as well as the latest, luckily unsuccessful, action against the gas pipeline at the border with Ukraine expose the risk caused by deliberate actions (e.g. by means of cyberattack) directed at raising the pressure in the pipeline to excessive levels which results in destruction of the pipeline and likely damages caused by uncontrollable emissions of methane from the infrastructure.

In hybrid warfare complexity of the distribution network makes it impossible to decide which damages were done on purpose. That would require a meticulous study of the attacker's secret military documents at different decision levels which would provide an in-sight into expectations of political and military decision-makers.

Better efficiency can be achieved by the attacker by coordinating of the a/m means of attack aimed at the distribution network. E.g. blowing-up of a gas-pipeline and the considerable methane emission involved can be unnoticeable for supervisors of the given part of the network because of the parallel successful cyberattack aimed at the network monitoring system together with the psychological pressure at the local personnel of the gas company and its forced relocation. Key issues for safe operation of EU distribution system are provision of counterpart delivery, closing ring networks, options to connect alternative sources of energy, identification and getting-rid of the so called "bottle necks". If the attacking country applies strategy involving occupying or damaging the important elements of the distribution network, it can easier obtain a better strategic and negotiating position. Considerable level of informatization of natural gas providers as well as the large number of their pipelines are responsible for the amount of destruction resulted in this way.

The scale of methane emissions caused by the attacks will substantially increase the scope of repairs at the time of hostilities. Damaged installations cannot be used largely because of the scale of destruction inflicting substantial losses in the raw material being transported as well as extra emissions of methane and the danger of explosion involved which would result in further damage of infrastructure, casualties among locals as well as workers and the loss of gas. When there is no spare workforce and alternative pipeline connections, repairs of facilities increase the likelihood of gas supply cuts for industry which plays a key role in national defense system.

Time needed for repairs will be extended not only because damaged supply lines or the ordering, delivery and assembly of damaged (or stolen) parts. Russia's actions during its hybrid war with Ukraine before 2018[20] indicate the possibility of blocking access to damaged installations or shelling repair teams by the attacker's men. In contrary to Poland, the lion's share of the Ukraine's distribution network is above the ground, which makes it even more exposed to damages resulted by shelling or sabotage activities.

Considerable industrial activity of military importance may occur in the EU region which is under attack. In such case, because of the interdependence of different economic entities, an accurate hit would enable the attacker to temporary stop e.g. the total manufacturing of tanks. It is worth noting that some EU countries are the most important armament manufacturers in the world (France, Germany and Italy). It is therefore important to provide alternative delivery sources of gas for such plants. (e.g. LNG).

It should be added that assaults of anti-government or terrorist groups on delivery and distribution infrastructure may occur in the EU too (e.g. in 2012 in Tatarstan which is in European Russia). As LNG terminal rise in number and importance, these may be targeted too. The likelihood of such attack is rather small for the EU. Other targets, resulting in many more casualties among civilians are considerably more attractive for terrorists than targeting gas infrastructure[21]. But killing hundreds of people, however tragic, will not influence the economy or the security of the country as much as the paralysis of a gas terminal or key gas pumping stations.

The extent of the distribution network, a well-developed ring system and the amount of alternative and spare connections can minimise the efficiency of possible targets. Such reserves are achievable in the run-up period before the war or when the economy and individual consumers considerably reduce their demand on gas.

In future, an attack or even a threat of an attack on a gas distribution network will have a negative effect on the level of use of gas

---

[20] V. Butrimas [et al.], *op.cit.*, p. 35.

[21] H. Jakson [et al.], *Energy in Irregular Warfare*, „Energy and Conflict Series", 2017, v. 2, pp. 31-32.

infrastructure for the transmission of gas blended with e.g. hydrogen or other gases obtained through renewable energy sources. In case a EU member state takes part in a war, hydrogen's broad ignition limits may force undertaking additional remedial measures or even reducing the distribution of pure hydrogen in a gas network. The scale of damage to gas pipelines connected with hydrogen explosions will threaten to destroy gas infrastructure and a part of enterprises connected with the defence industry for which the gas mixture would be dedicated. This issue is by no means of marginal importance, considering the scale of the EU's investments in planned use of hydrogen for energy purposes.

Emission factor

Efforts aimed at ensuring the security of transport and transport infrastructure in the scope of natural gas as well as creating its strategic reserves is strictly linked with non-military preparations of state defences[22]. During a NATO summit in Brussels in 2018, the leaders of the alliance, who include leaders from major EU countries, emphasised that stable and reliable supply of energy was most of all the responsibility of the authorities of individual countries. It was agreed that such supply is of crucial importance as it strengthens the resilience of NATO member states against political and economic pressures[23].

In preparing EU states for a potential conflict, it is vital to determine the values of losses of natural gas in the distribution network. This allows estimating the real amount of gas that must be available in a given state to cover the needs of the economy and the citizens during a potential armed conflict. A vast majority of EU member states recognises NATO's doctrine as their own. The doctrine provides for increasing energy security by, among others, strengthening the existing infrastructure and using it in a more efficient way; expanding distribution and other network connections; and ongoing monitoring of possibilities of using civilian parts of gas distribution networks for military purposes[24].

---

[22] M. Kuliczkowski, *Dziedziny, zakres i zasady pozamilitarnych przygotowań obronnych w Polsce*, „Wiedza Obronna", 2021, no 2, pp. 29-42.

[23] A.C. Dupuy [et al.], *Bezpieczeństwo energetyczne w czasach wojny hybrydowej,* „NATO Review", https://www.nato.int, 13.01.2021 (5.08.2022).

[24] *Energy security,* [in:] *NATO 2030: United for a New Era Analysis and Recommendations of the Reflection Group Appointed by the NATO Secretary General,* NATO, https://www.nato.int, 25.11.2020 (9.08.2022).

The implementation of the EU's plans (and of the proposals of the NATO Energy Security Centre of Excellence[25] in the scope of increasing the resilience of the energy system by replacing gas within the economy by renewable energy sources requires time and vast investments. The fulfilment of both these conditions is hindered by the consequences of Russia's invasion of Ukraine.

A significant rise of gas price prices additionally increases the need for accurate calculation and elimination of methane emissions from distribution systems in the EU. At the same time, methane emissions cause gas undertakings to incur financial and image losses in relation to their business partners. Considering the diversity of use of natural gas in the economy, its appropriate quality and transmission capacity affects the preparedness of the defense industry particularly in the winter season, when gas consumption by the economy in many EU countries is a few times higher than in summer months.

Thus, when planning future activities, enterprises have always taken into consideration care for the tightness of the components of distribution networks. However, in some EU countries there have been significant differences in including such considerations in annual and multi-annual plans. They resulted, among others, from giving priority to the urgency of investment plans or obtaining higher profits. Sometimes, they were policy-driven.

From the military point of view, determining the scale of methane emissions from a network may facilitate forecasting gas reserves required in case of war, setting the directions of necessary investments to prevent shortages in times of crisis or armed conflict. Due to the high costs of investments in this sector of the economy, it is necessary to complete them before any military activities begin. Once a country is faced with a serious crisis, any actions taken to limit emissions can be postponed. There is also one other problem. Carrying out large-scale investments in gas infrastructure during military operations is time-consuming and easy to detect by enemy forces. Therefore, it entails a high risk of counteractions on the part of enemy units.

The determination of the optimal volume of gas reserves and minimal volumes to satisfy the needs of the army is hindered by:

- versatile use of natural gas in the economy;
- lack of possibility to predict the average temperature in individual months in upcoming winter;

---

[25] J. Lauf, R. Zimmermann, *Connecting production facilities and transport infrastructure for creating robust and carbon-neutral sector-integrated energy systems,* NATO Energy Security Centre of Excellence, https://enseccoe.org, 15.11.2020 (5.08.2022).

- possible increased demand for natural gas in the economy caused by a negative effect of weather conditions on the amount of energy obtained through renewable energy sources;
- necessity to take into account the economy's increased demand for natural gas, also considering switching the industry to serve military purposes and giving priority to military production.

In the face of the stance of state authorities, technical associations and enterprises dealing with the distribution of gas fuel in EU countries and in North America have established cooperation in the scope of, among others, measuring methane emissions from individual components of the gas transmission and distribution infrastructure. Studies on the determination of methane emissions and ways to measure them are conducted, among others, by the United States Environmental Protection Agency, Intergovernmental Panel on Climate Change (IPCC; Switzerland), Oil and Gas Institute – National Research Institute (Poland), Technical Association of the European Gas Industry (Marcogaz)[26], International Energy Agency.

From the military point of view (and from other perspectives), the estimation of distribution network emission rates during times of peace requires stepping beyond the general system of classification of CH emissions from distribution networks, which takes into account explosion risks and consequences for the climate[27]. It is crucial to determine which types of infrastructure elements produce the highest emissions and what affects them. Emissions from a given type of gas system component are equal to the product of the activity factor (AF), which defines the population size of a given emission source, and the emission factor (EF), i.e. the amount of CH_4 emitted from a given type of emission source.

AF is the number of equipment under consideration; for example, in the case of determining CH_4 emissions for main cocks, it is their number in the analysed gas system. EFs determine to what degree a given infrastructure element affects gas emissions from a given gas system. The results are averaged values from as many data as possible. They are collected from all available measurement samples of acceptable quality and

---

[26] MARCOGAZ is an international association representing European gas industry. It represents interests of the EU countries. The association cooperates closely with gas industry and EU agencies.

[27] M.F. Hendrick [et al.], *Fugitive methane emissions from leak-prone natural gas distribution infrastructure in urban environments,* „Environmental Pollution", 2016, no 213, pp. 710–716. DOI: 10.1016/j.envpol.2016.01.094.

are generally adopted for representative, long-term averaging of all objects in a source category, the so-called average population. If collected data is representative for a given category of facilities in a given area, then it is possible to quickly generate theoretical estimates of emission rates of distribution networks. A more accurate determination of EFs is facilitated by procedure systems used to identify and repair leaking elements in order to minimise methane emissions from single elements or groups of elements. The calculation of the values of methane emissions is significantly complicated and slowed down by the number of variables on which the EF depends.

The major ones include:

- equipment age;
- equipment operating pressure;
- type of infrastructure element (main cock, gas pipeline, gas station, etc.);
- workmanship quality;
- atmospheric and geological conditions affecting the degradation of materials, permeability and, consequently, tightness of gas pipelines.

Also important is the material from which infrastructure elements are made. Gas pipelines made from plastic have much higher emission rates than pipelines made from steel and cast iron. Assuming that EFs determined by the American Gas Association are accurate and representative, it can be concluded that steel gas pipelines with anti-corrosion protection generate five times less methane emissions than polyethylene gas pipelines. Due to attractive prices and a number of advantages resulting from the operation of such gas pipelines, in many European countries the number of gas pipelines made from plastic is much higher than the number of steel gas pipelines, which also affects the end result of CH_4 emissions.

The temperature-pressure relationship also affects the increase in equipment emissions. It is not only about the location of the equipment in relation to sea level. The dependence of gas density on temperature, change in gas volume and some properties of its particles (e.g. viscosity) make the amount of lost CH_4 higher in rising ambient temperature. On the other hand, however, low temperatures have an adverse effect on the failure rate of e.g. fragments of distribution networks dedicated for the defence industry in the territory of the EU.

This is further complicated by the fact that pressure and temperature are not constant over time. The amount of methane emissions determined in the part of gas installation being analysed is also affected to a high degree by the varying sensitivity of measuring devices. It is one of the reasons for which differences between locally applied emission factors for the same facility can be very high, sometimes over ten-fold[28].

Many EFs have been introduced into the scientific literature so far. However, it is very difficult to determine them empirically and unify them.

In the 21st century, the task of EF unification was taken on by organisations operating within the European Commission, e.g. Marcogaz, as well as organisations cooperating with the European Commission, such as IPCC.

In 2005, Marcogaz developed and published a methodology for harmonising the EF using the experience of EU gas infrastructure operators. This was to be the starting point for establishing a common EU methodology in this field. A common methodology would enable a harmonised approach to estimating methane emissions from individual infrastructures for Member States with different transmission systems and different experience in determining CH_4 emissions from operating gas infrastructure. Using the above-mentioned guidelines, in 2007 the first determination of the scope of emission factors for the transmission and distribution of gas was made. In 2014, the documentation was updated in an attempt to estimate overall CH_4 emissions from the natural gas industry in the EU.

The problem would only partly be solved by implementing plans to average existing EFs and to conditionally assign a single EF to a given device operating under specific conditions. In 2020, Marcogaz has set its sights on an absolute reduction of CH_4 emissions within the EU. The organisation specified an absolute reduction target of 67% by 2025 compared to 2016 and a reduction of specific emissions, such as from distribution networks, of 33% by 2025 compared to 2012, i.e. 1/3 of all CH_4 emissions[29] (There are ideas to reduce emissions even further (even to a level of 45%).

Measurement data will be collected[30]. All EFs are the effect of work of the industry, scientific or academic institutions. The members of Marcogaz are most of all people working in transmission and distribution companies, all of which will be forced to calculate emissions. The number of measurements is not laid down. It depends on the enterprise. Each company operating in the scope in question in the EU is to make every effort and undertake research works to determine factors or calcu-

---

[28] J. Holewa-Rataj, E. Kukulska-Zając, *Przegląd współczynników emisji metanu dla gazociągów,* „Gaz, Woda I Technika Sanitarna", 2017, no 7. DOI: 10.15199/17.2017.7.1

[29] *Guidelines methane emissions target setting,* Marcogaz, https://www.marcogaz.org, 10.04.2020 (16.08.2022).

[30] More about methods of emission measurements: J. Holewa-Rataj, E. Kukulska-Zając, *Przegląd metod pomiaru emisji metanu wraz z analizą możliwości ich zastosowania do pomiaru emisji metanu z gazociągów*, „NAFTA-GAZ", 2018, v. 74, no 1. DOI: 10.18668/NG.2018.01.04, pp. 37-43.

late emissions; however, the way they do it is not specified as long as their results are reliable and backed by scientific works. LDAR (Leak, Detection and Repair) is the most comprehensive solution setting the direction for research and tests. In Poland, the Chamber of the Natural Gas Industry is preparing a technical standard entitled "Methods of determining the amount of methane emissions from the gas network," which should be published this year.

The use of LDAR-type programmes for CH_4 emissions will soon be imposed[31]. Due to the vast extent of the infrastructure in question, it is impossible to maintain ongoing emission detection directly on the infrastructure; that is why, it will be necessary to use theoretical calculations, which will obviously be generalised to some degree, but it will be otherwise impossible to determine infrastructure emission rates (to make it economically justifiable as well), and consequently take actions aimed at reducing emissions.

As part of the programme, Marcogaz plans to develop guidelines to monitor, control and report leakages in extraction (upstream), transmission, storage (midstream) and distribution (downstream) installations used for the production, transport and storage of natural gas. For this purpose, sniffers (computer programs or devices designed to capture and analyse data for gas emissions) and specialised soap sprays as well as Optical Gas Imaging are used. Key elements of the programme include methods to verify its performance. The calculations will be based on the EFs defined by Marcogaz and AF, so that once the emission sources are identified, they will be quantified.

"For the state and the society to be better prepared for potential external threats”[32]

Methods for determining emission from distribution networks

In the EU, the literature mentions four methods of determining emissions. The first method consists in calculating the total sectoral emissions on the basis of the volumes of gas distributed and received by end users. An advantage here is the small amount of information needed to deter-

---

[31] R. Kowalski, *Obniżanie emisji metanu z sieci gazowych z wykorzystaniem programu LDAR,* [in:] *Konferencja naukowowo-techniczna Forgaz 2022: Techniki i technologie dla gazownictwa*, Kraków 2022.

[32] K. Janik, *Działania Ministra Spraw Wewnętrznych i Administracji na rzecz zapewnienia bezpieczeństwa i porządku publicznego, w warunkach zewnętrznego zagrożenia państwa i w czasie wojny: wybrane problemy*, „Wiedza Obronna”, 2021, no 2, p. 71.

mine gas losses. The method is not applied in practice due to the scale of differences between the data obtained with it and the actual values measured using specialised instruments. The second method, more detailed, consists in determining the factor individually for each group of objects[33], such as gas stations, gas pipelines and connections. This method is more precise compared to the one discussed above. However, it has been developed for given or e.g. normal environmental conditions[34], and therefore, may give different results when applied to a different location. It also includes only some of the relevant variables affecting the EF determined. In the third method, several EFs are determined for each group of objects. They take into account the characteristics of each group, which, due to their diversity, such as operation under given weather conditions or physical parameters of the device, can be divided into subgroups including the year of construction, operating pressure, and material.

In the example below, the second and third methods are presented together, because with certain data, including AF and EF, the calculations are performed in the same way. The difference will be in the EF values due to the accuracy of their determination. The example below presents the calculations of emissions from a gas pipeline with a total length of 35,000 m and with 3,500 main cocks. For instance, the EF value adopted for the main valve is 0.04 m³/item/year and 568 for a gas pipeline.

$$Emission = \sum(AF * EF)$$

$$Emission_{gas\ pipeline} = 35000 * 568 = 19880000 \frac{m^3}{year} CH_4$$

$$Emission_{main\ cocks} = 3500 * 0.04 = 140 \frac{m^3}{year} CH_4$$

The calculation result is a theoretical value of methane emission from the pipeline and main cocks during one year of operation. In the third method, in order to bring these values closer to the actual ones, the analysed gas pipeline is divided into smaller fragments, taking into account the differences resulting from e.g. the material, age of construction, and other factors affecting the pipeline integrity. The calculation procedure remains the same as presented above.

---

[33] J. Holewa-Rataj, E. Kukulska-Zając, M. Pęgielska, *Emisja metanu z zespołów zaporowo-upustowych, "Nafta-Gaz", 2016, no 72, p. 536. DOI: 10.18668/NG.2016. 07.06.*

[34] Normal conditions for gases are: normal pressure: 101 325 Pa = 1 atm; normal temperature: 273,15 K = 0 °C.

The determination of the EF for a gas pipeline using the fourth method developed by Marcogaz is done by using a factor with the most approximate correlation between the emissions and the length of the pipe based on the biggest possible amount of measurement data (Fig. 3). This explains the larger number of sample tests conducted on real operating conditions of the system.

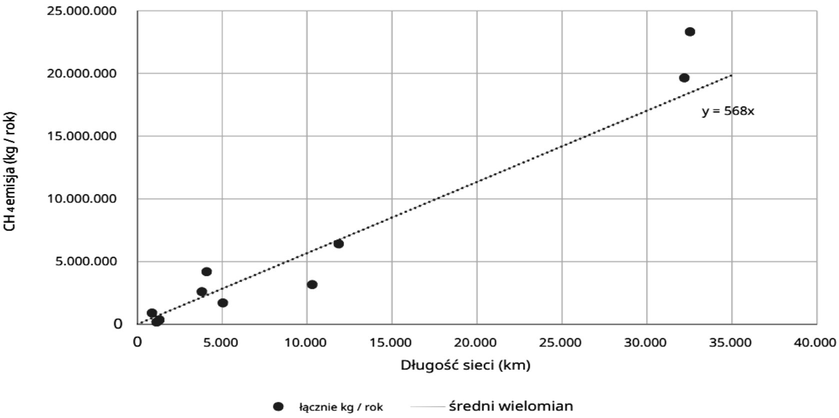

Fig. 3. Example of emission-gas pipeline length correlation according to Marcogaz

Source: *Urvey Methane Emissions For Gas Transmission In Europe Update 2017*, Marcogaz https://marcogaz.org (15.08.2022).

Since the emission value is not constant in time, it must be narrowed to a certain period, $\frac{kg}{year}$. The method requires determining a trend line, i.g. averaging results to an approximate value.

A linear graph is obtained and there must be determined the correlation between the domain and the set of values of the linear function $y = ax + b$, where the set of values is the CH_4 emission and the domain is the length of the gas pipeline. The "b" coefficient is omitted. This is because in no case will the y-axis be intersected at a point other than 0. The correlation formula is simplified to $y = ax$, where x – the gas pipeline length [km], y – methane emission [kg/year], coefficient "a" – EF.

It follows that EF, i.e. the correlation between the network length and emissions over time, can be written as:

$$EF = \frac{EmissionCH\ 4/year}{pipeline\ length}$$

$$EF = \frac{19880000 \frac{CH4}{year}}{35\ km}$$

$$EF = 568 \frac{CH4}{km * year}$$

The analysis of all the methods showed that the third method is the most accessible. Each of the four methods differs in the type of variables used in the calculation. Also important is the level of accuracy of the result averaging and the precision of measuring instruments. Another effect comes from the variations in the "park" of measuring devices and related sensitivity of applied measuring methods to cyber-attacks. It is necessary to consider the practical aspect: not only the existing regulations, but also the significant differences in internal regulations in gas industry enterprises in different countries in the scope of network operation and observance of safety norms.

Theoretical determination of the emission factor

The author's own approach to calculating the EF is outlined below. An EF representing the emissivity of a given component, a gas infrastructure facility, should be determined. Its determination may be laboratory-based or by experiment through repeated emission measurements using dedicated equipment[35]. Determining the number of variables affecting the emissivity factor is a difficult, expensive, and time-consuming challenge requiring numerous measurements that must be properly executed.

To determine the EF, the theoretical number of variables affecting the emission change for a given site must be provided; the greater the number, the more accurate the calculation results. Such variables for gas stations may be the age of the apparatus, operating pressure, ambient temperature, humidity and more. For gas pipelines, the ground conditions of the pipeline alignment are also crucial. In mining areas, they are particularly vulnerable to stresses that can cause extra leaks and increased emissions at pipeline connections.

A new factor – the *age factor* (AGF) – should also be considered, which, as the age of an apparatus or pipelines increases, adversely affects

---

[35] The measuring equipment sensitivity should be adjusted to the expected measurement results. The best and, at the same time, most expensive ones provide a wide field of activity as they transmit aggregated data on emissions, location as well as the infrastructure where the leaks are found.

the magnitude of the emissivity factor (EF), thereby leading to an increase in emissions. Determining the AGF involves a number of laboratory tests and a vast database. The derived factor shall improve the accuracy of the emission scale calculations.

Conclusions

Methane emissions have a significant effect from the point of view of ensuring an optimal level continuity of energy supply to military infrastructure and industrial plants which are important from the perspective of state defence. As it has been proven, attacks aimed at gas distribution networks as part of hybrid warfare will be used in different ways to weaken political, economic and military capabilities of the attacked country. By exploiting damage to gas distribution networks caused by the enemy as well as resulting methane emissions and related threats, the enemy deals a blow to the reliability and efficiency of the network in a large part of the country. Thus, the claim of a significant effect of methane emissions from gas distribution networks on the military security of EU states has been confirmed.

Distribution networks need to play an important role in the process of assessing reliability and efficiency risks and threats connected with states' critical energy infrastructure. It allows states to more effectively predict threats to their functioning and to more accurately respond to challenges brought by hybrid warfare in the scope contemplated in this article.

It is important to ensure proper care for gas distribution networks in the defence policies of EU states. In a period prior to a conflict, it is important to increase the attention of armed forces to ensuring energy security in this scope. Particularly important will be the intensification of monitoring and careful updating of detailed action plans in case of cyber attacks as well as diversion and sabotage activities.

The estimation of the scale of emission rates of a part of a gas distribution network in conjunction with a list of connections to such network that are important from the point of view of military security allows identifying and determining the order of investments in a given gas network that is favourable from the military point of view. It is also possible to use the analytic hierarchic process (AHP), currently used both for energy and military purposes[36]. A practical application of the EF will

---

[36] More about it: W. Grządzielski, T.M. Mróz, *Planowanie zrównoważonego rozwoju systemu gazowego*, Lublin 2017, pp. 47-50, 63-166; W. Grządzielski, M. Dziado-

facilitate determining to what degree losses are caused by emission factors caused by intentional acts of the enemy.

The article outlines a new concept which, on the one hand, standardises and, on the other hand, increases the accuracy of emissivity factors from a gas grid. It is worth emphasising that the innovative nature of the methodology outlined in this text addresses all the most significant variables, such as the proportionality factor of diffusion, pressure, weight density or velocity of the transferred liquid. As a result, a theoretical model can be developed that allows a very accurate representation of actual emissions, provided that accurate input data is available.

The best EF calculation method is one that incorporates as many variables as possible. Comparing the methods existing in the literature to date, it should be acknowledged that none of them is optimal. This applies even to method 3, where several factors are determined for each group of objects, taking into account the characteristics of each of them. The main disadvantage of this method is of key importance here: change of a given parameter, e.g. pressure, causes the emission value to vary. In the present state of research, the most optimal method used in the EU is the fourth method presented in the study by Marcogaz (LDAR). The methodology outlined is easily imagined in relation to the determination of heat influx with characteristic numbers. With tabulated numerical values as well as ambient and material physical properties, we are able to determine the heat flux or other properties, such as the heat transfer coefficient.

Thus, it is relatively uncomplicated to perform the required calculations by altering or updating only the values of the individual variables. The presented method of determining the EF facilitates an analysis of infrastructure durability and resistance in relation to potential acts of war. An analysis of the above-mentioned dependencies also points to a possibility of calculating to what degree the emission scale results from the level of corrosion/deformation of gas installations. This factor, which depends on state policies, increases the scale of emissions caused intentionally by enemy activities during war activity. EFs will be developed and specified more precisely over some years, while the implementation of artificial intelligence will allow improved detection, prediction and making more accurate decisions concerning the replacement of defective infrastructure.

---

wiec, *Uwarunkowania rozwoju dystrybucyjnej sieci gazowej zasilanej skroplonym gazem ziemnym lub biogazem/biometanem*, Lublin 2019, pp. 49-54.

Bibliography

Alvarez R.A. [et al.] *Assessment of methane emissions from the U.S. oil and gas supply chain, “*Science”, 2018, no 361. DOI: 10.1126/science.aar7204.

Balcombe P. [et al.], *The Natural Gas Supply Chain: The Importance of Methane and Carbon Dioxide Emissions,* “ACS Sustainable Chemistry & Engineering”, 2017, z. 5. DOI: 10.1021/acssuschemeng.6b00144.

Boothroyd I.M. [et al.], *Assessing fugitive emissions of* CH_4 *from high-pressure gas pipelines in the UK. “*Science of the Total Environment”, 2018, no 631-632. DOI: 10.1016/j.scitotenv.2018.02.240.

Dell’isola M., Ficco G., Zuena F., *Analisi del delta in-out nelle reti di distribuzione del gas naturale in Italia,* 2021, researchgate.net/publication/353644728. DOI: 10.13140/RG.2.2.13943.96164.

Dupuy A.C. [et al.], *Bezpieczeństwo energetyczne w czasach wojny hybrydowej,* „NATO Reviev”, NATO, https://www.nato.int, 31.01.2021 (5.08.2022).

Dyakowska E., Przybył A., *Metody wykrywania i pomiaru wielkości niezorganizowanej emisji metanu z elementów infrastruktury przesyłowej – wyniki projektu GERG Detection and Measurement of Fugitive Emissions of Natural Gas from the Transmission Systems*, „Nafta-Gaz”, 2021, no 2.

Dyakowska E., Pęgielska M., Porównanie dokładności dwóch metod pomiaru emisji lotnych – według normy EN 15446 oraz z zastosowaniem urządzenia Hi Flow Sampler – wyniki projektu GERG (The European Gas Research Group)*, „Nafta-Gaz”, 2016, no 72. DOI: 10.18668/NG.2016.08.11.*

Energy security, [in:] *NATO 2030: United for a New Era Analysis and Recommendations of the Reflection Group Appointed by the NATO Secretary General,* NATO, https://www.nato.int, 25.11.2020 (9.08.2022).

Global Methane Budget shows methane emissions heading in the wrong direction with fossil fuel and agriculture sources leading the way Climate & Clean Air Coalition, https://www.ccacoalition.org, 15.07.2020 (20.08.2022).

Grubliauskas J., M. Rühle, *Energy security: a critical concern for Allies and partners,* NATO, https://www.nato.int, 26.07.2018 (10.06.2022).

Gryz J. [et al.], *Mobile Nuclear-Hydrogen Synergy in NATO Operations „Energies”,* 2021, no 14, 7955. doi.org/10.3390/en14237955.

Grządzielski W., Mróz T.M., *Planowanie zrównoważonego rozwoju systemu gazowego*, Lublin 2017.

Grządzieski W., Dziadowiec M., *Uwarunkowania rozwoju dystrybucyjnej sieci gazowej zasilanej skroplonym gazem ziemnym lub biogazem/biometanem*, Lublin 2019.

Guidelines methane emissions target setting, Marcogaz, https://www.marcogaz.org, 10.04.2020 (15.08.2022).

Hendrick M.F. [et al.], *Fugitive methane emissions from leak-prone natural gas distribution infrastructure in urban environments*. „Environmental Pollution”, 2016, no 213. DOI: 10.1016/j.envpol.2016.01.094.

Holewa-Rataj J., Kukulska-Zając E., *Przegląd współczynników emisji metanu dla gazociągów,* „Gaz, Woda i Technika Sanitarna”, 2017, no 7. DOI: 10.15199/17.2017.7.1.

Holewa-Rataj J., Kukulska-Zając E., Pęgielska M., Emisja metanu z zespołów zaporo-wo-upustowych*, „Nafta-Gaz", 2016, no 72. DOI: 10.18668/NG.2016.07.06.*

Holewa-Rataj J., Kukulska-Zając E., Przegląd metod pomiaru emisji metanu wraz z analizą możliwości ich zastosowania do pomiaru emisji metanu z gazociągów*, "Nafta-Gaz", 2018, no 74. DOI: 10.18668/NG.2018.01.04.*

Janik K., Działania Ministra Spraw Wewnętrznych i Administracji na rzecz zapewnienia bezpieczeństwa i porządku publicznego, w warunkach zewnętrznego zagrożenia państwa i w czasie wojny: wybrane problemy*, „Wiedza Obronna", 2021, no 2.*

Keršiulis V., *Strategy Options For Installation of Modern Energy Technologies into Military Bases Vytautas Keršiulis*, „Energy Security: Operational Highlights", 2013, no 2.

Kõrts M., *Liquefied Natural Gas (LNG) as an alternative propellant in the naval field,* Vilnus 2021.

Kowalski R., *Obniżanie emisji metanu z sieci gazowych z wykorzystaniem programu LDAR*, [in:] *Konferencja naukowowo-techniczna Forgaz 2022: Techniki i technologie dla gazownictwa*, Kraków 2022.

Kuliczkowski M., *Dziedziny, zakres i zasady pozamilitarnych przygotowań obronnych w Polsce*, „Wiedza Obronna", 2021, no 2.

Lauf J., Zimmermann R., *Connecting production facilities and transport infrastructure for creating robust and carbon-neutral sector-integrated energy systems,* NATO Energy Security Centre of Excellence, https://enseccoe.org, 15.11.2020 (5.08.2022).

Log T., Pedersen W.B., *A Common Risk Classification Concept for Safety Related Gas Leaks and Fugitive Emissions?* "Energies", 2019, no 12, 4063. DOI: 10.3390/en 12214063.

Lowry D. [et al.], *Fugitive methane emissions from UK onshore gas distribution: geochemical characterization and inventory verification,* Harvard University, https://ui.adsabs.harvard.edu (14.07.2022).

Nuttall W.J., Samaras C., Bazilian M., *Energy and the Military: Convergence of Security, Economic, and Environmental Decision-Making*, Cambridge Working Paper in Economics 2019, 1752, University of Cambridge, https://www.eprg.group.cam.ac.uk (11.08.2022).

Recommendations on the importance of critical energy infrastructure (CEI) stakeholder engagement, coordination and understanding of responsibilities in order to improve security executive summary, Vilnus 2018.

Robertson A.M. [et al.] *Variation in methane emission rates from well pads in four oil and gas basins with contrasting production volumes and compositions*. "Environmental Science & Technology", 2017, t. 51. DOI: 10.1021/acs.est.7b00571.

Ruszel M., *Bezpieczeństwo energetyczne w kontekście współczesnych wyzwań wywołanych wojną w Ukrainie w 2022 roku,* [in:] *Bezpieczeństwo Wybrane zagadnienia*, ed. A. Wiącek, M. Ruszel, J. Stec-Rusiecka, Rzeszów 2022.

Ruszel M., *NATO and energy security in European Union*, [in:] *A Transatlantic or European Perspective of World Affairs: NATO and the European Union Towards Problems of International Security in the 21st Century*, ed. A. Podraza, Madrid 2018.

Ruszel M., *Znaczenie gazociągów tranzytowych Ukrainy dla bezpieczeństwa energetycznego Europy,* [in:] *Energetyka w czasach politycznej niestabilności,* ed. P. Kwiatkiewicz, R. Szczerbowski, Poznań 2015.

Uliasz-Misiak B., Lewandowska-Śmierzchalska J., Matuła R. Emisja ditlenku węgla i metanu związana z poszukiwaniem i wydobyciem węglowodorów w Polsce, *"Przemysł Chemiczny", 2019, no 95.*

Urvey methane emissions for gas transmission in Europe Update 2017, Marcogaz, https://marcogaz.org, 8.08.2018 (15.08.2022).

Ustawa z dnia 5 sierpnia 2022 r. o zmianie niektórych ustaw w celu wzmocnienia bezpieczeństwa gazowego państwa w związku z sytuacją na rynku gazu (Dz.U. 2022, poz. 1723).

Wasiuta O., Wasiuta S., *Wojna hybrydowa Rosji przeciwko Ukrainie*, Kraków 2017.

Emisje metanu z elementów dystrybucyjnej sieci gazowej a bezpieczeństwo energetyczne państw UE w dobie wojen gazowych

Streszczenie

Poważne konsekwencje dla bezpieczeństwa energetycznego; zapewnienia bezpieczeństwa przesyłu gazu ziemnego i ograniczenia strat gazu w trakcie transportu ma skala emisji metanu z systemu gazowniczego. Dlatego istotne jest określenie skali tej emisji z poszczególnych elementów infrastruktury. Potwierdzono tezę o znacznym wpływie tych emisji na bezpieczeństwo militarne państw UE. Współczynnik emisyjności (EF) zależy od wielu innych czynników. Najlepszą metodą obliczenia EF będzie ta, która uwzględnia jak najwięcej zmiennych. Opracowano od strony teoretycznej metodę wyznaczania EF uwzględniającą wiek aparatury oraz ciśnienie, temperaturę i prędkość. Porównując funkcjonujące dotąd w literaturze metody, należy mieć na uwadze, że żadna z nich nie charakteryzuje zmiennych, które wpływają na wielkość współczynnika emisyjności. Aby móc odwzorować rzeczywistą emisję, kluczowe jest posiadanie danych opisujących analizowany element infrastruktury gazowej, wraz z jak najbardziej precyzyjnymi informacjami opisującymi warunki pracy.

Słowa kluczowe: bezpieczeństwo energetyczne, bezpieczeństwo militarne, współczynniki emisyjności metanu, dystrybucyjna sieć gazowa, gaz ziemny