UDC 620.92:662:696.2

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https://doi.org/10.32347/2409-2606.2025.55.66-78

INCREASING THE RELIABILITY OF ENERGY SUPPLY IN UKRAINE

Abstract. *The use of alternative energy sources and fuels is one of the most important areas of modern energy policy, aimed both at improving the environment and saving traditional fuel and energy resources. The meaning of the process of ecological and energy optimisation isn't the replacement of one energy source with another, but economic and industrial transformation, decarbonisation, and decentralisation. Russian aggression caused unprecedented destruction of Ukraine's fuel and energy infrastructure, which created a threat to the reliability of providing end consumers with natural gas – the main organic energy carrier capable of fully satisfying the state's own needs. Agricultural waste and solid waste landfills can, under certain conditions, be transformed from environmental pollution into renewable energy sources with the generation of biogas. Its main components are methane and carbon dioxide. Biogas utilisation will simultaneously solve environmental problems associated with "thermal" environmental pollution. The results of the analysis of the European Green Deal strategy and global pricing of carbon dioxide emissions show the need to increase tax obligations in Ukraine for greenhouse gas emissions into the atmosphere to achieve the goals of limiting the increase in global environmental temperature to 1.5-2 ˚C. The article substantiates the possibility of full or partial replacement of natural gas with biomethane obtained from the utilisation of agro-industrial waste, household waste, etc. to meet the needs of the housing and communal services of Ukraine. A comparison of the physicochemical parameters of traditional natural gas and biomethane with the requirements of current regulatory documents has been made. The areas of application of biomethane in gaseous and liquefied states have been determined. The design solutions of technological installations for autonomous gas supply systems have been substantiated.*

Keywords: *sustainable development, natural gas, carbon dioxide, methane, biogas plant, biogas, biomethane, physicochemical properties, gas supply system, gas supply reliability.*

Problem statement. The problem of rational use of energy resources, improving energy efficiency and energy and environmental security is a necessary condition for the harmonious development of any country. The changes taking place in the modern world necessitate a critical rethinking not only of many existing theories and historical views, but also a search for unique conceptual approaches to developing a new paradigm of social development. The intensive and global impact of humans on the environment throughout their existence is usually accompanied by negative consequences.

Since the beginning of systematic meteorological observations in 1958, the concentration of carbon dioxide – the most important anthropogenic greenhouse gas – in the atmosphere has increased by more than 20% and by approximately 40 % since 1750. The concentration of methane in the atmosphere has increased by 150 % compared to the pre-industrial period, and the concentration of nitrous oxide by 20 %. Of particular concern is the rate of atmospheric pollution, which is unprecedented in the last 20,000 years.

Currently, the entire Earth's climate system is changing. The main disaster is the increase in the frequency and intensity of dangerous climatic phenomena, which is confirmed by direct observations over the last decades [1-3]. This is sufficient reason to introduce measures for energy efficiency and energy conservation, the development of renewable energy sources, the modernisation of transport, etc., which are currently extremely necessary.

Analysis of recent studies and publications. The concept of sustainable development [4] is considered the most promising ideology of the 21st century and even the entire third millennium, which, with the deepening of scientific justification, will supplant all existing world view ideologies as fragmentary and incapable of ensuring the further balanced development of civilisation [5].

Sustainable development is systematically managed development. Its manageability is based on a systematic approach and modern information technologies, which allow for rapid modelling of various development scenarios, highly accurate forecasting of their outcomes, and selection of the most optimal option.

In September 2015, the UN Sustainable Development Summit was held in New York as part of the 70th session of the UN General Assembly, at which new development guidelines were approved. The outcome document, "Transforming our world: the 2030 Agenda for Sustainable Development," approved 17 global Sustainable Development Goals (SDGs) and 169 targets [6]. Among them is the seventh goal, "Affordable and Clean Energy," which aims to ensure that humanity has access to affordable, reliable, sustainable, modern, and environmentally friendly energy sources. Expanding infrastructure and technological modernisation to ensure

environmentally friendly energy in all countries is a critical task that can both stimulate growth and contribute to environmental conservation.

Ukraine, like other countries, has joined the process of ensuring sustainable development. Each global goal was reviewed and adapted to the specifics of national development. This resulted in the National Report "Sustainable Development Goals: Ukraine" [7], which provided Ukraine's own vision of the benchmarks for achieving the SDGs. It contains 86 tasks and 172 indicators for monitoring them, providing a solid foundation for further planning Ukraine's development and monitoring the status of SDG achievement. One of the main groups of tasks is ecological balance and sustainability. Economic growth will be based on a "green" economy model. Thanks to energy-efficient measures and technologies, the energy intensity of gross domestic product (GDP) will be significantly reduced. The share of environmentally friendly energy production will steadily increase, replacing traditional technologies in particular, which will significantly reduce emissions of pollutants and greenhouse gases into the atmosphere. This will contribute to improving the quality of life of the population without harming the environment and will be a significant factor in increasing life expectancy.

The purpose of the article is to address the issue of rational use of available energy resources in Ukraine, in particular natural gas, and to improve energy efficiency and environmental safety.

Presentation of the main material. In 2019, the European Green Deal (EGD) was presented to the European Parliament, which approved the move towards a climate-neutral European continent by 2050 [8, 9]. Its main goal is to transform Europe into the first climate-neutral continent by 2050, i.e., a place where all greenhouse gas emissions caused by human activity will be absorbed by ecosystems and carbon capture and storage technologies.

The annual United Nations (UN) conference on climate change, known as the Conference of the Parties or COP, brings together world leaders, country delegates, the public, and the media to reach a consensus on addressing climate change [10]. Since COP21 in 2015, the COP has focused on implementing the provisions of the Paris Agreement [11].

Given that emissions from burning coal, oil, and gas are the main cause of the climate crisis, it is striking that for the first time at COP26, the text of the final decision (cover decision) mentioned fossil fuels, and the parties agreed to accelerate "efforts to phase out uncompensated coal power and phase out inefficient fossil fuel subsidies."

Russia's full-scale war against Ukraine also has an impact on the climate, but these emissions are usually left out of countries' national reports. Over 12 months, greenhouse gas emissions related to the war are estimated at 120 million tons of CO_2

equivalent. This is roughly equivalent to the total annual emissions of a country such as Belgium. The aggressor country must be held accountable for these emissions, as well as for future emissions associated with the restoration of facilities in Ukraine that have been damaged by military action – approximately 50 million tons of CO_2 equivalent. Overall, emissions from military actions, including armed conflicts, can account for a significant share of global greenhouse gas emissions, reaching about 5.5%.

In 2021, more than 100 countries, including Ukraine, joined the Global Methane Pledge initiative, which aims to reduce methane emissions by 30% by 2030 from 2020 levels. For Ukraine, reducing methane emissions is possible through the implementation of climate measures in the oil and gas and coal sectors, agriculture, and the establishment of a waste management system.

In recent years, carbon pricing has become a key policy tool in the fight against climate change for many governments. The World Bank report "The State and Trends of Carbon Pricing in 2024" [12] provides a comprehensive overview of the current state and trends in carbon pricing instruments, which currently remain inadequate to meet the ambitious climate goals set by the Paris Agreement. To achieve meaningful change, it's necessary to improve both the coverage of carbon emissions and the level of their price. Estimated carbon prices to achieve the goal of limiting global temperature rise to 1.5 °C are \$226-385/ton CO_2, and to limit it to 2 °C are \$63-127/ton CO_2. In 2024, only seven countries, accounting for less than 1% of global greenhouse gas emissions, will have reached prices at or above the inflation-adjusted minimum of US\$63/ton CO_2. The Netherlands is one of the countries where the price of carbon dioxide emissions into the atmosphere slightly exceeds this amount. In Sweden, where the main source of electricity generation is the nuclear industry, the corresponding figure is 127, while in Norway, a powerful oil and gas producing country, it is around 90, and in Germany it is close to 50 USD/ton of CO_2. Overall, the average fee for carbon emissions in the European Union currently slightly exceeds US\$48/ton. In Ukraine, for comparison [13], tax liabilities for carbon dioxide emissions into the atmosphere in 2025 will be US\$0.77 (UAH 30)/ton of CO_2, which is one of the lowest prices in the world.

After gaining independence, Ukraine inherited a huge, "insatiable" industry in terms of energy consumption. For example, in 1991, the country used an incredible 114 billion m^3 of blue fuel, mainly of imported origin, for its own needs.

Over time, Ukraine lost or modernised a significant part of its industrial facilities, and consumption decreased significantly. Domestic production remained virtually unchanged, at around 20 billion m^3. Today, the state no longer needs as much gas as it did in 1991. At the end of 2023, Ukraine used only 19.8 billion m^3 of gas. Gross natural gas production in 2024 amounted to 19.12 billion m^3. Compared to

last year, it increased by 2.2 %. The majority of fuel is consumed by the population and heat producers in populated areas (public utility companies) – approximately 11 billion m^3. The share of industry in 2025 will be approximately 4 billion m^3, and the rest (approximately 5 billion m^3) will be used for electricity generation.

According to the provisions of the Energy Strategy [14], natural gas will remain the main energy source/fuel in Ukraine. It accounts for almost a third of all primary energy consumption. At the same time, it is the most environmentally friendly fuel compared to other traditional and alternative fuels [15].

The country has its own natural gas resources (which currently meet almost all of the economy's needs) and developed gas transportation and distribution networks in populated areas, which contribute to the priority use of blue fuel.

Table 1

Emissions into the atmosphere from the combustion of natural gas [15, 16]

Fuel	Ingredient	Emission factor [g/GJ]	Emissions		Tax liabilities		
			[ton]	[%]	[UAH/ton]	UAH	%
Natural gas, 1000 m^3	Nitrogen oxides	48,85	$1{,}73 \cdot 10^{-3}$	0,09	2574,43	4,46	7,03
	Carbon monoxide	17,0	$0{,}6 \cdot 10^{-3}$	0,03	96,99	0,06	0,1
	Carbon dioxide	55442	1,936	99,88	30,00	58,89	92,84
	Methane	1,0	$3{,}54 \cdot 10^{-5}$	0,002	145,5	0,005	0,01
	Nitrous oxide	0,1	$3{,}54 \cdot 10^{-6}$	0,0002	4216,92	0,015	0,02
		Total	1,9384	100,0	Total	63,43	100,0

However, the destruction of gas production, transportation, and distribution infrastructure, which continues and peaked in the second half of 2025, imposes significant constraints on ensuring the reliability of energy supplies to end consumers [17]. Thus, there is currently a problem with maintaining gas infrastructure in working order and providing consumers with blue fuel. One way to solve this problem is to replace natural gas in the future (completely or partially) with artificial biogas, at least during the warm season.

The potential for biogas production in Ukraine is about 10 billion m^3/year, which would reduce carbon dioxide emissions by approximately 20 million tons/year [18] and, accordingly, reduce "thermal" pollution of the environment. A biomethane plant capable of producing approximately 10 million m^3 of biomethane per year costs approximately EUR 15 million. If raw materials are purchased at EUR 40/ton (bales

of straw or corn stalks), which will provide additional income for farmers, and biomethane is sold at EUR 900/1000 m³, the return on investment for such projects becomes attractive to investors, with a profitability of 25% [18].

If we compare the physical and chemical properties of biogas with the quality requirements for natural gases established, for example, by the Gas Transmission System Code [19], then without additional purification, biogases are unsuitable for transportation through existing networks or for use in traditional gas equipment. Various methods of using such biogas are known in global practice, ranging from simple flaring directly at the point of generation without utilising the heat of combustion products to significant purification with methane content reduced to 90-95% (so-called biomethane) or the production of commercial carbon dioxide [20]. Currently, in Ukraine, given the partial destruction of the gas infrastructure, the use of biogas purified to biomethane level will prevent emergency shutdowns of gas transmission and distribution systems and ensure that end consumers are supplied with blue fuel.

Analysis of the data presented in Table 2 clearly demonstrates that the quality of biomethane is not lower than (and in some respects exceeds) that of natural gas supplied through the network. In general, the physical and chemical characteristics of these fuels meet the requirements of regulatory documents, in particular the Gas Transmission System Code [19].

Once biomethane is obtained, the question arises as to how it can be used, for example, to improve the reliability of existing gas supply systems in populated areas. The volume of fuel generated and the regularity of its supply impose conditions on how it can be transported to consumers.

First and foremost, biomethane can be supplied to rural settlements, most of which are connected to existing high-pressure gas distribution networks (0.6-1.2 MPa) – the so-called inter-settlement gas pipelines of network gas [21, 22]. The priority and main consumer is the population, which uses gas for domestic and heating needs. Large-scale industry is usually absent. Accordingly, in rural areas gasified with network natural gas, there is a significant seasonal unevenness in the consumption of blue fuel: during the warm season, there is no need to heat buildings and structures for various purposes, and during this period, gas consumption accounts for up to 15% of the total gas consumption during the heating season.

The diameters of gas distribution network pipes, the calculation and selection of gas control equipment, gas metering units, etc. are determined for maximum hourly consumption [22]. Accordingly, during the warm season, the storage capacity of the gas distribution network can be used to store fuel. If there are large agro-industrial holdings nearby, they can become enterprises for the generation of biogas with subsequent conversion into biomethane.

Table 2

Quality indicators for combustible gases

Indicator	Meaning		
	bio-methane	natural gas	requirements of the Customs Code [19]
1. Component content, %:			
- methane	98,1251	89,5161	≥90,00
- ethane	-	5,0357	≤7,00
- propane	-	1,2027	≤3,00
- butane	-	0,3518	≤2,00
- pentane	-	0,6099	≤1,00
- hexane and others	-	0,0571	
- oxygen	0,0340	0,0073	≤0,02
- nitrogen	1,0595	1,6745	≤5,00
- carbon dioxide	0,6814	2,0498	≤2,00
2. Density (20/25 °C; 0.101 MPa), kg/m³	0,6821	0,7545	0,555-0,7*
3. Heat of combustion, MJ/m^3:			
- higher	36,3990	38,26	36,20-38,30
- lower	32,8013	34,58	32,66-34,54
4. Wobbe index, MJ/m^3:			
- higher	48,3671	48,35	44,9-53,7
- lower	43,5865	-	**
5. Impurity content, g/m^3:			
- hydrogen sulfide	< 0,006	< 0,006	< 0,006
- mercaptan sulfur	< 0,02	< 0,02	< 0,02
- mechanical	<0,0005	missing	missing

Notes: * - relative gas density. ** - indicators are not normalised.

In this case, it is advisable to connect the biomethane plant to the existing gas distribution network with subsequent verification of its throughput capacity. If necessary, such a system should be reconstructed. During the warm season, with appropriate calculations, network natural gas can be completely replaced by biomethane. Natural gas is stored in underground storage facilities during this period.

If there is no network of inter-settlement gas pipelines near the biomethane plant, the best option is to transport it in a liquid state (using the property of any gaseous medium to change its aggregate state when the temperature decreases and the pressure increases – to turn into a liquid), which makes it convenient for further

storage of biomethane (the volume decreases by 600 times). Thus, an infrastructure similar to that for the transportation, storage, and use of liquefied hydrocarbon (propane-butane) gases can be created [23]. The main difference lies only in the parameters of energy carriers. In European countries, liquefied gases are the most popular compared to other types of fuel.

Such autonomous gas supply installations consist of the following structural elements: a container for storing biomethane in liquefied form (cryogenic tanks with a volume of 1 to 60 m^3, depending on the gas consumption mode), atmospheric evaporators for regasification (heated during the cold season), control and measuring instruments, control and regulation systems.

For an individual residential building near Kiev for a family of four, equipped with a domestic gas stove to meet the household needs of the residents and a water boiler for heating and hot water supply, the total maximum hourly gas consumption during the cold season will be 11 m^3/h, and during the warm season, it will be 1.5 m^3/hour. Thus, during the warm season, gas consumption will decrease by 86 %. For a settlement with 50 similar houses, this is 438 and 27.5 m^3/hour, respectively, or a 93 % reduction in consumption (taking into account the coefficients of uneven simultaneous operation of gas appliances and water boilers) [22].

The average fuel consumption of gas equipment in a individual residential building during a month in the heating/non-heating period will be 3410/174 m^3/month, respectively. During the warm period, a 3 m^3 gas tank with an evaporator capacity of at least 1.5 m^3/hour is suitable for supplying an individual house. For uninterrupted gas supply to the consumer during the non-heating period (6 months of active consumption), it is necessary to fill the tank of the specified volume at least once every 6 months, and during the heating period – at least twice a month, while increasing the evaporator capacity by installing a heater.

For a residential group in an urban-type settlement consisting of five 5-storey buildings with 65 apartments each, with instantaneous water heaters and domestic stoves installed in the kitchens, a 60 m^3 tank with an evaporator capacity of at least the total maximum hourly gas consumption of 170 m^3/hour during round-the-clock operation must be connected for autonomous gas supply. Heating needs during the cold season are met from alternative sources, such as ground source heat pumps. The tank should be filled at least 9 times during the year. The distance from such an underground gas tank facility to the nearest building must be at least 40 m [22].

For small agricultural enterprises, such as milk processing, butter and cheese production, where natural gas is used for technological needs and heating, and a G16 meter is installed to measure fuel consumption, the average monthly gas consumption during the cold/warm periods of the year is 12,580/1,520 m^3/month, respectively. For autonomous gas supply, a 5 m^3 gas storage tank should be used, which should be

filled at least four times per month during the heating period and once every two months during the warm period.

For backup gas supply in case of emergencies near the main gas control points, small gas distribution stations that supply fuel to settlements with a population of up to 5,000 people, it is necessary to install mobile units with tanks with a capacity of 40-60 m^3, equipped with evaporators with a capacity (during round-the-clock operation) of 200 m^3/hour.

Conclusions. Currently, despite full-scale aggression by the russian federation, Ukraine is implementing its strategic course – to become a full member of the European Union, which, among other things, involves decarbonising the economy (increasing energy efficiency, recycling accumulated waste, development of renewable energy sources and the circular economy, and synchronisation with the European Green Deal initiative). By declaring its commitment to the principles of sustainable development, Ukraine has recognised that the development of renewable energy sources, the reduction of consumption of traditional organic fuels, etc. are important factors in increasing energy security and reducing the anthropogenic impact of the economy on the natural environment. Replacing natural gas with biomethane obtained from the disposal of household and agricultural waste will contribute to improving the reliability of gas supply to end consumers, utilising the existing potential of the gas infrastructure, continuing its accident-free operation, etc.

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УДК 620.92:662:696.2

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https://doi.org/10.32347/2409-2606.2025.55.66-78

ПІДВИЩЕННЯ НАДІЙНОСТІ ЕНЕРГОПОСТАЧАННЯ В УКРАЇНІ

Анотація. *Використання альтернативних джерел енергії та палив є одним із найбільш важливих напрямів сучасної енергетичної політики, спрямованої як на поліпшення стану довкілля, так і на заощадження традиційних паливно-енергетичних ресурсів. Сенс процесу еколого-енергетичної оптимізації – не заміна одного джерела енергії іншим, а економічна та індустріальна трансформація, декарбонізація та децентралізація. Російська агресія спричинила безпрецедентні руйнування паливно-енергетичної інфраструктури України. Це створило загрозу надійності забезпечення кінцевих споживачів природним газом – основним органічним енергоносієм, здатним повністю задовольнити власні потреби держави. Відходи сільськогосподарського виробництва, полігони твердих побутових відходів за певних умов можна перетворити з забрудників довкілля на відновлювані джерела енергії з генеруванням біогазу. Його основними компонентами є метан і вуглекислий газ. Утилізація біогазу дозволить вирішити водночас екологічні проблеми, пов'язані з «тепловим» забрудненням довкілля. За результатами аналізу стратегії Європейського зеленого курсу та світового ціноутворення на викиди вуглекислого газу показана необхідність збільшення податкових зобов'язань в Україні за викиди парникових газів у атмосферне повітря для досягнення цілей щодо обмеження підвищення глобальної температури довкілля на 1,5-2 °С. У статті обґрунтовано можливість повної або часткової заміни природного газу біометаном, отриманим при утилізації відходів агропромислового комплексу, побутових відходів тощо для задоволення потреб житлово-комунального господарства України. Виконано порівняння фізико-хімічних показників традиційного природного газу та біометану з вимогами чинних нормативних документів. Визначено області застосування біометану в газоподібному та скрапленому*

станах. Обґрунтовано конструктивні рішення технологічних установок для систем автономного газопостачання.

Ключові слова: сталий розвиток, природний газ, діоксид вуглецю, метан, біогазова установка, біогаз, біометан, фізико-хімічні властивості, система газопостачання, надійність газопостачання.

Received/Надійшла до редакції 16.12.2025
Reviewed/Рецензована 23.12.2025
Accepted/Прийнята 24.12.2025