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Production and Use of Biogas and Biomethane from Waste for Climate Neutrality and Development of Green Economy

Inna Honcharuk[1], Dina Tokarchuk[1], Yaroslav Gontaruk[1], Tetiana Kolomiiets[1]

[1] Vinnytsia National Agrarian University, Sonyachna St. 3, 21008 Vinnytsia, Ukraine

* Corresponding author's e-mail: e050122015@gmail.com

ABSTRACT

The following article provides an analysis of the current state and potential development of biogas and biomethane production, and their significance in promoting a "green" economy. The main areas of "green" economy focus were identified as the development of alternative energy sources, an effective waste management system with recycling, organic agriculture, improved water resource and ecosystem management, sustainable ("green") transport, as well as increased energy efficiency in housing and communal sectors. It was shown that the production and use of biogas/biomethane can contribute to achieving almost all of these goals, while also ensuring climate neutrality. Analysis of European experience in using waste for biogas/biomethane production reveals a steady trend in the development of industry. This growth has become particularly relevant following the full-scale Russian invasion of Ukraine, which has also impacted the European energy market. The report assessed the Ukraine's potential for biogas/biomethane production from organic waste of various origins, highlighting its importance in addressing energy supply issues, both in times of peace as well as during the periods of martial law and energy system destruction. Successful biogas production cases in Ukraine were also analyzed, demonstrating that some enterprises are equipped to produce biogas and biomethane. The research findings were used to develop the recommendations for Ukrainian manufacturers on effective biogas production to expedite the transition towards a climate-neutral, "green" economy.

Keywords: biogas, biomethane, waste, "green" economy, energy system, potential.

INTRODUCTION

Rising levels of carbon emissions are one of the most serious problems in human history facing the modern world. Over the last decade, climate change has become an issue for many governments, companies, households, politicians, and scientific communities. The energy obtained from traditional fuels plays a significant role in contributing to global climate change, accounting for more than 75% of global emissions of greenhouse gas and approximately 90% of all carbon dioxide emissions (Osman, 2023). Renewable energy sources (RES) constitute a key strategy in mitigating the impact of climate change on society and the environment as well as changing the way energy production is perceived, which is a vital element of sustainable development in the future. The reduction of fossil fuel sources and the problem of anthropogenic climate change have a great emphasis on the sustainable development of energy: the amount of electricity produced from renewable production in the electric power industry is growing rapidly today due to society's awareness of care for the environment. However, despite this, approximately 80% of the global population resides in the countries that that primarily rely on fossil fuels import (IRENA, 2022). Currently, most countries are still dependent on fossil fuels for electricity generation due to the lack of technology, resources and conditions enabling the full use of renewable energy sources for generation of electricity. Due to their reliance on fossil fuels from abroad, roughly six billion individuals are exposed to geopolitical disruptions and emergencies (AaH et al., 2021). At the same time, it is worth noting that renewable energy sources are available in all countries, but

their potential has not yet been fully used. The International Renewable Energy Agency (IRENA) suggests that by 2050, it is both feasible and advisable for renewable sources to account for 90% of the global energy supply.

Different countries have different policies and approaches to mitigate severe climate change. The European Green Deal aims to reduce the greenhouse gas (GHG) emissions in the European Union (EU) by 55% by 2030. The Green Deal is integrated into the United Nation's Sustainable Development Goals. This directive will turn Europe into the first climate-neutral continent. To achieve this goal, rapid decarbonization of the EU economy is needed. This will require a deep transformation of the energy system to ensure an increase in the share of renewable and low-carbon energy sources. The European Commission (NGVA Europe, 2022) estimates that at least 44 billion cubic meters / 467 TWh of biogas and biomethane will be available in 2030, and Climate Gas is estimated at 95 billion cubic meters (1020 TWh) by 2050. From today's production of 22 TWh of renewable gas, Europe has a potential of 1200 TWh. Of this, 117 TWh of renewable gas is expected to be allocated as transport fuel (bio-LNG and bio-LNG) in 2030, accounting for 40% of the total gas used for mobility.

The necessity to reduce the dependence on Russian fossil fuels led the European Union to expedite its shift toward cleaner energy sources. Initially, crises such as war and pandemic of the COVID-19 were viewed as chances to advance toward a low-carbon energy transition. However, the current efforts are now concentrated on short-term, apparently quicker remedies, such as finding new supply routes for fossil fuels to improve energy security. The analysis shows that Europe's long-term energy security can be guaranteed by relying on clean energy provisions. Furthermore, the energy transition stands out as a primary driver in mitigating the consequences of disruptions in fossil fuel energy on the worldwide economy.

The war between Russia and Ukraine has the potential to expedite the European Union's efforts to boost the proportion of renewable energy in its energy balance. Theoretically renewable energy has the capacity to fulfil approximately two-thirds of the global total energy needs. Consequently, there is a compelling argument for a swift shift towards clean energy. Nevertheless, the hastened adoption of renewable energy and other strategies aimed at reducing Europe's reliance on Russian fuels encounter the challenges that necessitate innovative technologies, including energy storage solutions.

The scientific novelty of the author's approach consists in considering the prospects of production and use of both biogas and biomethane as components of the "green" economy, which have significant development potential at the meso-level (Europe), macro-level (Ukraine) and micro-level (individual enterprises). The successful Ukrainian case of Yuzefo-Mykolaivska APC LLC in the field of biogas production to reduce the cost of primary production and the application of innovative ecologically effective technologies for growing agricultural crops using digestate in the modern realities of the functioning of the Ukrainian economy is presented.

MATERIAL AND METHODS

Conceptual principles of sustainable development and "green" economy were the methodological basis of the study. A distinctive feature is the emphasis on the production and use of biogas and biomethane in the implementation of the directions of the "green" economy. The authors considered biogas technologies as a basis for the transition to a climate-neutral economy, which will allow solving both the problems of efficient waste management and the problems of greenhouse gas emissions into the atmosphere. The research was based on a systematic approach, as well as various logical bases for conducting the research.

The author's approach involved the identification of structural components of effective development of biogas/biomethane production at different levels: pan-European – at the level of Ukraine – at the micro level (best Ukrainian practices). The study involved the use of monographic, abstract-logical, statistical, graphic and tabular methods. The information base was served by the data of the European Biogas Association, the State Statistics Service of Ukraine, the Bioenergy Association of Ukraine, as well as the data of the Ukrainian biogas producer to illustrate a successful case.

RESULTS AND DISCUSSION

Excessive use of fossil fuels and non-renewable energy sources contributes to the phenomenon of global climate change through the emission of large amounts of greenhouse gases (Chen et al.,

2022). Managing the greenhouse gas emissions originating from energy generation and consumption is imperative to combating global warming. In order to meet the objectives outlined in the Paris Agreement, which involve constraining global temperature rises to 1.5–2°C by 2100, energy systems must undergo swift, ongoing innovation and promote the effective use of renewable energy in all sectors (Fawzy et al., 2020).

In the Framework Convention of the United Nations Organization in 1992, a provision was adopted on the danger of an increase in the average global temperature by 1.5°C (or even by 2°C) above the pre-industrial level. The solution to prevent rising temperatures is to develop a circular economy and move away from the current linear economy. According to the waste management hierarchy, products and materials are reused and recycled in an ideal circular economy. Their life cycle is constantly being extended, and environmental pollution and greenhouse gas emissions are decreasing. The concept of the circular economy (CE) has arisen as a strategy that has the potential to minimize resource input and waste generation, reduce negative impacts resulting from agricultural ecosystems and enhancing economic viability (Velasco-Muñoz et al., 2022).

On March 11, 2020, the European Commission adopted a special plan – the Circular Economy Action Plan – the basis of the Strategy for the Development of the "Green" Economy in the EU. Research in the framework of the development of the "green" economy covers various areas: efficient production of biofuels (Kupchuk et al., 2022; Pryshliak et al. 2021; Lohosha et al. 2023 b), waste recycling (Kaletnik et al. 2020, Honcharuk et al. 2023), organic fertilizing (Berezyuk, et al. 2021), sustainable food value chains (Varchenko et al. 2020), improving the legal regulation of the biofuel market (Kaletnik et al. 2022), etc. A systematic approach to the study of the "green" transformation of the agricultural sector is presented in the work of Kovalchuk, Kravchuk, 2019, who studied the experience of the Eastern Partnership countries.

The authors' research concerning the energy use of waste deserves special attention, since the organization of such production results in systemic "greening" of the economy. Agricultural waste is one of the wastes that could be transformed from valueless products into environmentally friendly materials. Using food waste compost in agriculture is a natural way to return nutrients to the soil. According to the European waste hierarchy, nutrient recovery from food waste through composting is a better option than incineration or disposal. Anaerobic digestion is one of the most widely used technologies introduced in the European market to treat and increase the value of organic solid waste, reducing the impact of improper waste management (Abdel-Shafy, 2018).

Biogas production from co-digestion of food waste, potash and cow dung with the attention to technical aspects of the process was investigated by Adamma et al., 2023. The investigation of Ignatowicz et al., 2023 assessed the contemporary technology of generating biogas within specific European instances, focusing on the efficiency of methane fermentation and the realized energy output. The ways to increase biogas production from sewage sludge were presented by Lima et al., 2023. Case studies of anaerobic digestion with the production of biogas and biomethane were conducted by Tavera-Ruiz et al., 2023; Ortiz-Sánchez, Cuevas-Rodriguez, 2023.

The technical and economic aspects of the production of biogas from agricultural waste on the example of Ukraine were studied by Tokarchuk et al. 2020. The effectiveness of using digestate from biogas plants in Ukraine as a component of "green" technologies was presented in the work of Lohosha et al. 2023 a. In view of the negative impact of the full-scale invasion of Russia into Ukraine both on the energy system of Ukraine (destruction of infrastructure due to shelling) and on the European energy market, production and use of biogas and biomethane in order to solve existing problems and build a "green" economy require further research.

The purpose of the study was to analyze the current state and prospects of the production and use of biomass as a component of the "green" economy at three levels: pan-European, pan-Ukrainian, and individual successful Ukrainian cases. The research objectives were as follows: (1) to investigate the directions of the "green" economy and the role of biogas technologies in their implementation, (2) to assess the current state and prospects of biogas and biomethane production in the EU and general trends in the development of the industry, (3) to analyze the potential of Ukraine in the production of biogas/biomethane, (4) to study the state of biogas production in Ukraine in general and successful cases in particular, and (5) to develop proposals for the development of production and use of biogas and

biomethane for the construction of a climate-neutral and "green" economy in Ukraine, which will facilitate the processes of European integration.

Environmental issues have become an integral part of economic discourse, characterized as a restricted resource. A recent phenomenon, the "green" economy, has emerged and is currently in a phase of active expansion. "Green" economy represents a facet of economic theory that posits the interdependence of the economy and the natural environment, recognizing the economy as an integral component of the environment itself. Its primary objective is to safeguard societal well-being by efficiently utilizing natural resources and promoting the process of reintegrating of used products back into the production loop.

The following system of directions is distinguished within "green" economy:

1. Implementation of renewable energy sources. According to environmentalists, more than half of all combustible minerals must remain unexplored to mitigate a substantial climate change on Earth.
2. Introducing of effective system of waste management. Presently, advanced countries across the globe show the daily per capita generation of solid municipal waste ranging from 1 to 3 kilograms, for example only in the United States, this amount increases by 10% every decade. In Ukraine, landfills in general occupy more than 42 thousand km^2.
3. Promotion of environmentally friendly and sustainable transportation. The United Nations Environment Programme is actively engaged in the efforts to decrease the reliance on transportation, particularly private vehicles, while maintaining overall mobility. These efforts also involve minimizing the use of artificial additives and ensuring the storage of products without contact with synthetic substances.
4. Enhancing the management of water resources. Currently, one out of every six individuals globally experiences a shortage of access to clean and safe drinking water.
5. Introducing organic farming as sustainable and environmentally-friendly agricultural practices. It contributes to the preservation of natural ecosystems, reduces the reliance on synthetic chemicals, and fosters healthier soil and biodiversity. Organic farming promotes responsible land stewardship, reduces carbon emissions, and provides consumers with nutritious, chemical-free food.

Enhancing energy efficiency within the housing and public sector. To date, thermal insulations and heating systems within residential complexes result in substantial heat dissipation.

Conservation and effective governance of ecosystems. The various range of human activities within the biosphere result in alterations, often termed an ecological crisis, with differing directions and levels of impact. Environmentally sustainable technologies, notably the generation of biogas and biomethane, hold a significant role in the advancement of "green" economy. Biogas is a gas obtained from biomass. The possible sources of biogas include: waste from animal farms, sewage or organic matter in landfills. Biogas is a mixture of methane (60–70%), CO_2 and small amounts of the other gases. Biogas can be used to generate electricity and satisfy heating or cooking needs. Biomethane is almost 100% methane produced either by biogas enrichment or by gasification of solid biomass. Enriched biomethane is the same as natural gas, so it can be transported and used in the same way. Biomethane has the advantages of natural gas while remaining carbon neutral (UABIO, 2023).

The significance of biogas and biomethane production and utilization in fostering the growth of a "green" economy can be summarized as follows:

- biogas is a renewable source of energy
- the feedstock for biogas production is organic waste of various origins, their use as energy carriers is a contribution to establishing an effective system of waste management;
- biomethane finds application in transport as a "clean" (sustainable, "green") fuel;
- a by-product of biogas production is digestate, which is an environmentally friendly fuel and is used in organic farming
- the use of biogas/biomethane for individual energy supply in housing and public economy contributes to increasing the energy efficiency.

Biogas production from organic waste of various origins (biowaste produced by the population (organic fraction of MSW), agricultural waste, wastewater) is actively developing in Europe (Fig. 1).

In 2020, the gross domestic energy consumption of biogas in the EU-27 countries was 14,716 thousand t.e. and increased more than tenfold compared to 2000 (1,376 thousand t.e.). In terms of feedstock, the contribution of landfill gas utilization to biogas production was practically

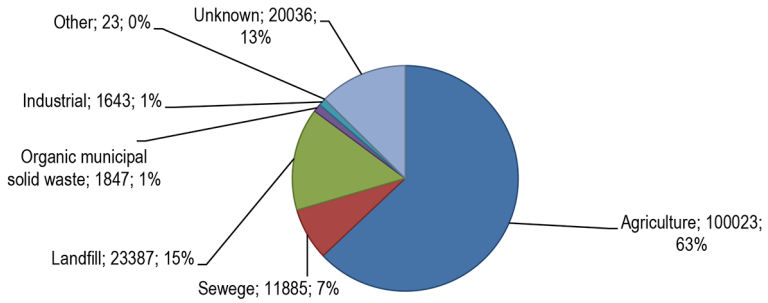

Figure 1. Biogas production per plant type in 2020 in Europe (in GWh/%); source: Calderón et al. 2022

stable during 2010–2020, the main contribution to growth came from anaerobic digestion plants.

In 2020, biogas provided 4.5% of total domestic gross gas energy consumption for the EU-27 and accounted for 10.5% of bioenergy consumption in the EU-27 (Figure 2).

Over the past decade, biogas has significantly contributed to heat and electricity generation in the EU. Nonetheless, there has been a recent inclination to expedite the production of biomethane. Biomethane is a universal energy carrier; unlike biogas, it is suitable for a wider range of sectors: transport, industry, energy and heat supply. Given the ability of using biomethane in the entire existing natural gas infrastructure (gas transport network in particular), which is not possible for biogas, this trend is expected to grow in the forthcoming years. The combined biogas and biomethane production in 2021 amounted to 196 TWh or 18.4 billion cubic meters of energy (Fig. 3).

In 2020, biomethane production in Europe was 31 TWh or 2.9 billion cubic meters; this figure increased to 37 TWh or 3.5 billion cubic meters in 2021. The production of biomethane and biogas concerning the overall gas consumption in 2021 in the sixteen largest European countries is presented in Figure 4. Thus, in Denmark, 5% of the total gas consumption is covered by biogas, 19% by methane, in Sweden by 5% and 10%, respectively. According to European Biogas Association (EBA), by 2050, 30 to 40% of the total gas consumption in Europe may be biomethane. By 2050, production may increase at least five times and exceed 1,000 TWh, and according to some estimates, nearly 1,700 TWh (Calderon et al., 2022). One

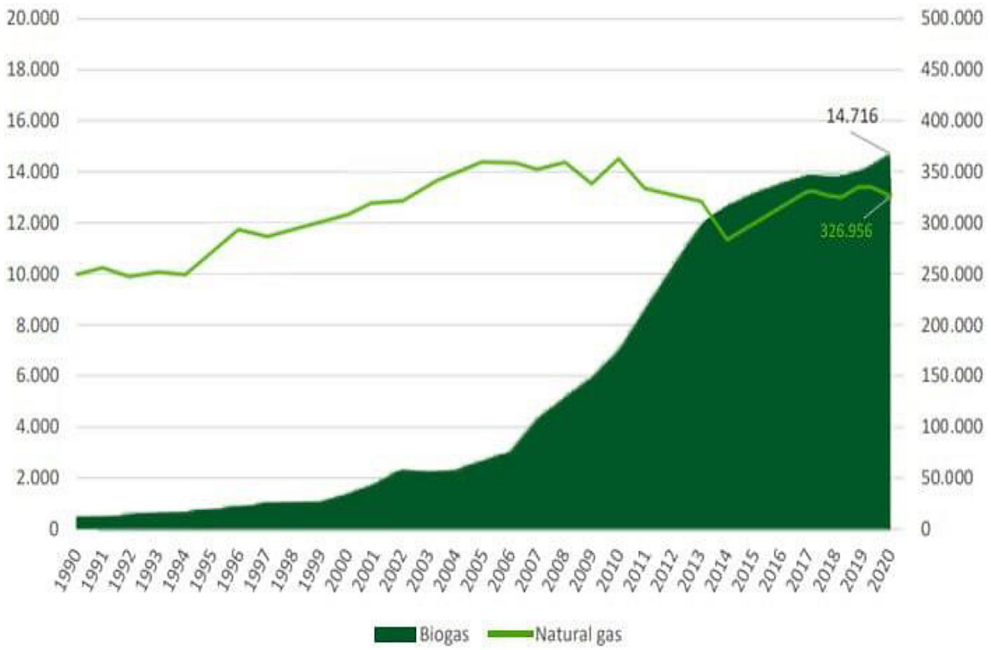

Figure 2. The changing trends in gross inland energy consumption for biogas (on the left axis) and natural gas (on the right axis) within the EU27 (in ktoe), source: Calderón et al. 2022

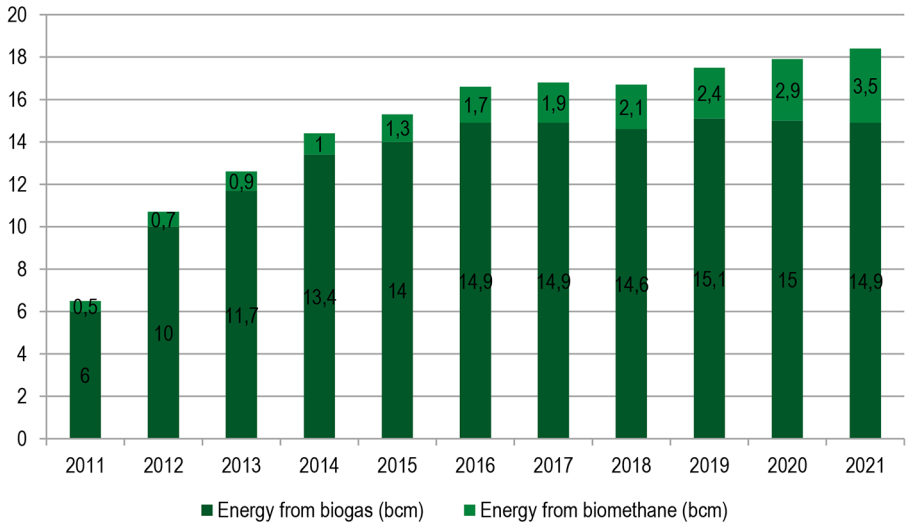

Figure 3. Biogas/biomethane production in European countries (bcm), source: EBA Statistical Report, 2022

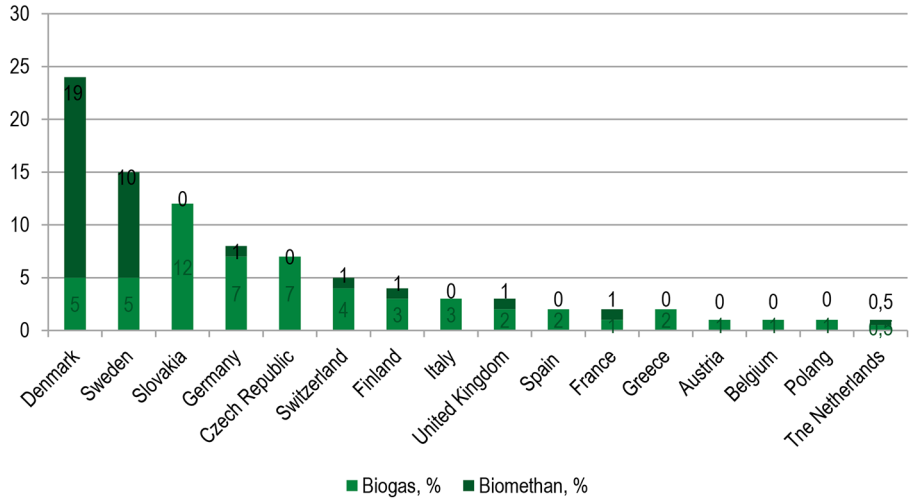

Figure 4. Biomethane and biogas production relative to total gas consumption, top 16 EU countries, 2021 (%), source: EBA Statistical Report, 2022

of the consequences of Russia's war against Ukraine was a significant rise in energy prices, in particular, for natural gas in Europe. After Russia began to use energy as a weapon, the EU announced a course to gradually eliminate the dependence on Russian fossil resources and began diversifying gas supply routes, along with more actively stimulate the use of waste for biogas and biomethane production. It is expected that European countries will accelerate the achievement of the set goals for reducing energy dependence on natural gas imports.

In early 2020, Ukraine declared its commitment to align with the EU's pursuit of climate neutrality and to join the European Green Deal initiative. Prior to the war, Ukraine had initiated extensive discussions with the European Union, endeavoring to incorporate corresponding goals and objectives into its strategic planning. However, the beginning of the full-scale invasion of Russia made its negative contribution to this process.

Since Ukraine is an energy-deficit country, as it is provided with only 70% of its own energy resources, and Russia carries out missile strikes that destroy the energy infrastructure facilities that require expensive reconstruction, the increase in production and use of biogas and biomethane as a component of "green" economy has for the country not only ecological, but also great economic importance. The production of own energy carriers for the decentralization of energy supply becomes exceptionally critical for Ukraine during the

hostilities. From the point of view of ecology, the organization of biogas and biomethane production will make it possible to solve the issues of excessive waste generation and their ineffective management. In total, 15,759 thousand tons of waste from production activity of the main branches of the agro-industrial complex and in the households of Ukraine were obtained in 2021 (Fig. 5).

Organic waste makes up the vast majority of this waste and has bioenergetic potential as a feedstock for the production of biogas/biomethane. The data of the Bioenergy Association of Ukraine shows that the potential for biomethane production is concentrated mainly in the Central, Southern and Eastern regions (Fig. 6).

When evaluating it, such sources of feedstock as: post-harvest residues, corn silage, manure and litter, wastewater from the food industry, organic fraction of MSW, and wastewater were considered. The greatest overall biomethane production potential is observed in the regions with developed agriculture: Vinnytsia, Kyiv, Cherkasy, and

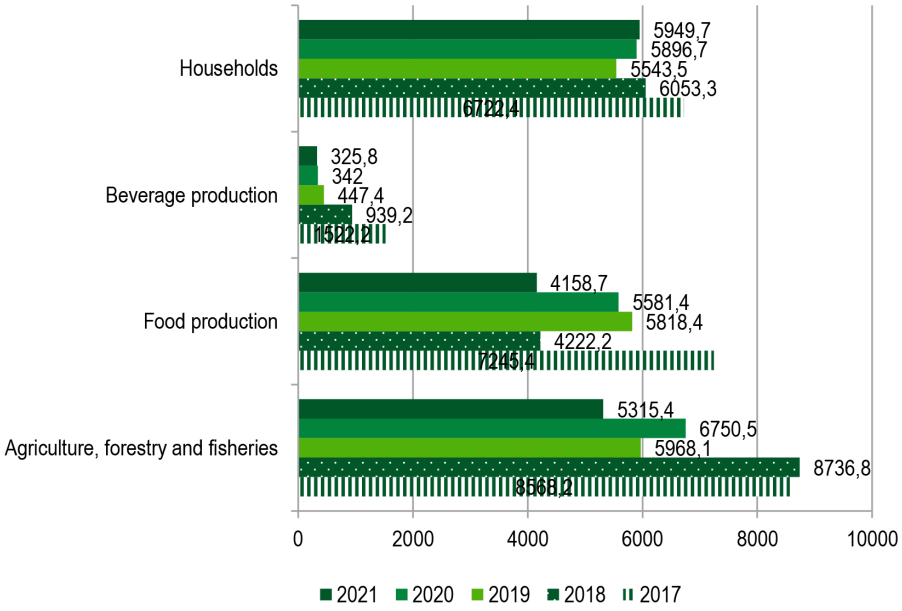

Figure 5. Waste generation from production activities of the main branches of the agricultural industry and in households of Ukraine (thousand tons).
Source: formed by the authors based on State statistics service of Ukraine, 2021

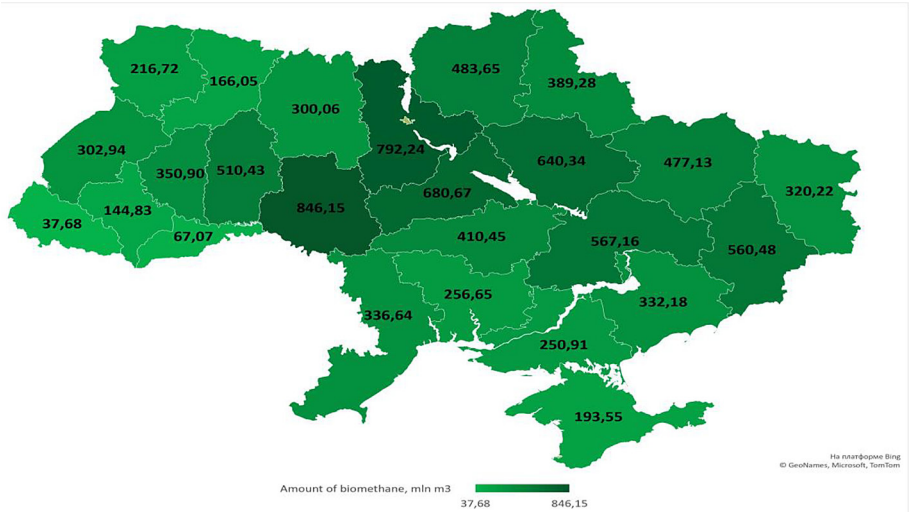

Figure 6. Biomethane production potential by regions of Ukraine, 2022 (million m^3).
Source: formed by the authors according to Bioenergy Association of Ukraine, 2023

Poltava regions. Only the potential of the organic fraction of MSW is distributed in a proportion that corresponds to the population of the regions of Ukraine (Fig. 7). The leading regions are those where the regional centers are cities with millions: Kyiv, Odesa, Dnipropetrovsk, Kharkiv.

The estimated Ukrainian potential of biomethane production is not absolute and can change either to a greater or to a lesser extent. The key factors that can affect the potential are:

- changes in volume and structure of gross production of plant and animal products in Ukraine;
- changing the area and structure of arable land use for growing food, fodder, technical and energy crops;
- population change (Bioenergy Association of Ukraine, 2023).

The main feedstock in the biomethane production potential in Ukraine is post-harvest residues and corn silage, which in the future amounts to more than 9.6 billion m^3 (Fig. 8). This indicator can provide half of the natural gas consumption from the level of 2022 and provide agriculture with organic fertilizers. On November 11th, 2021, Law of Ukraine No. 1820-IX «On Amendments

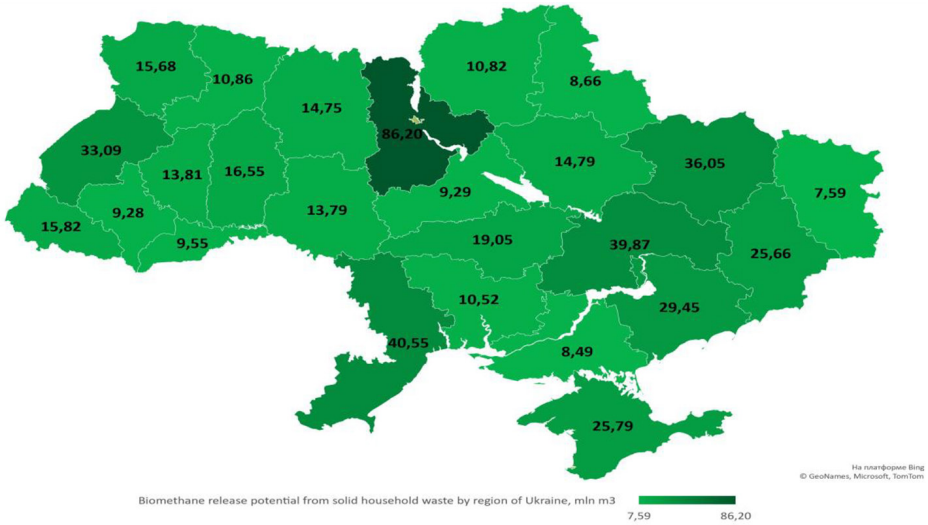

Figure 7. Biomethane potential from municipal solid waste, 2022 (million m^3).
Source: built by the authors according to Bioenergy Association of Ukraine, 2023

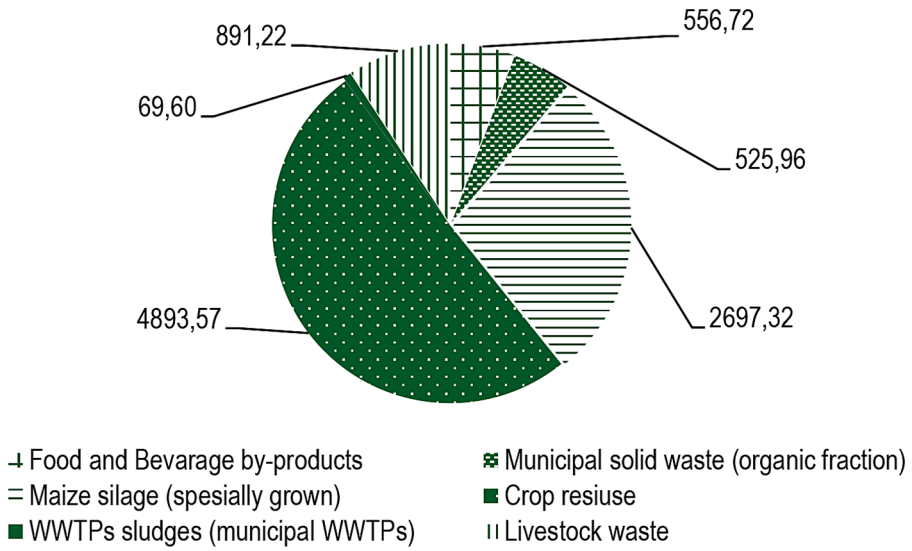

Figure 8. General structure of methane production potential in Ukraine in 2020 (mln m^3/year).
Source – formed by the authors according to Bioenergy Association of Ukraine, 2023

to Certain Laws of Ukraine Regarding the Development of Biomethane Production» entered into force. The law defines biomethane as biogas, which according to its physical and chemical characteristics meets the requirements of legal acts for natural gas for supply to the gas transportation or gas distribution system or for use as motor fuel. On July 22nd, 2022, Resolution of the Cabinet of Ministers of Ukraine No. 823 «On Approval of the Procedure for the Operation of the Biomethane Register» was approved.

When considering the problems of biogas/biomethane production and use in Ukraine, it is advisable to go to micro level in order to illustrate the successful cases that have already been implemented are actively participating in the advancement of a climate-neutral and environmentally sustainable "green" economy.

The most successful cases of biogas production in Ukraine, the capacities of which exceed 5 MW as of 2020, included:

1. Agroholding MHP – 17.5 MW (Biogas Ladyzhyn – 12 MW, Orel-Leader – 5.5 MW).
2. Theofipol Energy Company – 15.6 MW (on the basis of Theofipol Sugar Factory – 5.1 MW, at the corn silo – 10.5 MW).
3. Clear Energy – 13 MW (combines 12 biogas plants from 0.33 MW to 3.5 MW).
4. Bioenergy Complex in Globino (Astarta) – 12 MW (Globino Sugar Factory, Globino Processing Plant).
5. Korsun Eco Energo – 7.5 MW (on the basis of Selyshchansky Sugar Factory).
6. Horodishche-Pustorivska Agrarian Company – 6 MW (Hals Agro).

As of 2022, 61 enterprises of biogas production were operating in Ukraine, with 50 biogas facilities on their balance sheet, which in total ensured the obtaining of electricity of 183.6 million kWh (Fig. 9). The most powerful reactors were installed in the Khmelnytskyi, Vinnytsia,

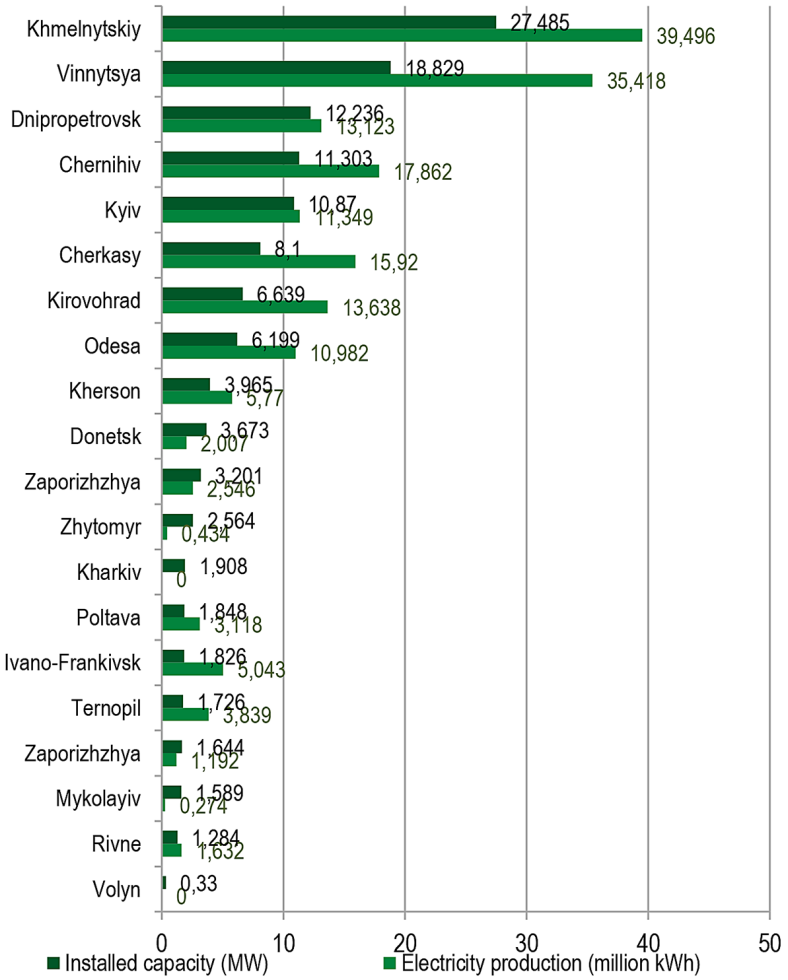

Figure 9. Capacities of biogas companies in Ukrainian regions, 2022.
Source: built by the authors according to Bioenergy Association of Ukraine, 2023

Dnipropetrovsk and Cherkasy regions. By the end of 2023, the first two biomethane plants should be operational in Ukraine. One, with a capacity of up to 3 million m^3 of fuel per year, is being launched by the Hals-agro company in the Chernihiv region, the other, with a capacity of up to 10 million cubic meters per year, is being launched by the Yuzefo-Mykolaiv biogas company in the Vinnytsia region. In November 2023, the regional gas company (RGC) has already connected the first biomethane plant to its networks. The enterprise will produce about 3 million cubic meters of gas per year, which will be consumed by about 1,500 customers – the population and industry. RGC resumed work on connecting the biomethane plant immediately after the deoccupation of Chernihiv region.

In November 2023, the regional gas company (RGC) has already connected the first biomethane plant to its networks. The enterprise will produce about 3 million cubic meters of gas per year, which will be consumed by about 1,500 customers – the population and industry. RGC resumed work on connecting the biomethane plant immediately after the deoccupation of Chernihiv region. Let us focus on the Ukrainian case of Yuzefo-Mykolaivska BGK LLC, which successfully carried out the production restructuring of the sugar factory and produced biogas and digestate with further processing into electricity and fertilizer application. Technical and economic indicators of the construction of the Yuzefo-Mykolaiv biogas plant with a capacity of MW are presented in Table 1.

Therefore, the modern capacities of the enterprise under study make it possible to produce 2,800 m^3 of biogas and 5,200 kW/h of electricity, while the consumption does not exceed 150 kW, at a load of 80%. The volume of produced digestate per year is 100,000 tons. The company is experimenting with the composition of feedstock for biogas production. Research indicates that incorporating cereal straw into the biogas production substrate is preferable to using corn straw. This choice leads to a substantially higher biogas yield per hectare of crops because of the greater concentration of dry organic feedstock (Table 2). Considering the example of Yuzefo-Mykolaivska BGK LLC, it is possible to draw general conclusions and proposals for the arrangement of biogas production at enterprises that have similar waste as raw materials: sugar beet pulp, cereal straw, and corn silage. Advantages of the implementation of the biogas facility project and the obtaining of electricity from raw materials of plant origin:

- it is environmentally friendly, as "green" technologies are implemented, there is no environmental pollution;
- it is economically beneficial, as it can provide a cheap source of energy;
- it is social because it can create new "green" jobs.

However, there are also some risks while the construction of a biogas plant:

- the project requires significant investments;
- can have a negative impact on the environment if not properly planned and implemented.

The feasibility of construction a biogas plant and generating electricity from the feedstock of sugar beet pulp, cereal straw and corn silage is quite high in general. This project can

Table 1. Technical and economic indicators of the construction of the Yuzefo-Mykolaiv biogas station (Ukraine) in 2022

Indicator	Value
Use of feedstock, t/d	380
Biogas output, m3/h	2800
Electricity production, kW/h	5200
Power consumption (installed), kW/h	150
Average annual workload, %	80
Output of liquid digestate, t/year	100000
Total volume of reactors, m3	22500
Capital investments, € mln	12,0
Income from electricity sales, €/year	4613130
Simple payback (without taxes and depreciation), (DPP), years	5
Specific investments of KGS, €/MW	2307392

Note: Source – data of Yuzefo-Mykolaivska BGK LLC.

Table 2. Calculation of biogas output from various raw materials at Yuzefo-Mykolaivska BGK LLC (Ukraine) in 2022

Indicator	Corn			Cereal straw		
	min	max	fact	min	max	fact
Productivity, t/ha	58	92	80	2	5	4.5
Dry matter content, %	25	32	27	76	92	80
Yield of dry matter, t/ha	2.00	2.56	2.16	1.52	4.60	3.60
Content of organic dry matter, %	23-28%			74-90%		
Biogas output, m^3 from 1 ton of organic dry matter	700-800			600-650		
Biomethane content, %	58-65			45-62		
Predicted biogas output, m3 from 1 ha	1400	2048	1620	912	2990	2200
Estimated output of electricity from 1 ha, kW	2520.0	3686.4	2916.0	1641.6	5382.0	3960.0
Amount of the green tariff EUR/kW (with VAT)	0.16			0.16		
Estimated gross profit EUR/ ha (incl. VAT)	403.96	590.94	467.44	263.15	862.74	634.79

Note: Source – data of Yuzefo-Mykolaivska BGK LLC.

bring significant economic, social and environmental benefits.

Summarizing the successful cases of production of biogas in Ukraine and the prospects for the advancement of the industry, the following proposals for Ukrainian companies regarding the successful implementation of biogas production projects were developed:

- guaranteeing the availability of feedstock (it is advisable to use own waste);
- ensuring that the price of feedstock is minimal (considering logistics, in particular, not transporting raw materials over long distances because of the high cost of transport services);
- choosing the optimal composition of feedstock that are loaded into the biogas reactor, based on feedstock potential of the enterprise (if necessary, contact specialists for help);
- ensuring the biogas production with using the most modern technologies: energy- and resource-saving, such that the maximum yield of biogas is guaranteed;
- using the potential of digestate to enhance the yield of cultivated crops or sell it on the market;
- with large volumes of production of biogas, purifying it to biomethane, which will make it possible to expand the scope of its application.

Ukraine has been considering the possibility of supplying biomethane to the gas distribution and gas transportation systems for a long time, this possibility is described in the Law of Ukraine "On amendments to certain laws of Ukraine regarding the development of biomethane production". In turn, a biomethane producer who wishes to supply his product to the gas transportation (GTS) or gas distribution system (GDS) must register in the biomethane register. Supplying biomethane to the gas network is possible if at least three conditions are met at the same time, namely: conformity of the quality of biomethane with the requirements of the GTS/ GDS Code and other regulatory documents; the physical possibility of the gas network to receive this volume of biomethane at the specified connection point, including the summer period; sufficient pressure of biomethane at the point of entry into the gas network.

CONCLUSIONS

As a result of the conducted research, the following conclusions can be summarized. “Green” economy is founded on alternative sources of energy and fuel, environmentally friendly production technology, clean technologies in agriculture, “green construction”, along with programs for cleaning air, water and soil from pollution, processing and disposal of waste, etc. Biogas production and use is a component of almost all areas of the “green” economy and makes a significant contribution to the construction of a climate-neutral economy.

Today, more than ever, the European Union’s excessive dependence on external energy supplies from Russia hinders European energy

security. The EU is determined to avoid Russian gas while continuing the efforts to mitigate the consequences of climate change by accelerating the production and use of renewable energy. This sector already supplies 18.4 billion cubic meters of renewable gas (biogas, biomethane) to Europe. The trend towards faster development of the field of biomethane production than biogas is taking place. By 2050, it can provide up to 167 billion cubic meters, covering 35–62% of gas demand in 2050. Ukraine has a significant potential for the biogas and biomethane production from waste of various origins. Agricultural waste, which can become a feedstock for production of biogas, is mainly represented by post-harvest residues, bird droppings and animal manure; in general, the potential yield of biogas/biomethane from the corresponding raw materials will be 9.6 billion m^3, which will provide more than 50 percent of natural gas consumption in Ukraine.

In Ukraine, there are successful cases of biogas production using waste of various origins: household, agricultural waste, however, a significant part of this potential remains untapped. The two enterprises plan to organize the production of biomethane on the basis of existing biogas production capacities already this year, following the European example. A detailed analysis of one of them – Yuzefo-Mykolaivska BGK LLC – became the basis for developing proposals for future Ukrainian biogas producers. For the successful implementation of the practice of efficient biogas production, derived from the experience of Yuzefo-Mykolaivska BGK LLC (Ukraine), it is advisable to adapt this practice at most sugar factories through production restructuring. For the effective organization of biogas and biomethane production in Ukraine, producers are suggested to focus on the availability, cost and optimal composition of feedstock, together with using efficient technologies of biofuel production.

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