SYSTEM SAFETY: HUMAN - TECHNICAL FACILITY – ENVIRONMENT
6(1), 2024, pp. 154-166

PROSPECTS FOR BIOGAS PLANT IMPLEMENTATION IN THE UNIFIED ENERGY SYSTEM

DOI: 10.2478/czoto-2024-0017
Received: 29/11/2024
Accepted: 20/12/2024

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Abstract: The study suggests using biogas plants as highly flexible energy sources. A critical step in deciding on their use involves predictive insights on the energy-efficiency metrics of the proposed biogas-based energy supply system compared to the current centralized model. Energy efficiency metrics were assessed through an analysis of energy balances, built using average statistical data on losses and energy consumption at biogas facilities. This approach is recommended for use in the early stages of defining technical requirements, enabling informed decisions about constructing or upgrading existing energy systems. Implementing biogas plants (BGP) as local power sources proves economically competitive when compared to centralized systems like thermal power plants (TPP) and boiler facilities. BGPs share a similar structure with these systems but operate with fewer areas needed for operations. Integrating BGPs can help reduce national dependence on imported energy, correct imbalances in the energy system due to their flexibility, and lower the cost of energy – whether electrical, thermal, or chemical

(such as fertilizers) – for specific manufacturing enterprises. Data on the energy balance reveals that 73% of BGP energy resources are concentrated in biomass.
Keywords: biogas plants, combined energy supply system, energy balance, renewable sources, energy efficiency

1. INTRODUCTION

Amid rapid growth in renewable energy generation – primarily from wind turbines (WPPs) and solar power plants (SPPs) – the need to balance their variable power output is increasing to ensure operational stability (Qawaqzeh, et al., 2022, Syromyatnikov, et al., 2021, Cierlecki et al. 2024, Bień and Bień, 2024). A key characteristic of both WPPs (Trunova, et al., 2020, Rubanenko, et al., 2020) and SPPs is their dependence on weather conditions, which results in inconsistent energy production (Chub, et al., 2019, Savchenko, et al., 2021). Research suggests that the most effective universal approach for balancing this variability is to build flexibility into the energy system, enabling adjustments in electricity production or consumption in response to fluctuations from renewable energy sources (RES). When large-scale renewable sources are integrated into power systems, challenges arise in maintaining both static and dynamic stability of operating modes (Pimentel, et al., 2018, Androniceanu et al., 2020, Halko, et al., 2021, Tymchuk and Miroshnyk, 2015, Ulewicz et al. 2021). For instance, if RES contributes more than 2% to the overall energy mix, existing grids often lack the technical capability to handle peaks in generation and flow, necessitating infrastructural upgrades and network modernization (Kolcun et al. 2019, Belik, et al., 2023, Qawaqzeh, et al., 2020, Roncero-Clemente, et al., 2017, Karaiev, et al., 2021). RES also indirectly impact the amortization properties of power systems, leading to stability issues, reduced stability margins (such as shorter critical disconnection times during short circuits), and deterioration in transient process quality (e.g., increased generator rotor angle deviations and reduced damping) (Halko, et al., 2021, Viacheslav, et al., 2019, Qawaqzeh, et al., 2023, Olatomiwa, et al., 2015, Redko, et al., 2023).

Today, for instance, the development of wind power plants involves integrating a large number of wind turbines into the energy systems of numerous countries worldwide (Komada, et al., 2019). For this to be effective, the centralized energy supply system must become "flexible," necessitating the resolution of various significant scientific and technical challenges. One potential solution to this issue is the use of biogas plants (BGP) as a backup power source for wind (WPP) and solar power plants (SPP). The produced biogas, which can be stored long-term, may then be utilized as needed by consumers. Therefore, the objective of this work is to conduct initial research on the feasibility of incorporating BGP into the centralized energy supply system and to justify its competitiveness (Aslani, et al., 2014, Qawaqzeh, et al., 2020, Geletukha, et al., 2017).

The prospects for implementing biogas into the gas system are very promising, also in the context of effective use of a renewable energy source in high-quality but energy-intensive production of castings in the automotive industry (Czerwińska et al., 2020; Markovic et al., 2021) requiring support from industrial statistics (Dwornicka and Pietraszek, 2018). A particularly useful solution may be the combination of boiler rooms (Fialko et al., 2019) powered by easy-to-store biogas with efficient but unstable photovoltaic installations (Bogdanowicz et al., 2023), which could be located in reclaimed contaminated areas (Radzymińska-Lenarcik and Ulewicz, 2015; Skrzypczak-Pietraszek and Pietraszek, 2024). Unfortunately, generally speaking, in the components of energy installations powered by biofuels, it is necessary to counteract very strong corrosive degradation (Lipiński, 2010; Scendo et al., 2013; Lipiński and Szabracki, 2015). Krynke and Klimecka-Tatar (2022) emphasize that the use of computer simulation techniques provides invaluable opportunities for optimizing production management processes in complex systems, which is particularly relevant for addressing the challenges of balancing renewable energy sources.

2. PROSPECTS FOR THE DEVELOPMENT OF BIOENERGY IN EUROPEAN UNION

The current policy of the European Union (EU) is aimed at establishing sustainable economic development, which includes social, economic and environmental components (Ingaldi and Ulewicz, 2024). The energy field is the key to establishing this concept. The idea of protecting the environment and preserving the climate occupies a leading place in European energy. Increasing the number of renewable energy sources that confirm the security of the energy system, minimizing the use of coal in electricity production and reducing harmful emissions are among the main measures in the process of sustainable energy development. This principle is of great importance for the economy and social welfare of EU member states.

The combination of these principles is embodied in the European Green Deal. In December 2019, the European Commission introduced a roadmap of measures aimed at transitioning to a climate-neutral economy. A primary objective of this strategy is to achieve zero carbon dioxide emissions by 2050. This requires optimizing the fuel and energy sector and reducing dependence on imported raw materials. Beyond energy, reforms should also address the following sectors: transport, agriculture, construction, as well as the food and chemical industries. The key elements of this strategy are illustrated in Fig. 1 (Karaiev, et al., 2021, Miroshnuk, and Tymchuk, 2013).

Fig. 1. Main objectives of the European Green Deal

Source: EU, 2019

EU member states are required to implement green policies, but this strategy presents a real challenge for some. Despite ambitious goals, the national energy strategies of EU countries remain uncoordinated. Most European nations lack sufficient natural resources

and cannot quickly reduce their dependence on energy imports. Economic development levels also vary significantly across Europe. Furthermore, some countries rely heavily on their own fossil fuels, such as coal, making a forced shift away from these resources particularly challenging in the transition to green energy. Additional obstacles include outdated energy infrastructure, inconsistent power generation, and dependency on renewable sources. Achieving these targets is difficult even for highly developed economies. Under the Treaty on the Functioning of the EU, each member state is independently responsible for developing and implementing its own energy strategy.
EU countries have significant experience in generating energy from biomass processing. By the end of 2021, Europe had 1,067 biomethane plants, an increase of 184 compared to 2020, making 2021 the largest year for growth in biomethane installations. According to the European Biogas Association (EBA), by September 2022, 155 new biomethane plants had already been launched (Fig. 2).

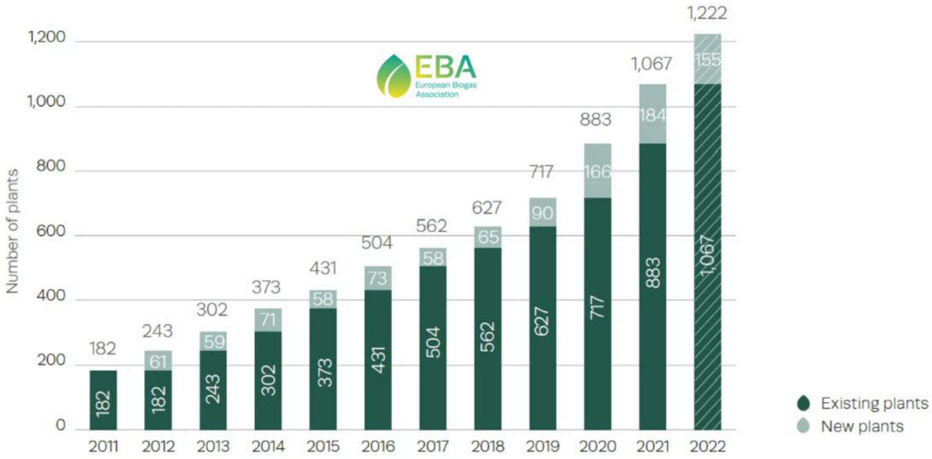

Fig. 2. Number of biomethane plants in Europe
Source: The European Green Deal, 2019

The production of biogas and biomethane in Europe in 2022 amounted to 21 billion cubic meters, which is 6% of the consumption of natural gas in the EU. Biomethane production alone has increased to 4.2 billion cubic meters in 2022, (Fig. 3).

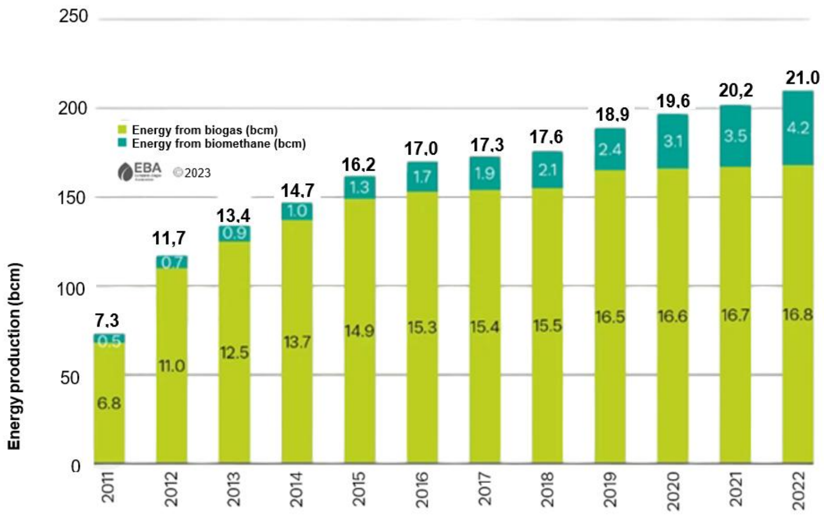

Fig. 3. Aggregate production of biogas and biomethane
Source: The European Green Deal, 2019

Biomethane production has continued to grow, unlike biogas production. The largest annual increase occurred in 2021, with an addition of 6.1 TWh, or 0.6 billion m^3. The total biomethane production in 2021 was 37 TWh, equivalent to 3.5 billion m^3.
Currently, 58% of biomethane plants in Europe are connected to the gas distribution network, while 19% are linked to the gas transmission network. Additionally, 9% of European biomethane plants operate independently, and information on the remaining 14% is not available in the EVA database (Fig. 4).

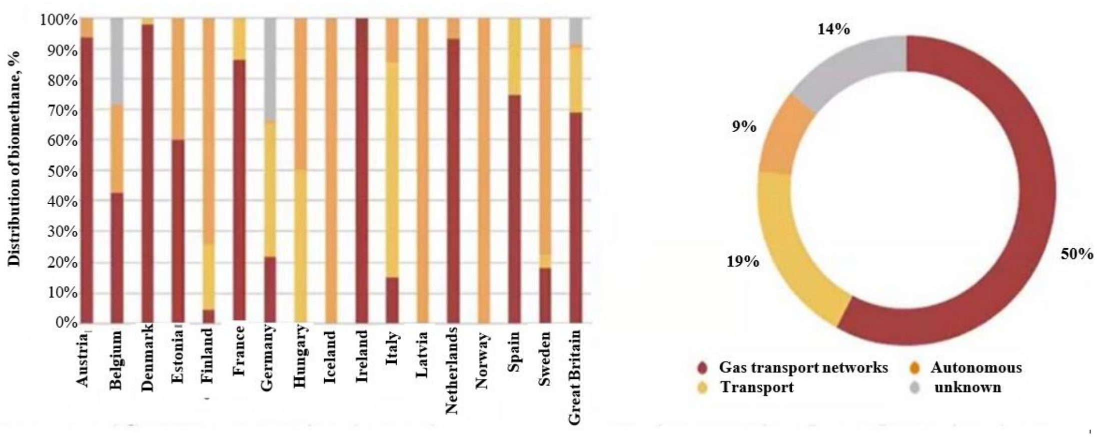

Fig. 4. Connection to natural gas networks
Source: Qawaqzeh, M. et al., 2022

In France, Netherlands, Spain, Austria, Denmark and the United Kingdom, biomethane plants are primarily connected to distribution gas networks. In Italy, however, large biomethane plants are predominantly built to connect with transport gas networks (TGN). The TGN also plays a major role in Germany. In Scandinavian countries, biomethane plants mostly operate in standalone mode. Across all regions, the share of arable land designated for cover crops is set at 20%. The feasibility of increasing coverage for additional crops on each plot has been assessed.
This approach projects that, on average, 10% of the theoretical potential will be achievable by 2030 (with 65% for Italy, 20% for France and Germany) and 100% by 2050 (Fig. 5).

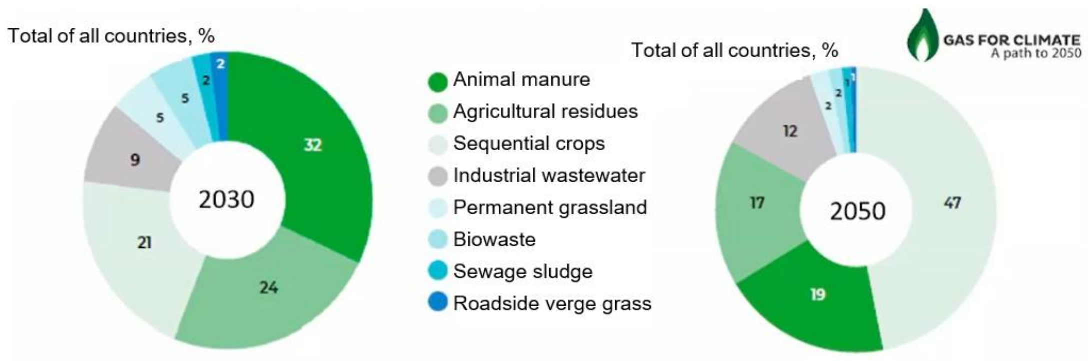

Fig. 5. Structure of biomethane production potential in Europe
Source: The European Green Deal, 2019

The potential for biomethane production includes:

- roadside grass: This refers to grass collected during roadside maintenance, which is processed as waste material for biogas.
- permanent meadows: These are areas of long-term pastures. Germany, for instance, has a significant area of such meadows that aren't required for animal feed, with around 2 billion m³ used annually for biogas production.

In Ukraine, the potential for biogas (biomethane) production is estimated at approximately 10 billion m³ per year (Table 1). Plans are in place to increase biogas output through cover crops, aiming to reach over 20 billion m³ per year by 2050. The resulting increase in biomethane volumes will significantly enhance Ukraine's energy independence, making the development of this industry a promising opportunity.

Table 1. Biogas/biomethane production potential in Ukraine in 2021* and 2050

Biogas/Biomethane, billion m^3/year	**2021**	**2050**
Biogas from animal waste	0.83	0.9
Biogas from harvest residues of agricultural crops	4.36	5.2
Biogas from by-products of the food processing industry	0.66	0.7
Biogas from solid household waste	0.53	0.5
Biogas 3 sewage sludge (municipal treatment plants)	0.07	0.1
Energy plants: biogas from corn silage (from 1 million hectares)	3.00	3.8
Biogas from cover crops (20% of arable land)	0.00	9.8
Biogas from BM obtained by thermal gasification (10%)	0.00	1.0
Biogas/Biomethan, total	**9.45**	**21.8**

* the assessment was made on the basis of technically available raw materials

But the interest of consumers in the mass use of BGP in most cases is possible only if they are competitive in comparison, for example, with a centralized energy supply system (SS). We will consider the evaluation of the effectiveness of BGP implementation based on the analysis of their energy balance.

3. ENERGY BALANCE OF THE BIOENERGY COMPLEX

The energy balance is a crucial element in conducting energy audits, which encompass installations, processes, and technologies related to the production and consumption of energy. Through the analysis of energy balances, it is possible to determine energy consumption levels, losses, and costs, forming a valuable foundation for the design and optimal management of energy systems. The primary functions of energy balances include:

- analysis of receipts, losses, and costs for various types of energy;
- assessment of the efficiency of energy conversion processes.

The energy balance, understood as a set of interconnected indicators that reflect quantitative relationships between the acquisition and utilization of energy resources, serves as the main document for a comprehensive analysis of resource use and the planning of actions to improve energy efficiency.

In practice, various types of energy balances can be developed based on different sources of data, including technical documentation, operational data, and experimental research results. The most commonly used types of energy balances include:

- synthetic balance: shows the distribution of acquired, supplied, and produced energy resources within the energy supply unit;
- actual balance: enables the assessment of energy efficiency indicators of installations and equipment in comparison with their design specifications;

- analytical balance: presents the nature of changes in energy resource consumption, breaking down their useful value and losses;
- normative balance: takes into account the possibilities for rationalizing energy use and minimizing losses;
- prospective balance: encompasses long-term production development forecasts extending to five years or more.

Key sources of information used in creating an energy balance in enterprises include statistical reports, energy passports, cost standards, design and operational documentation, as well as energy consumption data over various periods (daily, seasonal, annual) and experimental studies with their mathematical analysis.

Energy balances can be presented in the form of charts (e.g., pie and step charts), tables, and graphs, which enable, among other things, visualization of energy resource consumption, comparison of components in both dimensional and dimensionless units, and tracking of consumption dynamics.

In an energy supply system based on biogas plants (BGP), it is essential to account for all types of generated energy, as well as losses and costs at each stage of energy conversion. Based on the analysis of energy balances for agricultural facilities, technical and organizational actions are formulated to achieve energy resource savings.

For BGP, a deterministic approach has been applied to create a synthetic energy balance, with technical and economic indicators of BGP used as input parameters, as outlined in Table 2.

Table 2. Technical and economic indicators of biogas plants

Indicator	**Kobos- I**	**Biogas 301**	**UkrNII Agro-project**	**Enbom Finland**	**Zorg Biogas Ukraine**	**LLC Ekoten**
Reactor volume, m^3	225	300	150	120	3x2400 + 1000	100
Fermentation	40	40	40	35-40	35-40	35-40
Daily biogas output,	500	350	178	140	9000	50
Daily biogas	50	30.9	16.5	7	400	2.4
Biogas output from 1t of biomass, m^3	2	1.1	1.2	1.46	1.4	1.4
Biomass turnover	5	10	9	14	15	15
Biomass moisture at the output, %	96.2	99.5	93.7	95.2	94	94
Commodity biogas,	59.3	55.2	52.1	60	80	80
Capacity, kWh/day	100.2	151	24.5	-	22000	50
Number of personnel	4	4	4	4	10	2
Purpose	**biogas, fertilizers**	**farm waste disinfection**	**biogas, fertilizers**	**biogas, fertilizers**	**biogas, fertilizers**	**biogas, fertilizers**

Source: own study

The potential for biogas production depends on the type of raw materials used, the design of the biogas plant, the quality of thermal insulation and the implementation of the technological process conditions, the materials and design of their main elements, as well as on the climatic conditions in the areas of their location. At the same time, the average

consumption of energy produced to ensure the operation of the biogas plant in the climatic latitudes of Ukraine is on average: thermal - 20 - 50%, and, additionally, electrical - 6 - 9% of the total energy produced.
In the future, to obtain generalized results of the energy balance, we will evaluate their indicators in relative values based on the above experimental data.
In this way, the generalized energy balance of BGP will be presented in the form of a dependence:

$$E_{ow} + E_e + E_t = E_f + E_{bg} + \Sigma\Delta E \quad (1)$$

where E_{ow} - amount of biological energy present in organic waste; E_e - denotes the electricity consumed to meet the internal needs of the biogas plant (such as mixing, grinding, loading, unloading, and moistening of organic waste, as well as the operation of compressor units); E_t - the thermal energy required to maintain the plant's thermal regime; E_f - indicates the biological energy retained in the fertilizers produced; E_{bg} - the energy potential of the biogas generated; $\Sigma\Delta E$ - total losses of electrical and thermal energy across all production stages.
Based on references (Krasnozhon, et al., 2020, Dudnikov, et al., 2020, Korchevoi, et al., 2009), Figure 6 illustrates the generalized energy balance of the biogas plant (BGP) for the production of biogas, electricity, thermal energy, and fertilizers (Sadchikov, 2016).

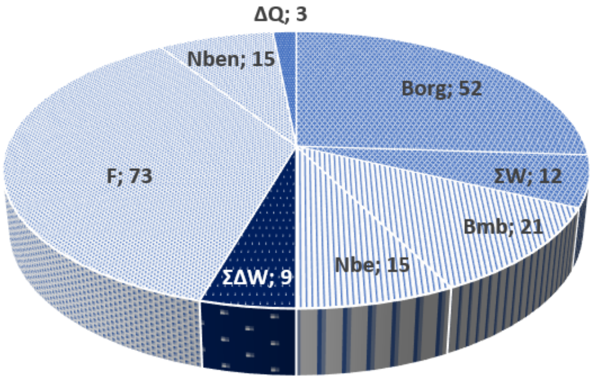

Fig. 6. Generalized energy balance of BGP

The structure of the generalized energy balance for a Biogas Production Plant (BGP) includes the following components:
B_{org} - energy from organic waste, %.
ΣW - total thermal and electrical energy costs necessary to support the BGP's technological process, %.
B_{mb} - energy from manure as a result of acid- and methane-forming bacteria activity, %.
N_{be} - biogas energy generated through the action of methane-forming bacteria, which can be used in the technological process and converted into electrical or thermal energy, %.
$\Sigma\Delta W$ - total energy losses and costs (both electrical and thermal) associated with BGP operations, %.
F - energy contained in the fertilizer, %.
N_{ben} - volumes of biogas from the BGP that have been utilized per customer request.
ΔQ - heat energy losses incurred during the fertilizer unloading process, %.
We compare energy supply systems from BGP and SS, considering activities in spheres (Sadchikov, 2016, Al_Issa, et al., 2021, Krasnozhon, et al., 2016). It was found that both systems have a similar structure: A - preparation of organic waste for use (production or

extraction, transportation, preparation for use, loading, etc.); *B* - production from organic steam waste, with BGP producing biogas and organic fertilizers and facilitating their distribution; *C* - conversion of biogas energy (steam) into mechanical, then electrical or thermal energy; *D* - distribution of thermal and electrical energy to consumers; *E* - conversion of thermal or electrical energy into other types. Analysis of the overall energy balance shows that 73% of BGP's energy resources are contained in fertilizers ($F = B_{jrg} + B_{mb}$). The total energy losses and costs for ensuring the technological process are 12% ($\Sigma W = \Sigma \Delta W + \Delta Q$). When BGP is supplied with energy from other renewable sources, for example from WPS and SPP, the amount of commercial biogas energy corresponds to 15% of the total, i.e. in this case $N_{be} = N_{ben}$.

The generalized energy balance of the biogas plant (BGP) encompasses all operational sectors (*A*, *B*, *C*, *D*, *E*) of the centralized energy supply system (Szafraniec, et al., 2021, Mykolyuk, et al., 2018), although here the power capacity, transmission distance, and number of energy transformations are significantly lower.

Based on the generalized energy balance of the BGP (Fig. 6), the formula (1), and an analysis of the literature (Dudnikov, et al., 2020, Korchevoi, et al., 2009), we determine the values of the energy utilization coefficient (EUC) as follows:

- For sector "*A*" when a gravity system for manure removal is established, the EUC is approximately 1;
- For sector "*B*" the EUC is 0.91;
- For sector "*C*" which includes a diesel power plant, the EUC is 0.16;
- When the distance to consumers in sector "D" is minimal, the EUC approaches 1;
- For sector "*E*" which involves conversion of the produced energy to another type, we assume an average EUC of 0.8.

The quantitative average estimate for the EUC (excluding fertilizer energy) in the electricity production process at the BGP is thus expected to fall within the range:

$$K_{BGP\mathrm{e}} = K_A \cdot K_B \cdot K_C \cdot K_D \cdot K_E = 0{,}115. \quad (2)$$

Based on the conditions of thermal energy production:

$$K_{BGPt} = K_A \cdot K_B \cdot K_C \cdot K_D \cdot K_E = 0{,}58. \quad (3)$$

Based on the data (Redko, et al., 2023, Belik, M. and Rubanenko, O. 2023), a quantitative assessment of the EPS of centralized power supply systems from thermal power plants was carried out

$$K_{\mathrm{CHP}} = K_A \cdot K_B \cdot K_C \cdot K_D \cdot K_E = 0{,}29, \quad (4)$$

and thermal power plants (CHP):

$$K_{\mathrm{TPP}} = K_A \cdot K_B \cdot K_C \cdot K_D \cdot K_E = 0{,}12. \quad (5)$$

Based on the analysis of the obtained EUR values (2-5), it can be concluded that energy production (both thermal and electrical) by local systems based on BGP is comparable to centralized thermal power plants and boiler facilities. However, for remote consumers and agricultural enterprises, using BGP will enhance the reliability and independence of energy supply and contribute to environmental improvements.

3. CONCLUSION

The conducted studies highlight the significant role of energy sector reform, incorporating the development of renewable energy sources, in shaping the future energy landscape and improving energy efficiency. Specifically, the implementation of biogas plants (BGP) as a local energy source represents a competitive alternative to traditional, centralized energy systems such as thermal power plants (TPP). Biogas plants are characterized by their high flexibility and lower infrastructure requirements, which results in lower operational costs compared to other energy sources. In the context of sustainable energy development, biogas plants provide an effective solution that promotes increased innovation and competitiveness within the economy.

The economic viability of implementing biogas plants in the energy sector is evident, especially when compared to larger energy units such as thermal power plants. Due to their lower infrastructure requirements and greater flexibility, biogas plants can be an attractive alternative, particularly in regions facing limited access to traditional energy sources. Moreover, biogas plants have the potential to reduce a country's reliance on imported energy, contributing to the stabilization of the national energy system and enhancing energy security.

Furthermore, the introduction of biogas plants in the industrial sector can bring measurable economic benefits. Manufacturing enterprises can reduce costs for electricity, thermal energy, and chemical energy in the form of fertilizers by utilizing local energy sources. Such solutions also enable more efficient energy management, which helps lower operational costs and improve business profitability.

Energy balance analyses indicate that 73% of the energy resources used in biogas plants come from biomass, highlighting the importance of biomass as a renewable energy source. As such, biogas plants have the potential to strengthen the role of renewable energy sources in the energy system.

REFERENCES

Al_Issa, H.A., Qawaqzeh, M., Khasawneh, A., Buinyi, R., Bezruchko, V., Miroshnyk, O., 2021. *Correct Cross-Section of Cable Screen in a Medium Voltage Collector Network with Isolated Neutral of a Wind Power Plant*, Energies, 14, 3026, DOI: 10.3390/en14113026

Androniceanu, A. M., Georgescu, I., Dobrin, C., Dragulanescu, I. V. (2020). *Multifactorial components analysis of the renewable energy sector in the OECD countries and managerial implications*. Polish Journal of Management Studies, 22(2), 36-49. DOI: 10.17512/pjms.2020.22.2.03

Aslani, A., Helo P., Naaranoia, M., 2014. The role of renewable energy policy in energy dependence in Finland: a system dynamics approach, Applied energy, 113, 758-765. DOI: 10.1016/j.apenergy.2013.08.015

Belik, M., Rubanenko, O. 2023. *Implementation of Digital Twin for Increasing Efficiency of Renewable Energy Sources*. Energies, 16, 4787. DOI: 10.3390/en16124787

Belik, M., Rubanenko, O., Rubanenko, O., 2023. *Optimization of PV-system design for household*, 2023 IEEE 4th KhPI Week on Advanced Technology (KhPIWeek), Kharkiv, Ukraine, 1-6, DOI: 10.1109/KhPIWeek61412.2023.10312893

Bień, J., Bień, B. 2024. Rapid assessment of solar PV micro-system energy generation in Poland based on freely pvlib-python library. Production Engineering Archives, (30)3, 326-332. DOI: 10.30657/pea.2024.30.32

Bogdanowicz, K.A., et al., 2023. *A new look at imines and their mixture with PC71BM for organic, flexible photovoltaics*. Scientific Reports, 13, art. 13240. DOI: 10.1038/s41598-023-38978-x

Chub, A., Vinnikov, D., Stepenko, S., Liivik, E., Blaabjerg, F., 2019. *Photovoltaic Energy Yield Improvement in Two-Stage Solar Microinverters*, Energies, 12, 3774, DOI: 10.3390/en12193774

Cierlicki, T., Zawada, M., Piasecka, I., Leda, P. 2024. *Management the efficiency of a photovoltaic installation*. Production Engineering Archives, (30)3, 296-302. DOI: 10.30657/pea.2024.30.29

Czerwińska, K., Dwornicka, R., Pacana, A., 2020. *Improving quality control of siluminial castings used in the automotive industry*. METAL 2020 - 29th Int. Conf. Metall. Mater., 1382-1387. DOI: 10.37904/metal.2020.3661

Dudnikov, S., Miroshnyk, O., Kovalishyn, S., Ptashnyk, V., Mudryk, K., 2020. *Methodological aspects of evaluating the efficiency of local energy systems with renewable sources*, Renewable energy sources: 6th International Conference, Krynytsia, 12-14 June 2019, Krynytsia, 154, DOI: 10.1051/e3sconf/202015407013

Dwornicka, R., Pietraszek, J., 2018. *The outline of the expert system for the design of experiment*. Production Engineering, 20, 43-48. DOI: 10.30657/pea.2018.20.09

Fialko, N., et al., 2019. *Environmental aspects of heat recovery systems of boiler plants*. E3S Web of Conf., 10010, art. 00015. DOI: 10.1051/e3sconf/201910000015

Geletukha, G., Zhelezna, T., Bashtovyi, A., 2017. *Energy and ecology, analysis of technology for production capacity from biomass*, Part 1 Thermophysics and Thermal Power Engineering, 39(1), DOI: 10.31472/ and he.1.2017.09

Halko, S., Suprun O., Miroshnyk, O., 2021. *Influence of Temperature on Energy Performance Indicators of Hybrid Solar Panels Using Cylindrical Cogeneration Photovoltaic Modules*, 2021 IEEE 2nd KhPI Week on Advanced Technology (KhPIWeek), Kharkiv, Ukraine, 132-136, DOI: 10.1109/KhPIWeek53812.2021.9569975

Ingaldi, M., Ulewicz, R. 2024. The Business Model of a Circular Economy in the Innovation and Improvement of Metal Processing. Sustainability 2024, 16, 5513. DOI: 10.3390/su16135513

Karaiev, O., Bondarenko, L., Halko, S., Miroshnyk, O., Vershkov, O., Karaieva, T., Shchur, T., Findura, P., Prístavka, M., 2021. Mathematical Modelling of the Fruit-Stone Culture Seeds Calibration Process Using Flat Sieves, Acta Technologica Agriculturae, Slovak University of Agriculture in Nitra, 24(3), 119-123. DOI: 10.2478/ata-2021-0020

Kolcun, M., Rusek, K., Valentiny, T. (2019). *Power plants of Poland and Slovakia in aspect of sustainable development*. Polish Journal of Management Studies, 20(2), 300-310. DOI: 10.17512/pjms.2019.20.2.25

Komada, P., Trunova, I., Miroshnyk, O., Savchenko, O., Shchur, T. 2019. *The incentive scheme for maintaining or improving power supply quality*, Przeglad Elektrotechniczny, 95 (5), 79-82. DOI: 10.15199/48.2019.05.20

Korchevoi, Y. et al., *State and prospects of solid fuel energy development of Ukraine*, 2009. Heat energy – new challenges of the time, Lviv: Ukrainian Technologies Fund, 29-35

Krasnozhon, A. V., Buinyi, R. O., Dihtyaruk, I. V., Kvytsynskyi, A. O. 2020. *The investigation of distribution of the magnetic flux density of operating two-circuit power line 110 kV «CHTPP-Chernihiv-330» in the residential area and methods of its decreasing to a safe level*, Electrical Engineering & Electromechanics, 6, 55–62. DOI: 10.20998/2074-272X.2020.6.08

Krasnozhon, A.V., Buinyi, R.O., Pentegov, I.V. 2016. *Calculation of active power losses in the grounding wire of overhead power lines*. Technical Electrodynamics, 4(2016), 23-25. DOI: 10.15407/techned2016.04.023

Krynke, M., Klimecka-Tatar, D., 2022. *The use of Computer Simulation Techniques in Production Management*, Materials Research Proceedings, 24, 126-133, DOI: 10.21741/9781644902059-19

Lipiński, T., 2010. *The structure and mechanical properties of Al-7%SiMg alloy treated with a homogeneous modifier*. Solid State Phenomena, 163, 183-186. DOI: 10.4028/www.scientific.net/SSP.163.183

Lipiński, T., Szabracki, P., 2015. *Mechanical properties of AlSi9Mg alloy with a sodium modifier*. Solid State Phenomena, 223, 78-86. DOI: 10.4028/www.scientific.net/SSP.223.78

Markovic, S., et al., 2021. *Exploitation characteristics of teeth flanks of gears regenerated by three hard-facing procedures*. Materials, 14, art. 4203. DOI: 10.3390/ma14154203

Miroshnuk, O., Tymchuk, S., 2013. *Uniform distribution of loads in the electric system 0.38/0.22 kV using genetic algorithms*. Technical Electrodynamics, 4, 67-73.

Mykolyuk, O., Zhelavskaya, I., Lyakhovets, V., 2018. *Formation of key vectors for ensuring energy security through the prism of innovative development of alternative energy sources*, Bulletin of the Khmelnitsky National University. Economic sciences, 3(1), 199-204.

Olatomiwa, L., Mehilef, S., Huda, A., Ohunakin Olayinka, S., 2015. *Economic evaluation of hybrid energy systems for rural electrification in six geopolitical zones of Nigeria*, Renewable energy, 83, 435-446, DOI: 10.1016/j.renene.2015.04.057

Pimentel, S. P., Husev, O., Vinnikov, D., Roncero-Clemente, C., Stepenko, S., 2018. *An Indirect Model Predictive Current Control (CCS-MPC) for Grid-Connected Single-Phase Three-Level NPC Quasi-Z-Source PV Inverter*, 2018 IEEE 59th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), Riga, Latvia, 1-6, DOI: 10.1109/RTUCON.2018.8659840

Qawaqzeh, M. et al., 2022. *Development of Algorithm for the Operation of a Combined Power Supply System with Renewable Sources*, 2022 IEEE 3rd KhPI Week on Advanced Technology (KhPIWeek), Kharkiv, Ukraine, 1-4, DOI: 10.1109/KhPIWeek57572.2022.9916372

Qawaqzeh, M., Al_Issa, H., Buinyi, R., Bezruchko, V., Dikhtyaruk, I., Miroshnyk, O., Nitsenko, V., 2023. *The assess reduction of the expected energy not-supplied to consumers in medium voltage distribution systems after installing a sectionalizer in optimal place*, Sustain. Energy, Grids and Networks, 34, 101035. DOI: 10.1016/j.segan.2023.101035

Qawaqzeh, M., Lazurenko, A., Miroshnyk, A., Dudnikov, S., Savchenko A., Trunova, I., 2020. *Analysis of the energy balance of the local energy supply system based on the bioenergy complex*, 2020 IEEE 7th International Conference on Energy Smart Systems (ESS), Kyiv, Ukraine, 134-138, DOI: 10.1109/ESS50319.2020.9160050

Qawaqzeh, M., Shafranets, A., Halko, S., Miroshnyk, O., Zharkov, A., 2020. *Modeling of a household electrical supply system based on a wind power station*. Przegląd Elektrotechniczny, 96, 36-40. DOI: 15199/48.2020.11.08

Radzymińska-Lenarcik, E., Ulewicz, M., 2015. *The use of the steric effect of the carrier molecule in the polymer inclusion membranes for the separation of cobalt(II), nickel(II), copper(II), and zinc(II) ions*. Polish Journal of Chemical Technology, 17, 51-56. DOI: 10.1515/pjct-2015-0029

Redko, K., Borychenko, O., Chernyavskyi, A., Sayenko, V., Dudnikov, S., 2023. *Comparative analysis of innovative development strategies of the fuel and energy complex of Ukraine and EU countries: international experience*, International Journal of Energy Economics and Policy, 13(2), 301-308, DOI: 10.32479/ijeep.14035

Roncero-Clemente, C., Stepenko, S., Husev, O., Romero-Cadaval, E., Vinnikov, D., 2017. *Maximum boost control for interleaved single-phase Quasi-Z-Source inverter*, IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society, Beijing, China, 7698-7703, DOI: 10.1109/IECON.2017.8217349

Rubanenko, O., Yanovych, V., Miroshnyk, O., Danylchenko, D., 2020. *Hydroelectric Power Generation for Compensation Instability of Non-guaranteed Power Plants*, 2020 IEEE 4th International Conference on Intelligent Energy and Power Systems (IEPS), Istanbul, Turkey, 52-56, DOI: 10.1109/IEPS51250.2020.9263151

Sadchikov, A. *Increasing the energy efficiency of biogas plants*, 2016. Fundamentalnye issledovaniya, 10, 1. 83-87

Savchenko, O., Miroshnyk, O., Moroz, O., Trunova, I., Sereda, A., Dudnikov, S., Kozlovskyi, O., Buinyi, R., Halko, S., 2021. *Improving the Efficiency of Solar Power Plants Based on Forecasting the Intensity of Solar Radiation Using Artificial Neural Networks*, 2021 IEEE 2nd KhPI Week on Advanced Technology (KhPIWeek), Kharkiv, Ukraine, 137-140, DOI: 10.1109/KhPIWeek53812.2021.9570009

Scendo, M., Radek, N., Trela, J., 2013. *Influence of laser treatment on the corrosive resistance of WC-Cu coating produced by electrospark deposition*. International Journal of Electrochemical Science, 8, 9264-9277.

Skrzypczak-Pietraszek, E., Pietraszek, A.G., 2024. *Phytoremediation and Allelopathy as an Element of Sustainable Circular Economy to Prevent Environmental Pollution*. Materials Research Proceedings, 45, 140-145. DOI: 10.21741/9781644903315-17

Syromyatnikov, D., Druzenianova, V., Beloglazov, A., Bakshtanin A., Matveeva, T., 2021. *Evaluation of the economic profitability of using renewable energy sources in agro-industrial companies*, International Journal of Renewable Energy Development, 10(4), 827-837, DOI: 10.14710/ijred.2021.37908

Szafraniec, A., Halko, S., Miroshnyk, O., Figura, R., Zharkov, A., Vershkov, O., 2021. *Magnetic field parameters mathematical modelling of windelectric heater*, Przeglad Elektrotechniczny, 97(8), 36-41. DOI: 10.15199/48.2021.08.07

Trunova, I., Miroshnyk, O., Moroz, O., Pazyi, V., Sereda, A., Dudnikov, S., 2020. *The analysis of use of typical load schedules when the design or analysis of power supply systems*, 2020 IEEE KhPI Week on Advanced Technology (KhPIWeek), Kharkiv, Ukraine, 61-64, DOI: 10.1109/KhPIWeek51551.2020.9250120

Tymchuk S., Miroshnyk, O., 2015. *Calculation of energy losses in relation to its quality in fuzzy form in rural distribution networks*, Eastern-European Journal of Enterprise Technologies, 1(8), 4-10, DOI: 10.15587/1729-4061.2015.36003

Viacheslav, B., Roman, B., Andrij, S., Volodymyr, T., 2019. *Integration of New Single-Phase-to-Ground Faults Detection Devices into Existing SmartGrid Systems*, 2019 IEEE 6th International Conference on Energy Smart Systems (ESS), Kyiv, Ukraine, 84-87, DOI: 10.1109/ESS.2019.8764237

Ulewicz, R., Siwiec, D, Pacana, A., Tutak, M., Brodny, J. 2021. Multi-Criteria Method for the Selection of Renewable Energy Sources in the Polish Industrial Sector. Energies 2021, 14, 2386. DOI: 10.3390/en14092386