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Demand-Driven Biogas Plants in Poland – Potential and Growth Perspectives

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ABSTRACT

In recent years, Poland has seen a rapid increase in installed capacity in the renewable energy sources (RES) sector. This increase mainly concerns weather-dependent sources such as PV and wind installations, whose intermittent operation destabilizes the Polish power system (PPS). The solution to fluctuations in PPS operating parameters are stable and controllable RES sources, among which demand-driven biogas plants (with an energy storage in the form of biogas) have a special development potential. The aim of this paper was to describe the construction and principles of operation of peak biogas plants and to analyze the possibilities of including them in the operation of PPS. The paper shows the fundamental differences between the operation of typical biogas plants (producing electricity and heat continuously) and demand-driven biogas plants, in which biogas production takes place continuously, while electricity production occurs periodically, during the highest demand for power during the day. It was found that demand-driven biogas plants are a promising alternative to the previously used coal-fired units, battery energy storage units and pumped-storage power plants and in the future they may act as a stabilizer of the National Power System, achieving available electrical power of up to 11.1 GW.

Keywords: demand-driven biogas plants, exploitation mode, flexible power generation.

INTRODUCTION

With over 70% of electricity generated from coal in 2022, the Polish energy sector ranks among the most carbon-intensive systems not only in Europe but globally (Gajdzik et al., 2023). Additionally, compared to other sectors in Poland, such as transport or industry, electricity and heat production is characterized by the highest level of emissions, amounting to approximately 150 $MtCO_2eq$ (Forum Energii, 2023). The need to reduce the role of coal in the Polish Power System (PPS) is evident—both at the governmental level and within public awareness (Brauers and Oei, 2020; Mrozowska et al., 2021). However, for Polish energy experts, a rapid transition away from stable, conventional generation sources, such as coal-fired power plants, towards intermittent renewable energy sources (RES), poses significant challenges, especially in the absence of nuclear power and substantial hydro resources that would allow for a significant share of hydropower (Szczerbowski and Kornobis, 2019; Brodny and Tutak, 2022). This situation suggests that in the future, the PPS may lack sufficient controllable power sources to offset fluctuations arising from both the variable supply of electricity from intermittent RES, such as photovoltaic (PV) and wind power plants, and the demand from the Polish economy (Bartnikowska et al., 2017; Sowa, 2019). The variability of this supply and demand is substantial, as the output from Polish RES can theoretically fluctuate between 0.5 and 25 GW of electrical power, while the demand ranges between 12–14 GW during weekend nights and holidays and 25–28 GW during peak hours, particularly in the winter season. Stabilizing the PPS with battery energy storage systems is entirely impossible in the foreseeable future due to the enormous storage capacities required on a national scale (Dobrzycki and Roman, 2022). Meanwhile, the most efficient method of grid stabilization, namely pumped-storage power plants, is currently underdeveloped, as the total capacity of such plants in Poland is only 1.5 GW. Although the Polish government has adopted a program to expand pumped-storage power plants to a capacity of 5.5–6 GW, its implementation will take many years and is unlikely to be completed before 2035 (Kałuża et al., 2022).

Considering the current state of operation of the PPS and the increasingly frequent occurrences of power shortages (or surpluses) in the energy grids of Poland and neighboring countries, particularly Germany, there is a significant demand for the development of stable, controllable, and low- or zero-emission energy sources (Pochwatka et al., 2023). In the Polish context, such sources could primarily include biomass-based facilities, particularly biogas plants (Rozakis et al., 2021). A biogas plant is an installation that processes various types of agricultural biomass or bio-waste into biogas through anaerobic digestion. This biogas consists of methane (50–78%), carbon dioxide, and trace amounts of gases such as nitrogen, oxygen, or hydrogen sulfide (Czekała et al., 2023). The produced biogas is stored under flexible domes above the fermentation tanks or the post-fermentation tank, from where it is fed into a cogeneration unit, producing electricity and heat through cogeneration (Pochwatka et al., 2020a).

Biogas plants are the only renewable energy installations whose operation is entirely independent of the time of day, weather conditions, or seasonality. Additionally, electricity generation in biogas plants is fully controllable and manageable (Pochwatka et al., 2023). As previously mentioned, the continuously produced biogas is stored under flexible domes covering the fermentation tanks and post-fermentation storage tanks (Rieke et al., 2018). In typical biogas plants, the generated biogas is consumed immediately by the operating combined heat and power (CHP) unit. However, due to the use of flexible tank covers (made of plastic), it is possible to store the produced biogas for a certain period, especially during times when, for instance, the cogeneration unit is undergoing maintenance and is not consuming biogas (Marks et al., 2020). Therefore, it is important to emphasize that biogas plants naturally have an inherent energy storage system, allowing them to accumulate produced biogas under flexible domes (Dotzauer et al., 2019; Lafratta et al., 2020). Unlike typical battery storage systems, demand-driven biogas plants store energy in chemical form (methane) for several hours of operation, similar to how combustion vehicles store energy in chemical form in the form of fuel, such as diesel, gasoline, or CNG/LNG. This advantage of biogas plants can be leveraged to implement a non-linear operation schedule, enabling them to operate during peak times—when the demand for power in the PPS is at its highest (Lafratta et al., 2021; Pochwatka et al., 2023).

The objective of this study is to describe the construction of demand-driven biogas plants, assess their potential integration into the PPS, and analyze their investment potential.

The current situation in the biogas sector

Biogas undoubtedly plays a crucial role in the ongoing energy transition. Its production enables the processing of bio-waste, significantly reduces greenhouse gas emissions from agriculture (particularly from livestock production), and additionally provides clean energy and natural fertilizer (digestate). Methane fermentation is a natural process that is successfully conducted under controlled conditions in various regions around the world (Gadirli et al., 2024). The annual methane production in Europe currently stands at 21 billion cubic meters, which would be sufficient to meet the entire natural gas demand of Poland (EBA, 2023). Although biogas plants could potentially address many challenges associated with modern energy systems, their widespread implementation remains constrained by barriers related to technical, economic, market, institutional, and socio-cultural aspects. The presence of these barriers, detailed in Table 1, varies depending on the country and its level of development (Mondal et al., 2010; Nevzorova and Kutcherov, 2019).

Poland has significant potential for biogas production, which, depending on the amount and types of substrates taken into account in the studies, oscillates between 13.5 billion m^3 of biogas per year (Dach, 2016) and even 17.7 billion m^3 of biogas (Piechota and Igliński, 2021). Despite such high production capabilities, the share of this green gas in the national structure of obtaining electricity from renewable sources is less than 2% – Figure 1. Comparing the national substrate potential with the actual number of installations, presented in Figure 2, it can be stated that the above-mentioned potential is only used to a small extent.

Table 1. Types of barriers inhibiting the development of the biogas sector (Nevzorova and Kutcherov, 2019)

Type of barrier	Sub-bariers
Economic	• high investment costs • lack of subsidies and financial support programs • lack of funds for research and development (R&D) • high production prices compared to other renewable energy sources
Institutional	• legal instability • poor cooperation between the public and private sectors • lack of political support • long process of obtaining administrative permits
Market	• low prices of fossil fuels • competition with other renewable energy sources
Socio-cultural	• protests resulting from residents' concerns • low level of knowledge about biogas technology • conflict of interests between investors and residents
Technical	• lack or poor level of waste segregation • lack of transmission and distribution infrastructure • incorrect storage of waste

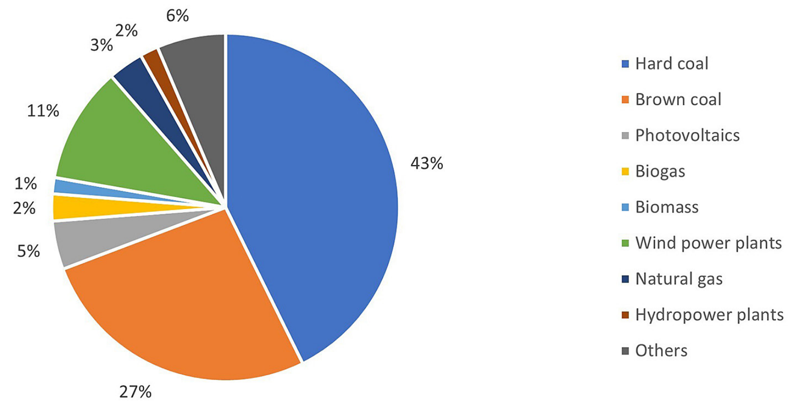

Figure 1. Electricity structure in Poland in 2022 (Energy Market Agency, 2022)

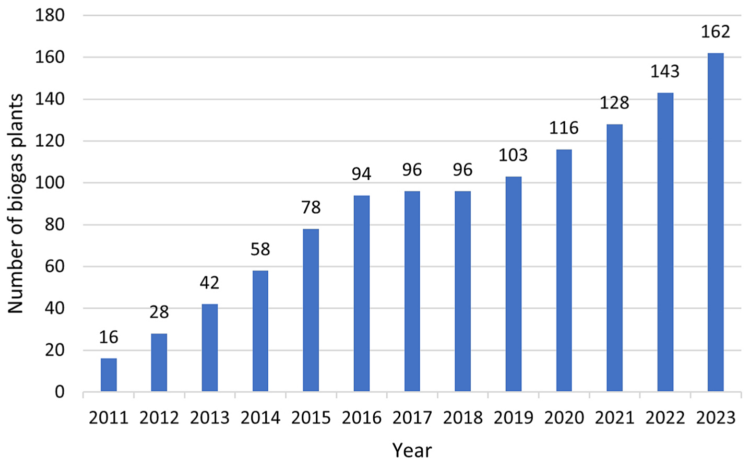

Figure 2. Number of agricultural biogas plants in Poland in 2011–2023 (The National Support Centre for Agriculture – KOWR, 2024)

It should be added that the potential number of agricultural biogas plants in Poland estimated by the Ecotechnologies Laboratory team (the largest Polish biogas laboratory located at PULS) amounts to 10–13 thousand installations, which is slightly more than the number currently in Germany (10.000). Considering that the number of agricultural biogas plants at the end of 2023 reached only 162 installations (less than 1.5% of the potential), it is clear that the Polish biogas market has one of the largest investment potentials in Europe.

Until now, the primary barriers limiting the construction of new biogas plants have been the lack of financing programs for their development (Igliński et al., 2015; Igliński et al., 2020), the absence of stable legal regulations concerning renewable energy sources, including digestate management, and difficulties in obtaining grid connection conditions (Kabel and Bassim, 2020; Pietrzak et al., 2021; Bednarek et al., 2023; Ciuła et al., 2023). Although these issues have remained unresolved for many years, 2023 appears to be a breakthrough year for the development of the biogas sector in Poland.

At the beginning of 2023, the government announced the launch of a new program called "Energy for the Countryside", under which a farmer or energy cooperative can apply for a grant or loan to build a renewable energy source, including biogas plants. For biogas installations with energy storage systems, applicants can receive a loan covering up to 100% of eligible costs, while grants can cover up to 65%. The introduction of this program has opened up a market previously dominated by large players to small and medium-sized farms, thereby positively stimulating the development of this type of renewable energy source in the country (Przygrodzka et al., 2023).

One of the key conditions for the profitability of any energy generation source is a secure market for its output. The currently implemented support systems, such as Feed-in Tariff (FIT) and Feed-in Premium (FIP), provide investors with the assurance that the electricity they generate will be sold at a price not lower than the reference price. According to the regulation issued by the Minister of Climate and Environment on November 8, 2023, concerning the reference price of electricity from renewable energy sources, the periods applicable to producers who won auctions, and the reference volumes of electricity sales, this year's reference price for agricultural biogas produced in high-efficiency cogeneration has been raised once again compared to the previous year (Table 2).

The decline in production costs for renewable energy sources is also of significant importance. Comparing the current unit cost of generation for various sources, expressed through the levelized cost of electricity (LCOE) metric, it can be observed that the cost of energy production from biomass, including biogas, is steadily decreasing (Idel, 2022; Kabeyi and Oludolap, 2023). Although such analyses should be approached with caution, as they do not account for environmental, legal, or operational characteristics, it does not seem likely that this trend will change in the near future (Dzierża, 2017; Nissen and Harfst, 2019). This is primarily due to the current European Union policy, which emphasizes the development of the biogas sector and the reduction of emissions from the economies of EU member states.

There is also evident progress in biogas technologies and the implementation of new solutions that replace the dominant German NaWaRo technology (developed in the 1980s) and reduce biogas production costs. Technological advancements, including improvements in the pre-treatment of substrates and the separation of different phases of the fermentation process, have allowed for a reduction in the use of traditional agricultural substrates (such as corn silage) in favor of utilizing bio-waste (Ferdeș et al., 2022; Czekała et al., 2023). The increased use of bio-waste in biogas production has minimized the need for crops solely dedicated to corn silage, thus reducing competition between food producers and bioenergy producers (Muscat et al., 2019; Ignatowicz et al., 2023). Additionally, adapting facilities to handle problematic waste, such as slaughterhouse or food waste, has led some biogas producers to charge fees for their processing, thereby altering the overall approach to operating biogas plants (Marks et al., 2020; Pochwatka et al., 2020b).

For the advancement of biogas, it is crucial to ensure a legislative environment that allows for the fulfillment of goals outlined in strategic documents at both the national level (including the National Energy and Climate Plan for 2021-2030

Table 2. Change in the reference price values for agricultural biogas plants operating in high-efficiency cogeneration in the years 2021–2023 (Energy Regulatory Office – URE, 2024)

Power of biogas plant	Reference price in particular year [PLN/MWh]		
	2021	2022	2023
Less than 500 kW	760	920	1025
Not less than 500 kW and not more than 1 MW	700	840	941
More than 1 MW	670	800	896

and the Polish Energy Policy until 2040) and the European level (such as the Green Deal and RE-PowerEU). In the past year, two significant laws have been enacted for the biogas sector in Poland: the Act of July 13, 2023, on Facilitating the Preparation and Implementation of Investments in Agricultural Biogas Plants and Their Operation (Dz.U. 2023, item 1597), commonly referred to as the special act, and the Act of July 28, 2023, Amending the Energy Law and Certain Other Acts (Dz.U. 2023, item 1681).

The primary aim of the special act was to streamline and accelerate the investment process for agricultural biogas plants. The introduced changes include, among others, liberalizing the interpretation of local spatial development plans, simplifying the use of digestate, and shortening the duration of certain administrative procedures. The legislation, authored by the Ministry of Agriculture and Rural Development, envisions that these new regulations will lead to the establishment of up to 2,000 agricultural biogas plants. This figure is not arbitrary, as it aligns with a goal set 14 years ago under the program "Directions for the Development of Agricultural Biogas Plants in Poland for 2010–2020," which has never been achieved.

Regarding the amendment to the Energy Law, the most significant change was the introduction of provisions allowing for the connection of biogas plants equipped with energy storage systems (in the form of enlarged biogas storage tanks) to the power grid—even in areas where the grid's capacity is theoretically fully occupied by weather-dependent renewable energy sources (such as photovoltaics and wind turbines). This provision is crucial as it facilitates the integration of demand-driven biogas plants into the grid and addresses one of the main technical barriers: the denial of grid connection conditions.

Problems of Polish power system

Biogas produced through the process of anaerobic digestion can be further refined into biomethane or directly combusted in CHP unit. Once upgraded to biomethane, it can be injected into the natural gas grid, compressed and used as bio-CNG (Compressed Natural Gas), or liquefied and used as bio-LNG (Liquefied Natural Gas). Till the middle of 2024, Poland has not established any biomethane plants, meaning that all domestic biomethane production is utilized solely for electricity and heat generation through cogeneration (Pavičić et al., 2022). There is potential for the development of this system to incorporate a trigeneration setup, where heat is also used to produce cooling. Alternatively, if heat utilization poses challenges, organic Rankine cycle (ORC) systems can be employed to generate additional electrical power from heat, with efficiencies ranging from 8 to 14%. Regardless of the heat utilization approach, due to technical and economic reasons, energy conversion and use are typically carried out as close to the production site as possible. In terms of energy transmission, electricity remains significantly more flexible compared to thermal energy.

In Poland, the lack of issued connection conditions prevents the integration of biogas plants into the power grid and restricts the ability to sell the generated electricity. The issuance of connection conditions in Poland is governed by Energy Law. To obtain these conditions, an application for connection conditions must be submitted, which each operator reviews based on criteria for assessing connection feasibility and technical requirements for generation units to be connected to the respective distribution network. If the assessment reveals that the impact of the requested source on energy quality parameters and network safety exceeds permissible criteria and standards, the operator may refuse to issue connection conditions, citing inadequate technical and economic conditions. These issues are primarily due to the overload of distribution network components, a lack of balance between the planned total generation capacity and the demand at the specific network node where the connection is proposed, and exceeding the permissible voltage levels in the distribution network. Although problems with connecting renewable sources, including biogas plants, have existed before, they have never occurred on such a scale (Dołęga, 2018; Kryszk et al., 2023). According to data published by the President of the Energy Regulatory Office, in 2022, 7,023 refusals for connection conditions were issued for a total capacity of 51.05 GW, representing a 188% increase compared to the previous year (URE, 2023). Similar situations are observed globally (Erdiwansyah et al., 2021; Abanades et al., 2022; Kataray et al., 2023).

The primary cause of this phenomenon is the fast growth of renewable, and consequently unstable, energy sources such as wind and solar power. In 2023 Poland has experienced the largest increase in capacity from photovoltaic installations, reaching 17,057 MW (IEO, 2024). During the same period, the capacity of wind farms was 9,428 MW (IEO, 2024). Given these figures, over 95% of installed renewable capacities in Poland are weather-dependent (Forum Energii, 2023). Consequently, this creates challenges in maintaining balance within the PPS, primarily due to the intermittent nature of electricity generation, daily and seasonal variability in output, reduced stability, and quality of transmitted energy, as well as difficulties in balancing energy supply with demand (Bayindir et al., 2016; Lehtola and Zahedi, 2020; Syahri et al., 2022). Analyzing the daily power demand of the PPS, as illustrated in Figure 3, reveals that there are two periods of increased energy demand - namely, the morning peak and the evening peak.

These periods do not coincide with the electricity production from PV, due to meteorological conditions. Specifically the lack of sunlight, especially during the winter months, energy production from PV is limited, which raises significant concerns about blackouts which is sudden drops in voltage in the power lines affecting large areas of the country (Nedic et al., 2006). Conversely, during the day, when the amount of energy produced is higher, the demand for it is lower, which leads to system overloads because the electrical grid in a given location can only accommodate a specific amount of energy (Maradin, 2021). To balance production and consumption, distribution system operators (DSOs) are compelled to export a portion of the energy and restrict the operation of certain power plants. Initially, the operation of photovoltaic and solar farms is curtailed, as they irretrievably lose the generated energy due to the lack of energy storage systems (Shakoor et al., 2022).

The role of demand-driven biogas plant in stabilizing the Polish power system

Energy storage is a solution that enhances the flexibility of the power system, improves the efficiency of energy generation and distribution management, and, most importantly for the energy transition, facilitates and accelerates the implementation of RES (Komorowska and Gawlik, 2018). There is a wide range of energy storage methods; however, given the scale of the problem, it is crucial to evaluate available solutions based on their technological advancement and cost considerations (Ceran, 2018; Taylor, 2018; Wang et al., 2024). It is noteworthy that despite the aforementioned technologies, such as battery-based energy storage systems and pumped-storage hydroelectric plants, the current solutions are insufficient to provide the national energy sector with an adequate level of security.

The most promising alternative appears to be demand-driven biogas plants, which generate energy only when there is demand for it. Traditionally, biogas installations have typically been designed to produce electricity continuously, operating 24 hours a day. However, it is possible to adjust the engine's operating mode to match daily peak periods, thereby optimizing energy production according to actual demand (Pochwatka et al., 2023). During periods of reduced demand, the

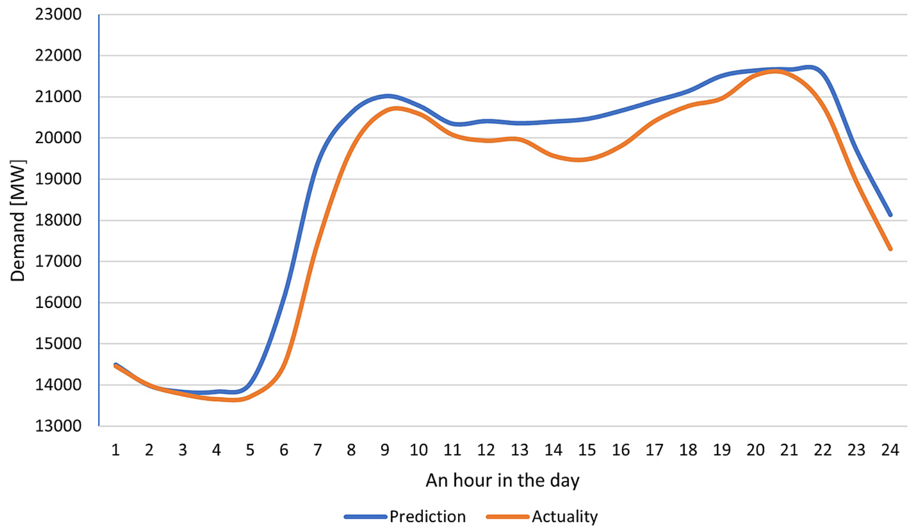

Figure 3. Sample demand for power of the Polish Power System on 27.05.2024 (PPS, 2024)

operation of the cogeneration engine would be limited or entirely stopped. Instead of continuous electricity production, biogas plants could operate only during peak times, when the output of other renewable sources, especially PV is restricted:
- for 6 hours during two peak periods: morning and evening, resulting in a total production of 12 hours per day – Figure 4;
- for 7 hours during two peak periods: morning and evening, resulting in a total production of 14 hours per day – Figure 5.

Operation of demand-driven biogas plants

Both the construction and the principles of operation of a demand-driven biogas plant differ from the method of use of a typical linear biogas plant. Figure 6 shows a diagram of the construction of a demand-driven biogas plant with a power of 499 kW, which in linear operation (24 h/day) has an electrical power of 250 kW.

The operation of a demand-driven biogas plant is identical to traditional biogas plant only during the initial stage: feeding substrates from the substrate tank (1) every 1 or 2 hours (after being shredded in the macerator (2) and possibly undergoing thermal treatment in the hygienizer (3) through pipes (4) to the fermentation tank (5). In the fermentation tank, methane fermentation occurs, producing biogas, which is continuously transferred to the post-fermentation tank (6) through the gas pipe (7) at a flow rate of approximately 125 m³/h, equivalent to 250 kW of electrical power.

This is where the similarities between the operation of traditional and demand-driven biogas plants end. In a linear biogas plant, the biogas is continuously transferred to the CHP unit, which operates non-stop, consistently producing electricity and heat, with downtime occurring every 1,000–2,000 hours for maintenance (such as oil changes, spark plug replacements, filter changes, etc.). In a demand-driven biogas plant, a double membrane is installed

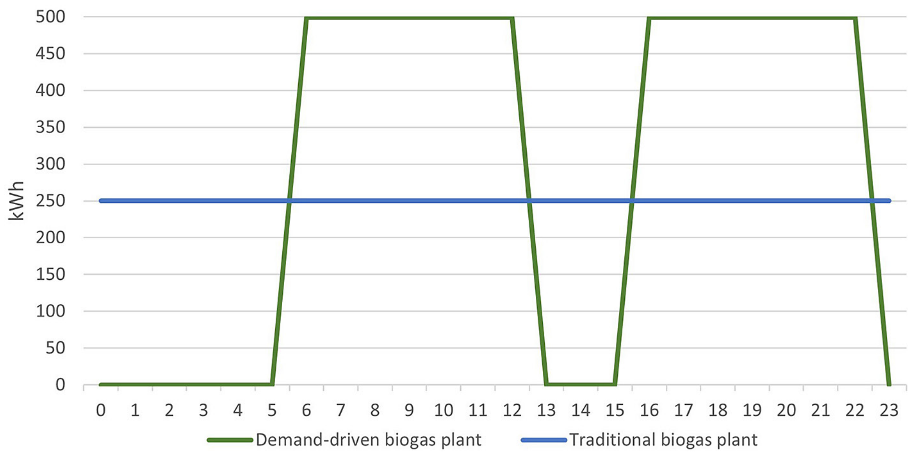

Figure 4. Comparison of the operation of a traditional biogas plant with demand-driven in the first variant

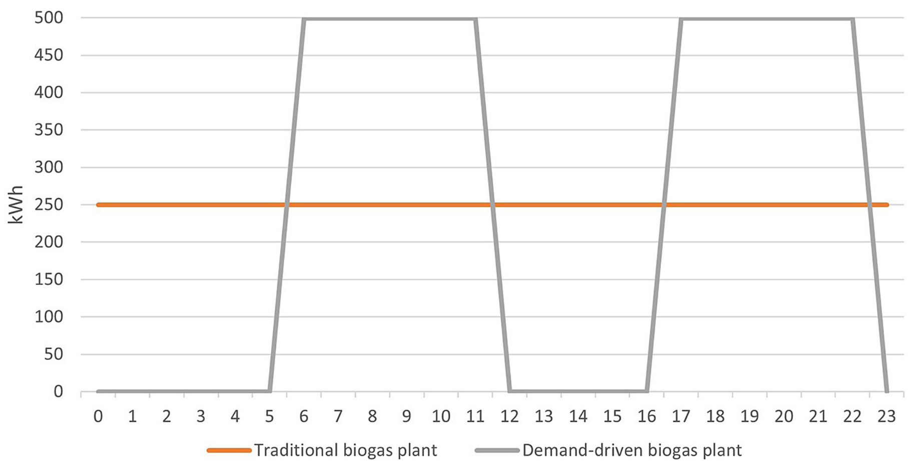

Figure 5. Comparison of the operation of a traditional biogas plant with demand-driven in the second variant

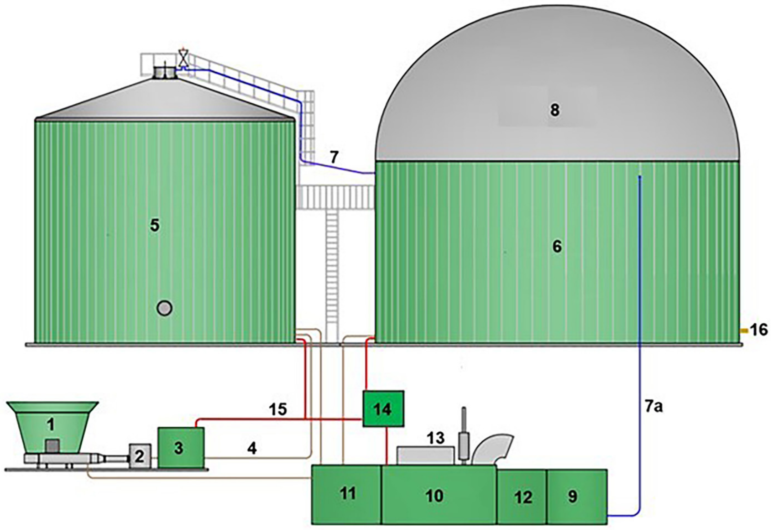

Figure 6. Diagram of a demand-driven biogas plant (linear power 250 kW, cogeneration unit 499 kW, designed for 12 hours of operation per day): 1 – substrate tank, 2 – macerator, 3 – hygienizer (optional), 4 – pipes for transferring diluted substrate and fermentation pulp, 5 – fermentation tank (1200 m³), 6 – post-fermentation tank (3600 m³), 7 – gas pipe, 7a – gas pipe to CHP with higher capacity, 8 – biogas storage tank (maximum 1700 m³), 9 – biogas blower with desulfurization section, 10 – cogeneration unit (CHP), 11 – pulp pump and distribution unit, 12 – switchboard and control room, 13 – heat exchanger, 14 – heat storage, 15 – heat pipeline, 16 – valve for digestate output

above the post-fermentation tank (6) to collect biogas. The outer membrane remains stationary, while the inner membrane rises or falls depending on the volume of biogas. During nighttime or midday, when the cogeneration unit is not working, the biogas injected into the post-fermentation tank through the gas pipe (7) increases the pressure, causing the inner membrane in the biogas storage tank (8) to rise up. However, when peak hours begin (either in the morning or late afternoon), the automation system in switchboard and control room (12) activates the CHP unit (10), which then draws biogas through the larger dimension gas pipe (7a) at a rate of approximately 250 m³/h, equivalent to around 500 kW of electrical power (in the specific case of Poland, the upper power limit for small biogas plants is 499 kW due to local regulations).

The biogas drawn into the CHP unit passes through a desulfurization section, as the concentration of hydrogen sulfide in raw gas can reach several thousand ppm, posing a risk to the engine. Since it operates only dozen hours per day and is turn on twice daily, it should be maintained in a ready-to-operate state at an elevated temperature to avoid mechanical damage during "cold" starts. To achieve this, a heat storage (14) is utilized, which is charged with thermal energy recovered from the heated engine block and exhaust gases via a heat exchanger (13). The heat storage also serves to warm the fermentation and post-fermentation tanks at the temperature 40–42 °C.

While the operation of the engine can be controlled, managing the actual biogas production process is much more challenging. Since methane fermentation occurs naturally with the involvement of microorganisms, there are very limited possibilities for halting or accelerating the process. There is, of course, the possibility of making gas production more flexible by managing the feeding of the installation, which can slightly reduce the necessary volume for biogas storage (Mauky et al., 2015; Mauky et al., 2017; Peters et al., 2018). However, on a scale larger than the laboratory, this solution may prove problematic (Hahn et al., 2014; Dotzauer et al., 2019). As more biogas plants operate on varying substrate mixtures, the decomposition time also changes. Therefore, to truly match the amount of biogas produced to the consumer's needs, a deep understanding of the physicochemical properties of the individual substrates is required (Tumusiime et al., 2022; Silva et al., 2024). As a result, there is no alternative to using biogas storage in the form of enlarged domes above the fermentation or post-fermentation tank. To allow a biogas plant to operate flexible, in addition to increasing the storage capacity, all parts of the gas installation must be dimensioned to account for changing flow rates, and the engine power must be selected to correspond to the maximum electrical output. It should be noted that these changes entail increased construction costs for such installations, particularly considering that one of the most expensive components of any biogas plant is the cogeneration engine, the cost of which rises with its power (Hahn et al., 2014; IEA Bioenergy, 2020).

Prospects for the development of the demand-driven biogas plants in Poland

Currently, no biogas plant in Poland operates in demand-driven mode, but this may change soon. For example, the company Dynamic Biogas, based in Poznań, is in the process of developing several dozen such projects across the country. A key factor in successfully completing the pre-investment phase, including obtaining necessary permits and starting construction, is the incorporation of provisions from the Act of July 28, 2023, amending the Energy Law and certain other acts (Dz.U. 2023 poz. 1681). The changes in the criteria for evaluating connection possibilities and the technical requirements for generating units connected to the distribution network of various Distribution System Operators (DSO) are crucial. Currently, the installed capacity, rather than the actual capacity, is considered for generating sources (including wind and solar power plants) during analysis. This results in weather-dependent sources utilizing only a small fraction of their allocated capacity (typically 10–30%). Given their operational nature, demand-driven biogas plants could utilize the previously unused capacity, particularly during early morning and evening hours.

Despite the increased investments costs, demand-driven biogas plants allow for the sale of electricity at the most profitable times of the day, ultimately increasing the overall return on investment. Analyzing prices on the Polish Power Exchange (TGE), it is evident that the price per MWh varies depending on the time of day and year. Flexible production and adaptation to the actual needs of the end consumer can also be leveraged when negotiating energy sale prices under Power Purchase Agreements (PPAs), which are gaining importance year by year. The ability to temporarily limit the power fed into the grid also protects producers from the occurrence of so-called negative electricity prices. Such a situation first occurred in Poland on October 15, 2023, when the sale price per MWh of electricity was negative for six consecutive hours on the TGE, resulting in those hours being excluded from the FIT/FIP support system, as per the Act of February 20, 2015, on Renewable Energy Sources (Dz.U. 2015 item. 478). Similar situations have previously occurred in Germany, where in 2022, there were 69 hours with negative prices, and producers were required to pay for injecting surplus energy into the grid - on December 23, 2022, this amounted to 79 cents per kWh (Energy Transition, 2023).

Demand-driven biogas plants may play a very important role in the stabilization of the national power system in the near future. The estimated potential for biogas production in Poland in 2016 from agricultural biomass and bio-waste (excluding energy plants) was estimated at 13.5 billion m^3 of biogas (7.8 billion m^3 of methane) (Dach, 2016), which allows for the production of 31.1 TWh of electricity and achieving 3.7 GW of electrical power from biogas plants operating in continuous operation mode. However, in the case of demand-driven biogas plants operating in the 12h/day regime, the available power increases to 7.4 GW, and in the case of the 8h/day operation mode up to 11.1 GW. In the latter variant, this allows for cover almost 50% of the national economy's demand for power during the morning and evening peak periods. Due to the full availability of work (the biogas plant can switch from standby mode to 100% power operation in about 3 minutes) - investments in demand-driven biogas plants are more rational than the construction of nuclear power plants, whose work flexibility is much lower. It should also be remembered that in addition to the beneficial impact on the power grid, biogas plants (both linear and demand-driven) also play a very important environmental role: - they recycle bio-waste in order to use it as a source for generating electricity, heat and valuable fertilizer.

CONCLUSIONS

Demand-driven biogas plants present a promising alternative to the traditionally used coal-fired units, battery energy storage systems, and pumped-storage power plants. In the future, they could play a crucial role in stabilizing the Polish Power System. The introduction of legislative changes, including the so-called special law and amendments to the energy law, will significantly accelerate and facilitate the process of constructing new agricultural biogas plants, thereby fostering the growth of the biogas sector in Poland. The activation of rural areas is particularly important, so it is essential to maintain funding programs aimed at rural residents, while continuing the FIT/FIP support system.

Given the increasing frequency of connection condition refusals and the occurrence of negative prices on the TGE, it can be assumed that a significant portion of new biogas plants will be adapted to operate in flexible mode. Despite the higher investments costs, demand-driven biogas plants have the potential to generate profits by selling electricity during the most profitable times and mitigating issues arising from imbalances in the power system. Therefore, further research should be conducted in this area, particularly in the context of evaluating the economic efficiency of demand-driven operation compared to traditional methods.

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