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# Enhancing the Fermentation Process in Biogas Production from Animal and Plant Waste Substrates in the Southeastern Region of Bulgaria

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**Abstract:** Annually, a huge amount of waste from plant biomass and animal manure is produced from agriculture and animal farming. Many studies provide information on the biomethane potential of agricultural and livestock wastes, but only a few studies have investigated the application of the substrates in combination. The objective of the study is to enhance the fermentation process in the digester for biogas production, obtained from animal and plant waste substrates. In four batch processes for three months, the temperatures and the residence time of the substrates in the fermenter were analyzed. Simultaneously, electricity and thermal energy were produced via cogeneration units, which were exported to the public grid and city heating network. The plant substrate is a silage mixture of corn and wheat waste. The animal substrate is a mixture of beef and pig manure. Animal and vegetable waste raw materials are collected and transported to the site, located in the region of southeastern Bulgaria. The total annual consumption of animal and plant waste is 17,971 t/year. The enhancement of the process leads to the production of 1,506,000 $Nm^3$ $CH_4$/a of methane, the generation of which requires 299.63 MWh/a of electricity and 649.09 MWh/a thermal energy.

**Keywords:** animal and vegetable waste substrates; biogas plants; production of combined energy; fertilizer for agriculture

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## 1. Introduction

Renewable energy sources (RESs) play an important role in the production of energy for a huge number of human, agricultural and industrial activities [1]. The technologies used to produce biogas have seen serious development in the last three decades. The main purpose of using these technologies is the conversion of energy from a different waste product into combustible gas (biogas). Huge amounts of waste raw materials are unavoidably generated every day, and this makes it increasingly difficult to deal with them. This is one of the key environmental problems of the modern world [2,3]. In this regard, programs for sustainable waste management and their processing have been introduced in a number of countries [4]. Many of the used modern methods are considered inappropriate in modern conditions [5,6]. Modern trends in waste management are primarily focused on the processing and beneficial utilization of waste materials, including both waste that can be recycled and organic waste materials [7–9]. One of the potential forms of waste management in municipalities and rural areas is the production of energy from biogas [10]. Biogas production combines different types of waste; for example, a very good combination is the use of agricultural and animal raw materials, and the interaction between them can have additional positive effects [11,12]. These combinations make the production of biogas extremely suitable for the policy objectives of the European Union, related to both increasing the share of renewable energy production and efficient use of resources and reducing the disposal of organic waste in landfills [13]. The Republic of Bulgaria will strive to achieve at least a 27.09% share of renewable energy in gross final energy consumption by 2030 [14,15]. The national goal of Bulgaria should be achieved by increasing the consumption of energy from renewable sources in all three sectors: electricity, heating and cooling, and transportation.

Biomass energy consumption is expected to increase in both final energy consumption and electricity generation. The additional consumption of energy from biomass requires an increase in the amount of biomass in Bulgaria, which will increase by 37% in the period 2020–2030 [16]. Rational solutions for the optimal use of plant and animal waste are increasingly sought to reduce the harmful impact on the environment and increase the share of the use of renewable energy sources in the final energy consumption. In most cases, by means of known fermentation technologies, the aim is to produce combustible gas (biogas), which could be used for the combined production of electrical and thermal energy.

The production of biogas from various organic waste materials, through anaerobic digestion, is a widely applicable method which finds significance in renewable energy and sustainable waste management. The different types of organic waste, such as those from food, biomass, and household waste, vary in their suitability for anaerobic digestion [17–19]. This process can be made more effective for some of them after applying specific studies and optimization. Precise analyses based on the specific properties of the raw materials have been conducted to determine the most suitable approach and enhance the process efficiency [20–22]. In addition to the generated biogas, anaerobic digestion also plays a crucial role in other environmental aspects [23]. This process aids in reducing waste volume, creating compostable material, and mitigating greenhouse gas emissions. A detailed analysis is required to understand the full impact of this process on the ecosystem and climate [24,25].

Despite being a beneficial method, anaerobic digestion faces specific technical challenges, arising from variations in waste properties and environmental conditions [26]. To ensure its successful implementation in the future, it is crucial to focus on the development of new technologies and methods to overcome these challenges. This is a key element for the effective and sustainable integration of anaerobic digestion as a waste treatment method [12,27].

A comprehensive study is required to analyze the infrastructure investments, operational costs, and revenue-generating opportunities, such as selling the produced biogas. To make anaerobic digestion sustainable and successful, it is crucial to introduce new technologies, expand its application, and optimize production processes [13]. This involves adopting new and improved technologies, increasing the scope of its utilization, and enhancing its efficiency through improvements in the production process. These steps are essential for achieving sustainability and successful integration of anaerobic digestion into our waste management system [14,28].

It is particularly important to note that the production of biogas from agricultural and animal waste raw materials deserves attention from farmers, politicians and persons interested both in obtaining energy from renewable energy sources and in climate protection [29]. In many of the literary sources on the subject, it is presented in a descriptive form [30,31]. The role and impact of policy on the development of renewable energy have been reviewed [32]. Several different policies have been implemented in EU countries to increase the production of energy from renewable sources [33,34]. The location of biogas farms relative to waste sources is also essential to minimize production costs. The construction of the biogas production facilities in the immediate vicinity of the landfills or in the industrial or agricultural workshops themselves, in turn, makes it possible to limit the transport costs [35]. Also of importance are the increased yields of the various types of waste raw materials. It is particularly important that these are alternative sources of income and independent renewable energy sources [36]. This enables users to produce more and more of their own energy and promotes greater uptake [37]. Farm-type biogas plants can have different design sizes and produce biogas using different technologies [38–40]. The manure is collected in a pre-tank, then pumped to the bioreactor. The residence time usually varies from 20 to 40 days and depends on the type of substrate and the fermentation temperature. Centralized co-fermentation plants are fed with manure and liquid fractions that are supplied from several farms. This is said to reduce the cost, time and labor of transporting the fertilizer to the plant. The dwell time is about 12–25 days [41,42]. The bioreactor itself is generally a hermetically sealed and thermally insulated tank in which a constant temperature is maintained. It is also equipped with a stirring system, with the help of which the substrate is mixed and homogenized. It also contains systems for removing residual products and a system for removing methane gas. In most cases, the management of the entire facility is automated. To collect the released gas, methane tanks usually have a cylindrical chamber with a cover. The volume of the chamber and the area of the hood are determined depending on the expected amount of gas released from the bioreactor [43,44].

Based on the presented literature review, it is evident that the research in this specific area is limited. To make significant progress, it is crucial to establish an integrated and comprehensive approach for improving fermentation processes. This approach should focus on optimizing temperature parameters and the duration of substrate residence in the fermenter.

The aim of this study is to refine the efficiency of an operational installation through which biogas is generated via anaerobic fermentation of animal and plant waste materials. This endeavor will facilitate the precise determination of temperatures and residence times for substrates within the fermenter. Furthermore, it will enable the assessment of the system's effectiveness when utilizing a combined approach involving animal and plant waste substrates for biogas production. The object of the present study is as follows:

- Feeding the plant with manure and plant substrates that are supplied from several nearby farms;
- Specification of the technological process for the production of biogas by anaerobic fermentation of animal and vegetable waste raw materials in the bioreactor;
- Application of the produced biogas.

## 2. Research Materials and Methods

### *2.1. Experimental Details and Methodology*

The operation of an agricultural plant for obtaining biogas for the utilization of renewable raw materials such as liquid cow manure, liquid pig manure, corn silage and silage from whole grain plants is considered.

The biogas installation is a flow-through installation of tanks, which, depending on the gas yield, work in a thermophilic or mesophilic mode of operation. Silage biomass is stored in silos at the installation site. The liquid manure is fed from the stables into the receiving tank.

The primary energy carriers are fed into the main fermenter in solid (silage) and liquid form (liquid fertilizer). The overflow of substrate into the additional fermenter is facilitated by an overflow pipe. The biogas produced by the wet fermentation method is later burned in a co-generator to obtain electrical and thermal power. The substrate from the fermentation residues is divided by a separator, respectively, on the solid and liquid phase.

The liquid phase is temporarily stored in three open liquid fertilizer storage facilities and then applied to the agricultural areas. The solid phase is stored on an asphalted area, provided for this purpose.

The produced electricity is sold at a feed-in tariff. The heat produced is partly used for internal needs and partly for heating purposes.

An emergency gas flare is installed, which is used to burn the biogas during the overproduction of gas, as well as during the maintenance and shutdown of the co-generator.

The gas tank (gas storage), a low-pressure tank, serves as intermediate storage for biogas and is used to balance production fluctuations.

*2.2. Installation Supply*

The feeding of the biogas plant with manure and plant silage was carried out, and the raw materials were supplied from several farms. Energy plants were preserved in silos at the plant site and stored for use in the biogas plant. The liquid manure was fed from the stables through pipelines into the receiving tank. From the collecting tanks, by means of a pumping system, they were fed into the fermenters. In Table 1, the amounts of raw material from plant and animal substrates are given; Table 2 provides the amounts of dry material from the plant and animal substrates. In Table 2, TS indicates the amount of solid residue (Total Solid) of the plant substrate and fertilizer mass in percentage as well as the total amount.

**Table 1.** Substrate amounts of raw material.

| Raw Material | (t/a) | (t/m$^3$) | (m$^3$/d) |
|---|---|---|---|
| Plant substratum | | | |
| corn silage | 9471 | 0.65 | 39.92 |
| wheat silage | 3000 | 0.50 | 16.44 |
| sum/average value | 12,471 | 0.61 | 56.36 |
| Animal substratum | | | |
| cattle fertilizer | 2500 | 1.10 | 6.23 |
| pig fertilizer | 3000 | 1.02 | 8.09 |
| sum/average/t liquid | 5500 | 1.05 | 14.32 |

**Table 2.** Substrate amounts of Dry material.

| | Dry Material | | | | |
|---|---|---|---|---|---|
| | TS, (% d.FM) | oTS, (% d.FM) | TS, (t/a) | oTS, (t/a) | oTS, (t/d) |
| | Plant substratum | | | | |
| corn silage | 33.00% | 31.35% | 3125 | 2969 | 8.13 |
| wheat silage | 35.00% | 30.80% | 1050 | 924 | 2.53 |
| sum/average value | - | - | 4175 | 3893 | 10.67 |
| | Animal substratum | | | | |
| cattle fertilizer | 10.00% | 8.50% | 250 | 213 | 0.58 |
| pig fertilizer | 6.00% | 5.10% | 180 | 153 | 0.42 |
| sum/average/t liquid | - | - | 430 | 366 | 1.00 |

*2.3. Fermentation Process*

In this case, primary and secondary fermenters are used to produce biogas. The main fermenter is a closed vessel, without access to air, in which biochemical processes take place and biogas is formed. In the main fermenter, the liquid and solid substrate are homogenized using stirrers. They mix the supplied material until a homogeneous mass is achieved with minimal energy consumption. Thus, the homogenized substrates are fermented in an anaerobic environment.

Studies were conducted on the volume of gas produced each day and the production rate of the substrates during four batch processes. The time duration was 3 months within a year, at 20 to 26 days to establish the residence time of the substrate in an anaerobic environment. The temperature varies during the study in mesophilic (from 37 to 41 °C) and thermophilic (from 52 to 56 °C) regimes. In three of the batch processes, the fermenters were heated, and in the one in the summer, the ambient temperatures were between 35 and 48 °C and heating was not necessary. In the case of batch processes, studies of the physio-chemical parameters of the incoming substrates, fermentation mixture, and final product, which are not the subject of this review, were also considered. It was found that the most optimal residence time of the substrates is 22 days at temperatures of 38 °C in mesophilic mode and 55 °C in thermophilic mode. With the help of methane-forming bacteria, the substrates are converted into methane, carbon dioxide and liquid fertilizer. As fresh substrates are added to the main fermenter, the fermented material is pushed through an overflow tube into the secondary fermenter. In this way, the residual potential of the gas is extracted, and the contained energy is fully utilized. From the secondary fermenter, the post-fermentation residue is pumped from the overflow by means of the pump installation into an intermediate tank with a double membrane. It consists of two highly resistant, gas-tight membranes.

### *2.4. Purification of Sulfur Oxides*

When the produced gas is transferred from the main to the secondary fermenter in the exhaust pipes by means of a fan, between 0 and 3% of fresh air, measured in relation to the biogas production, is fed, respectively, to clean the sulfur. This minimal amount of oxygen supplied with the fresh air is needed by sulfur bacteria to convert hydrogen sulfide into elemental sulfur.

The exact required amounts of air are obtained from the residual content of hydrogen sulfide, which is measured with a gas analyzer. The maximum allowable amount of supply air is 10% of the produced biogas.

### *2.5. Cogeneration*

For biogas utilization, cogeneration is carried out. The co-generator utilizes the production in the fermenter via the method of wet fermentation and the biogas stored in the intermediate tank, converting it into electrical and thermal energy. The electricity produced is fed into the power grid, and thermal energy is partly used to heat up the fermenters and heat the nearby farms and their greenhouses. Residual heat is used to heat buildings, dry agricultural products, etc. An emergency gas flare is also installed to burn biogas in case of overproduction of gas, as well as during maintenance and shutdown of the co-generator.

The gas storage is made as a low-pressure tank, which serves for intermediate storage of biogas and for balancing production fluctuations. The rest of the fermentation is fed into a separation plant and separated into liquid and solid fractions. The liquid fraction before utilization and as agricultural fertilizer for the farms is intermediately stored in three open storage tanks. The solid fraction is stored on a covered asphalt area. Figure 1 shows a diagram of the biogas plant (Figure 1). The system installation and its facilities have the following parameters: the heat output of the generator is 810 kW and the electrical output is 800 kW.

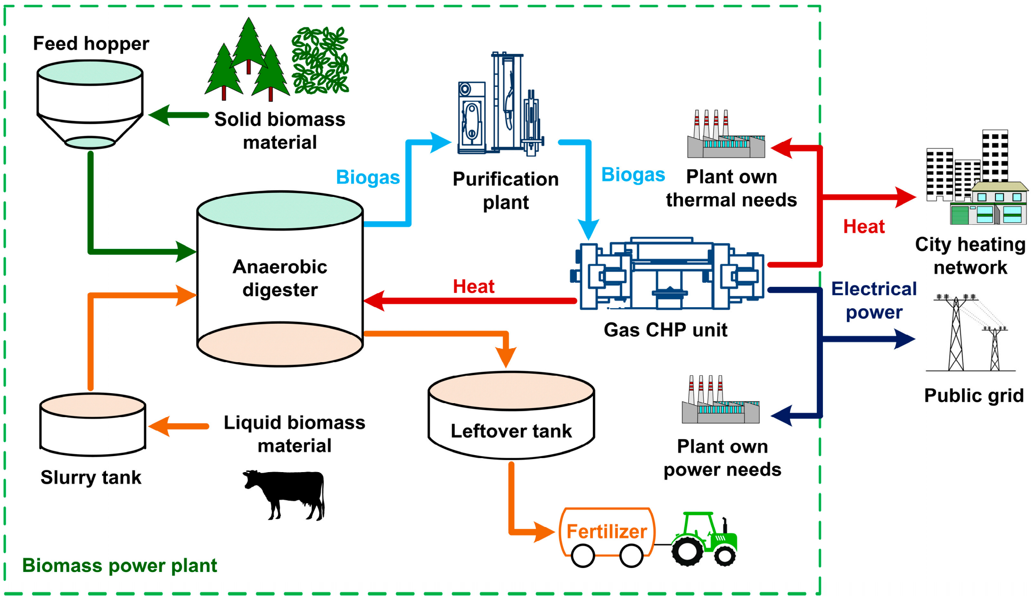


**Figure 1.** Biogas production installation.

## 3. Results

### *3.1. Produced Methane*

Through the biological fermentation process, biogas is formed in the biogas installation. Depending on the input of raw materials, different concentrations of methane are produced. Since the plant operates with energy plants and liquid fertilizer during the batch processes, the methane content in the gas produced is approximately 55%.

As a result of the processes described above, over one year, 1,423,942 $Nm^3$ $CH_4$/a was produced from plants and 81,940 $Nm^3$ $CH_4$/a form animal substrates, as shown in Table 3.

**Table 3.** Methane production summary.

| | Methane production | |
|---|---|---|
| | ($Nm^3$ $CH_4$/kg oTS) | ($Nm^3$ $CH_4$/a) |
| **Plant substratum** | | |
| corn silage | 0.38 | 1,128,262 |
| wheat silage | 0.32 | 295,680 |
| sum/average value | 0.37 | 1,423,942 |
| **Animal substratum** | | |
| cattle fertilizer | 0.22 | 46,750 |
| pig fertilizer | 0.23 | 35,190 |
| sum/average/t liquid | 0.22 | 81,940 |

Table 4 presents the produced methane for one year (1,505,882 $Nm^3$ $CH_4$/a) as well as the energy (15,058,820 kWh/a) and power (801 kWel) that were produced from it.

After the analysis of the energy consumption of the biogas plant for one year, it was found that the annual thermal energy for the fermenter was 819.94 MWh/year. The annual consumption of electricity for internal needs is 820 kWh/day, or 299.63 MWh/year. The net annual production of electricity and heat is 6099 MWh/year and 5656 MWh/year, respectively.

**Table 4.** Total substratum.

| Substratum | Methane | Energy | Power |
|---|---|---|---|
| | 1 | 2 | 3 |
| | (Nm$^3$ CH$_4$/a) | (kWh/a) | (kWel) |
| plant substratum | 1,423,942 | 14,239,420 | 757 |
| animal substratum | 81,940 | 819,400 | 44 |
| Total | 1,505,882 | 15,058,820 | 801 |

### 3.2. Systematization of Gas and Gross Energy Production

The gas production and gross energy for the described plant is shown in Table 5. It is seen that the daily amount of gas produced is 4126 Nm$^3$/d. The gross energy produced per day is 41 MWh/d, or 15,059 kWh/Nm$^3$ per year. The efficiency of the biogas production system is approximately 85.5%.

**Table 5.** Gas generation and gross energy production.

| | | |
|---|---|---|
| Annual methane generation | (Nm$^3$/a) | 1,505,882 |
| Daily methane generation | (Nm$^3$/d) | 4126 |
| HV | (kWh/Nm$^3$) | 10.0 |
| gross electricity production/annual | (MWh/a) | 15,059 |
| gross electricity production/month | (MWh/Month) | 1255 |
| gross electricity production/day | (MWh/d) | 41.0 |

The produced waste (animal and plant) is mixed in the mixing tank with the help of a conveyor worm. A screw elevator is used to feed the mixing tank. After the mixing tank, the substrate mixture is transferred to the fermenter, where the methane gas is expelled. The methane production process requires a constant temperature in both fermenters. Additional heat must be supplied to cover the heat losses through the fermenter cover. However, for the specific installation, no additional external heat was used to maintain the fermentation process throughout the entire year. The annual required heat energy for the fermenter, 819.94 MWh/year, is outlined in Table 6. The annual electricity consumption for internal needs is 820 kWh/day, or 299.63 MWh/year, which is also presented in Table 6.

**Table 6.** Necessary thermal energy for the fermenter.

| Heat Energy Requirements for the Fermenter | | | | | | |
|---|---|---|---|---|---|---|
| | Power, kW | | | | | (kWh/month) |
| | Heating | Losses | | | General | General |
| | Necessary Heat | Fermenter Bottom | Fermenter Lead | Fermenter Jacket | Total | Total |
| Jan. | 88.0 | 5.6 | 6.5 | 13.4 | 113.5 | 84,472 |
| Feb. | 85.7 | 5.5 | 6.1 | 12.7 | 110.0 | 73,907 |
| Mar. | 80.9 | 5.2 | 5.5 | 11.4 | 103.0 | 76,601 |
| Apr. | 76.2 | 4.9 | 4.8 | 9.9 | 95.7 | 68,906 |
| May | 71.4 | 4.6 | 4.1 | 8.5 | 88.5 | 65,840 |
| June | 64.3 | 4.1 | 3.6 | 7.5 | 79.5 | 57,206 |
| July | 59.5 | 3.8 | 3.3 | 6.9 | 73.5 | 54,687 |
| Aug. | 59.5 | 3.8 | 3.4 | 7.0 | 73.7 | 54,826 |
| Sept. | 66.6 | 4.3 | 3.9 | 8.2 | 83.0 | 59,768 |
| Oct. | 71.4 | 4.6 | 4.8 | 9.9 | 90.6 | 67,401 |

**Table 6.** *Cont.*

| Heat Energy Requirements for the Fermenter | | | | | | |
|---|---|---|---|---|---|---|
| | Power, kW | | | | | (kWh/month) |
| | Heating | Losses | | | General | General |
| | Necessary Heat | Fermenter Bottom | Fermenter Lead | Fermenter Jacket | Total | Total |
| Nov. | 80.9 | 5.2 | 5.6 | 11.6 | 103.3 | 74,365 |
| Dec. | 85.7 | 5.5 | 6.2 | 12.8 | 110.2 | 81,964 |
| min Temp. | 88.0 | 5.6 | 9.4 | 19.5 | 122.6 | - |
| max. Temp. | 88.0 | 5.6 | 6.5 | 13.4 | 113.5 | 84,472 |
| Ave. | 74.2 | 4.7 | 4.8 | 10.0 | 93.7 | 69,711 |
| Minimum | 59.5 | 3.8 | 3.3 | 6.9 | 73.5 | 54,687 |
| | | | | | Total | 819,943 |

### *3.3. Emission Analysis*

The combustion of biogas leads to the generation of gaseous harmful substances or harmful substances in the form of particles in the exhaust flow of the stationary engines of the co-generator. Due to the high combustion temperature, the generation of nitrogen oxides (NOx) is expected. NOx values do not exceed 500 mg/Nm$^3$ (at 5% $O_2$).

The specific installation is loaded only with substrates from agricultural primary production and liquid fertilizer from agricultural farms.

Odor problems in biogas plants occur especially when co-fermenters are also fermented. Since these products are not used in the specific case, only minimal emissions can be expected.

Desulfurization (purification of sulfur) is carried out by supplying air to the gas chamber of the fermenters.

The air supply fan is adjusted in such a way that it transports a maximum volume flow of 5% of the biogas produced in the same chamber.

The air supply is calculated so that, even with a malfunction of the quantity regulator, larger amounts of air cannot be transported.

In addition, backstops (guards) are installed in the air ducts for air supply to the gas chamber, to prevent gas escape.

## 4. Discussion of the Results

This study confirms that the temperature plays a crucial role in the anaerobic degradation process of a mixture of plant and animal waste substrates, with its impact on this process being more significant than the influence of acid concentration [45–47]. The findings of the authors in [48] are also confirmed, stating that the loss of thermal energy in biogas anaerobic degradation primarily involves the consumption of heat, necessary to elevate the temperature of incoming raw materials for fermentation, as well as the thermal consumption for transportation into the fermenter. As a result of the conducted research, the observation made by the authors in [32] is also confirmed, emphasizing that low temperatures are highly unfavorable for anaerobic degradation. Although digestion at high temperatures offers numerous advantages, it requires a greater energy input. Anaerobic degradation at moderate temperatures is often applied in the treatment of animal manure. The results confirm the findings in [49], indicating that the fermentation system at moderate temperatures exhibits greater stability compared to that at high temperatures. With equal mass of organic matter, the net methane production is more significant in the mesophilic temperature range.

The obtained data on methane production over a year from plant and animal substrates provide a key perspective on the efficiency of the biogas installation. The impressive result of 1,423,942 $Nm^3$ $CH_4$/year from plant components highlights the significant potential of these raw materials for methane generation. This aspect is crucial in the context of sustainable waste management and biomass utilization for energy purposes. Additionally, the production of 81,940 $Nm^3$ $CH_4$/year from animal waste further focuses the possibilities for sustainable conversion of animal waste into a valuable energy resource. This aspect has a dual positive effect, reducing waste and creating energy that can be used for various purposes.

The data related to energy consumption from the biogas installation provide fundamental information reflecting the complexity of the energy balance in the innovative biogas production systems. The analysis of these data not only traces important aspects of daily energy dynamics but also points out the opportunities for effective management of the production processes. The annual thermal energy measured for the fermenter is notable, with a value of 819.94 MWh/year. This indicator is key to understanding the use of thermal energy in the anaerobic fermentation process, highlighting the high energy potential resulting from combining biogas technology with fermentation processes. At the same time, the annual electricity consumption for internal needs is estimated at 299.63 MWh/year or 820 kWh/day. This aspect not only considers electricity consumption but also emphasizes the possibilities for internal energy self-sufficiency of the biogas installation. Such self-sufficiency underscores the sustainability of the system and reduces external dependence. The analysis of energy consumption from these parameters provides a comprehensive view of energy efficiency and management in the biogas installation.

The latest indicators in the analysis of the energy performance of the biogas installation enhance the impression of the high degree of efficiency and sustainability of this energy project. Specifically, the net annual production of electricity and thermal energy is estimated at 6099 MWh/year and 5656 MWh/year, respectively. These values show the successful integration of biogas technology into the daily energy landscape. The high levels of electricity and thermal energy not only mark the intensive energy activity of the installation but also show the potential for diverse and sustainable use of the produced energy. This approach has significant ecological benefits, reducing dependence on conventional sources and contributing to the ecological sustainability of the energy sector. The obtained energy production not only ensures the sustainability of the biogas installation but also makes a substantial contribution to ecological energy provision. In the context of the growing need for low-carbon energy solutions, the biogas installation represents a significant step towards achieving these goals. The obtained results provide a basis for process optimization and serve as a model for the development of similar innovative energy systems in the future.

The measured daily amount of gas produced by the biogas installation extends to 4126 $Nm^3$, demonstrating a significant capacity for energy production. Concurrently, the daily gross energy production is 41 MWh, and on an annual level, it reaches 15,059 kWh/$Nm^3$.

The efficiency assessment of the biogas generation process is of the utmost importance, and the provided value of approximately 85.5% serves as a key indicator of the success of the entire systemic approach. This efficiency indicator highlights the precise engineering management and integration of technologies, leading to optimized processes in the biogas production system.

In conclusion, the reported data reflects the high productivity and efficiency of the biogas installation. These results are of paramount importance in evaluating the sustainability and efficiency of the biogas production system. The obtained information establishes a foundation for further optimization and development of similar energy systems, showing the importance of biogas as an ecological and sustainable solution in the field of renewable energy.

In general, biogas obtained through the fermentation of plants and animal biomass is mainly used for firing a cogeneration plant for the simultaneous production of electricity and thermal energy. Given that these installations are outside populated areas, it is very difficult to fully utilize the produced thermal energy. This excessive thermal energy could be used for district heating as well as heating green houses. The partial use of thermal energy is also one of the reasons for the lower final efficiency of the facility. From a regulatory point of view, the limitations come mainly from the type of technology used and the release of harmful substances into the atmosphere during the fermentation process. A reduction in the relative number of cattle, and consequently, the amount of animal substrate available, is considered another limitation.

Additionally, if silage and manure loads are not used for bioenergy, they have several other applications. For example, silage mass with little processing can be used for feeding farm animals, and the manure mass can be used to fertilize the soil. In the second case, it is necessary to keep the manure mass in open-type storage for a certain period to facilitate the maximum release of ammonia before fertilization. When the manure and silage mixture is processed in the digestor for the purpose of bioenergy production, the output substrate has improved properties as a soil fertilizer with a reduced ammonia content.

## 5. Conclusions

In this study, the volume of gas produced each day and the production rate during four batch processes during three months within one year at a production plant was analyzed. The temperatures and residence times of the substrates in the fermenter of a real working anaerobic fermentation biogas installation utilizing animal and plant substrates in Southeastern Bulgaria were evaluated. It was discovered that the biogas installation works most efficiently at the optimal residence time of the substrates of 22 days and at temperatures in the mesophilic mode of 38 °C and in the thermophilic mode of 55 °C. The efficiency of the installation is about 85.5%. For one year, 1,505,882 $Nm^3$ $CH_4$/a methane was produced. The annual consumption of electricity for internal needs is 299.63 MWh/a (for all electrical equipment serving the digester) and 649.09 MWh/a thermal energy is required cover the heat losses through the bottom, lid and jacket of the fermenter, including the thermal energy for maintaining the fermentation process in the required temperature boundaries. The net annual production of electricity and heat is 6099 MWh/a and 5656 MWh/a, respectively. The presented technology, on which the plant works to obtain biogas from the smoothed substrates, allows an increase in the yield of biogas during the fermentation process at reduced electrical and thermal energy consumption at the digester in comparison with the available fermentation technologies on the market. The estimated energy efficiency improvement of the process is between 3 and 7%. This is in line with the needs of raw waste material producers, energy consumers, and the environmental standards aimed at reducing harmful emissions into the atmosphere.

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