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Article

Efficiency of Utilization of Wastes for Green Energy Production and Reduction of Pollution in Rural Areas

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Abstract: The aim of the study is to present the possibilities of simultaneous production of green energy and reduction of pollution in rural areas. Actions taken by small family businesses are in line with the goals of a low-carbon economy. The paper presents the results of research on the possibility of using ecological energy for production and, at the same time, utilizing harmful waste generated in farms in rural areas. Within a month, a medium-sized biogas plant can produce about 35–40 GJ of energy (depending on the input material). Biogas production may be of significant importance from the point of view of environmental protection, especially in the case of overproduction of animal waste and slaughterhouse materials. The production and use of energy generated from agricultural waste give a great opportunity for diversification and an increase in income of family farms. In addition to financial, energy, and environmental gains, we can obtain a very valuable fertilizer that is easily absorbed by plants in field cultivation. Energy efficiency is an important parameter in biogas production. The possibility of reducing pollution in rural areas and the possibility of using digestate as a fertilizer and an innovative addition to biocomposites.

Keywords: biogas; energy; green energy; waste; biomass; pollution

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1. Introduction

Population growth is the increase in the number of people living in an area, which is associated with the depletion of natural resources and can lead to specific environmental problems such as global warming, deforestation, and loss of biodiversity. Global changes in the environment, caused by the overexploitation of natural resources and the burning of fossil fuels, have a number of negative effects on human health and the functioning of ecosystems [1]. With the development of world economies and the exponential growth of the population, the production of waste also increases rapidly. It becomes a resource that must be used or disposed of in some way. As a result of industrialization, global urbanization, and economic development, the world is facing the problem of using industrial, agricultural, and urban waste [2–4].

Climate and climate change are generally influenced by many factors, including vigorous activities such as burning fossil fuels, deforestation, nitrogen fertilization, fluorine-based gases, and animal husbandry [5]. Along with the growing demand for the consumption of meat and milk, animal production is becoming one of the most harmful sectors for environmental protection phenomena. The emission of methane, carbon dioxide, carbon monoxide, ammonia, and hydrogen sulphide to the atmosphere is very high, especially in summer, which has a negative impact on the environment, and in the case of higher concentrations, it causes poisoning of the environment [6,7]. Rural areas are places where threats arise, but at the same time, they are places where biomass can be produced. Biomass, the raw material for biogas production, consists of three basic groups of organic compounds: carbohydrates, proteins, and fats. Apart from these nutrients, the growth of microorganisms in the fermentation chamber also requires soluble forms of potassium, sodium, iron, magnesium, and calcium, as well as trace elements such as molybdenum, manganese, copper, zinc, cobalt, nickel, selenium, and tungsten. The substrates most commonly used in biogas plants, such as raw materials, agricultural waste, and sewage sludge, contain the appropriate amounts of the listed elements. When using highly homogeneous substrates with the same composition, it is necessary to enrich the charge with microelements in a synthetic form or to introduce additives containing elements that are not present in strategic substrates.

In rural areas, where a lot of pollution is generated as a result of agricultural production, farms or agricultural enterprises can start implementing biogas production. Biogas can be produced from different raw materials and used for different purposes. It can be used for electricity, heat, and transport production [8]. Due to the fact that there are different possibilities for biogas production, diagrams of sustainable biomass development and calculation of GHG reduction taking into account different sources and different production methods should be prepared. For example, during the anaerobic digestion process, a significant reduction in the amount of methane emitted that would otherwise be released into the atmosphere is observed. Thanks to this fermentation, a significant reduction in GHG emissions is possible. A new approach to the topic of biogas plants is to show that there are innovative solutions. Since each biogas installation works on a different farm, in a different environment, or simply separately in the village, on a different substrate, individual solutions are needed to take advantage of the available conditions in a given area. The obtained biogas is used to produce electricity or directly to the gas installation in the village or city. Therefore, we cannot say that every installation for biogas production is the same and that there are no innovative solutions in it. Therefore, paying attention to this aspect constitutes a new approach to the issue.

The production of biogas also has a positive effect on the cycle related to fertilization and plant nutrition because when the produced digestate, as an excellent bio-fertilizer, replaces the use of mineral fertilizers, and thus prevents CO_2 emissions resulting from the production of artificial fertilizers [9]. The global CO_2 emissions from the production of artificial fertilizers is 600 million tons per year [10]. In the near future, sewage treatment plants and biogas plants will become the foundation of the circular economy. The circular economy will significantly contribute to achieving climate neutrality in the future. Thanks to biogas plants, valuable agricultural biogens will circulate in a closed circuit, significantly reducing the production of fertilizers based on fossil raw materials. Waste generated on farms will be processed into biogas and then into biomethane, which will allow to use of the raw material potential and move away from conventional fuels in heating.

It should be remembered, however, that methane is an important component of biogas. The composition of biogas consists of methane (50–75%), carbon dioxide (25–50%), and smaller amounts of nitrogen (2–8%). Traces of nitrogen sulphide, ammonia, hydrogen, and various volatile organic compounds are also present in the biogas, depending on the feedstock. Methane decomposes relatively quickly in the atmosphere compared with carbon dioxide. The advantage of methane is that it remains in the atmosphere for only about a decade, while CO_2 persists for several centuries [11].

The novelty of the research that has been carried out is to draw attention to the triple importance of biogas plants in rural areas. That gap in the literature concerning the triple meaning of green energy was covered by our study. The triple action of biogas stations is a cornerstone of using biogas installations in the countryside. First action: because of the growing human population and also the requirement for products coming from animal and plant production technology, it is obvious that something should be done with the huge amount of waste coming from this sector. Animals also produce large amounts of wastes and odors, which could be limited in local exposure by using closed tanks for biogas production. In the case of a well-produced biogas installation there is no harmful smell around the village. Even in a closed distance to the biogas system does not smell at all. Second action: energy production from agricultural waste and the third action: natural fertilizer production. Therefore, there is a positive influence on pollution reduction, energy production, and natural fertilizer production.

2. Literature Review Results

Issues related to biogas plants and their positive impact on the environment are the subject of numerous studies described in the literature. Much attention has been paid to the production of energy and the use of feedstock available in rural areas in biogas plants. The reuse of post-production materials allows one to create a closed production cycle. Aspects such as the reduction of pollutants and the possibility of using digestate as fertilizer have also been analyzed. The presented scientific papers show the most important aspects of biogas plants that have been published in the last few years. Papers presenting the most interesting solutions have been selected and presented in Table 1.

Table 1. Selected papers dedicated to biogas production.

Title of the Paper	Main Issues Discussed in the Paper
Renewables projects in peripheries: determinants, challenges, and perspectives of biogas plants—insights from Central European countries	In the transition to a low-carbon economy, agricultural biogas plants can be a very useful and sustainable element of the energy transformation carried out in rural areas [12].
Best practices for recovering rural abandoned towers through the installation of small-scale biogas plants.	The systematic development of renewable energy systems makes it possible to achieve the assumptions and goals created in Europe in the field of environmental protection and sustainable development. For production of agricultural biogas, the existing infrastructure in rural areas can be used, after minor modification [13].
Biogas production from small-scale anaerobic digestion plants on European farms	The technology of processing of animal manure and the organic fraction of waste can be implemented on a small scale by anaerobic digestion. Anaerobic digestion systems can convert organic matter into biogas (a mixture of mainly carbon dioxide and methane), making the technology suitable for a variety of applications in energy, agriculture and potentially in the emerging bioproducts and bioprocesses sector [14].
The efficiency of the biogas plant operation depending on the substrate used	Studies conducted among agricultural biogas plants have shown that the best efficiency is achieved by biogas plants processing: silage, cattle manure and chicken manure as well as slaughterhouse waste [15].
Small-size biogas technology applications for rural areas in the context of developing countries	In terms of net energy production, anaerobic digestion of methane is more competitive and more efficient than other forms of biomass energy production. This applies to both production costs and environmental impact. Therefore, in economic and ecological terms, biogas is a good solution for the economy [16].
Biogas as a sustainable energy source for developing countries: Opportunities and challenges	In areas of energy poverty, existing biomass resources (i.e., animal manure, crop residues, kitchen waste and green waste) can be converted to cleaner and more efficient energy carriers such as anaerobic biogas, which has the unique potential to provide clean and reliable energy [17].
Utilization of cow dung residues of a biogas plant for sustainable development of a rural community	In rural areas, biogas plants produce biogas and huge amounts of organic residues. Solid and slurry wastes are widely used as part of waste management and biogas production. The residues are used as organic fertilizer and biogas as fuel [18].
Towards a full circular economy in biogas plants: Sustainable management of digestate for growing biomass feedstocks and use as biofertilizer	Digestate is an excellent biofertilizer. The use of digestate on land characterized by low fertility, especially in areas located near biogas plants, allows the production of up to three times more biomass, which is then used for biogas production [19].

Table 1. *Cont.*

Title of the Paper	Main Issues Discussed in the Paper
Beyond energy crops and subsidised electricity—A study on sustainable biogas production and utilisation in advanced energy markets	Production of biogas is a costly investment, therefore the profitability of biogas production without subsidies depends on the price of alternative fuels [20].
Bio-methane and bio-methanol co-production from biogas: A profitability analysis to explore new sustainable chemical processes	The prices of electricity, natural gas and biomethanol can significantly affect the overall profitability of a biogas plant. A large biogas production plant can produce biomethanol with a profitable margin. On the other hand, small production requires subsidies or grants [21].
Socioeconomic impacts of domestic biogas plants on rural households to strengthen energy security.	Public participation should be increased in order to widely use biogas technologies as an alternative energy source. The positive impact of home biogas plants on farms should be presented [22].
The review of biomass potential for agricultural biogas production in Poland.	Appropriate management of biomass residues produced by the agri-food industry can reduce their negative impact on the environment. An alternative use of agricultural waste is the production of biogas. The most common agricultural and food residues used as substrates for biogas plants in Poland are maize silage, slurry and distillery waste [6].
Agricultural biogas plants in Poland.	A characteristic trend of changes in the development of agriculture is the growing importance of non-food use of raw materials of agricultural origin. In addition to ensuring food security, agriculture can also perform other functions, including those related to energy security. Agricultural biogas plants are a chance for diversification of agriculture and multifunctional development of rural areas [23].
Biomethane as an energy resource for achieving sustainable production: Economic assessments and policy implications.	Biomethane is a possible energy source that can meet the requirements of sustainable production. Circular bioeconomy models have been developed to reduce dependence on non-renewable and unsustainable resources, among others by including biogas in the green taxonomy [24].
A mini-review of biomethane valorization: Managerial and policy implications for a circular resource	The ecological transformation is based, among others, on based on renewable energy sources, so the role of biomass is very important. When producing energy from biomass and waste, the circulation of resources is promoted if sustainable substrates are used. The production of biomethane from waste is important for combating climate change and energy self-sufficiency. The closed circulation of resources uses substarts and thanks to this, from the point of view of environmental protection, the appropriate waste is valorised [25].

Source: own elaboration

3. Materials and Methods

The research was carried out using the method of quantitative and qualitative research. Quantitative research was carried out in the form of an experiment carried out on a farm producing biogas. In the experimental study, it was checked whether there is a cause-and-effect relationship between the input variables and the output variables. During the experimental tests in the biogas station, the input parameters were all the most important parameters affecting the fermentation process, namely: temperature inside the fermentation chamber, pH of the fermented material, redox potential, and the ratio of carbon to nitrogen (C:N). The carbon-to-nitrogen ratio is maintained between 20 and 30 for better biogas conversion because bacteria consume carbon at a rate 30 times faster than nitrogen. The optimum thermophilic temperature varies from 50–60 °C, and a pH value of 6.7–7.5 has to be maintained. Oxidation-Reduction Potential (ORP) meters are mainly used to determine the reducing or oxidizing capacity of the tested liquid solution. This is an important parameter when determining, for example, the efficiency of a biogas plant with slurry, mainly in terms of biochemical processes taking place in it and assessing their efficiency. The output variable was the amount of biogas obtained. During the research, a reinforcing variable was also used in the form of corn silage or green fodder. Qualitative research was carried out in the form of secondary desk research. Desk research consisted of the analysis of existing data in published reports, statements, and in scientific and popular science articles. Desk research allowed for a broader overview of the biogas plant sector and allowed for the analysis of the existing biogas plant market and its development potential in the near future.

4. Results

The production of biogas should allow for obtaining a clean, full-value fuel. Therefore, manufacturers face the challenge of implementing innovative technological solutions.

Contamination of ordinary biogas with hydrogen sulphide can reach even 3000 ppm, which results in its low quality. Therefore, the hydrogen sulphide content should not exceed 600 ppm. In Germany, industrial production reached 300 ppm. Depending on the starting material, the content of hydrogen sulphide ranges from several ppm to tens of thousands of ppm, as presented in Table 2.

Table 2. Content of hydrogen sulphide in various agricultural wastes.

Initial Material	Content of Hydrogen Sulphide [ppm]
cattle excrement	500–8000
pig excrement	500–10,000
poultry excrement	500–10,000

Source [26].

The market for the production of biogas, electricity, and heat in biogas installations is a relatively new market. In Poland, there are currently just over 130 agricultural biogas plants, but none of them produce biomethane. Biogas plants will have to introduce new and improved technologies. The assumed change is to enable the production of the highest quality renewable fuel—biomethane, which will be injected into the gas network or compressed and used in transport, e.g., as fuel for gas engines, for refueling buses, or a source of "green" hydrogen. The use of biogas for the production of electricity or heat requires the removal of hydrogen sulphide and water vapor, which contribute to corrosion and reduce the life of the equipment. Injecting biogas into the natural gas distribution network or using it to power vehicles requires, apart from the removal of sulphur compounds and trace impurities, additional biogas drying, and removal of carbon dioxide. (biogas upgrading to natural gas quality). The schema of the biogas production and use is shown in Figure 1.

Both solid biofuels and recycled biofuels, as well as biogas produced in rural areas, are able to reduce CO_2 emissions and, at the same time, provide heating and electricity for residents of neighboring areas.

In treatment plants with energy cogeneration, part of the biogas produced is used to ensure the operation of the installation, and the surplus is stored or delivered to the national grid as renewable energy. The hot water produced by the electric motor/generator (cooling water) is partly recirculated in the fermentation reactor to maintain the optimum process temperature. Excess hot water is used as a heating medium for the surrounding buildings and for neighboring municipalities.

Thus, the produced biogas can be used:

- For the production of electricity and heat in cogeneration systems (CHP);
- For heat production in industry or residential construction;
- In transport—biogas purified to the quality of natural gas can be used as fuel for vehicles if they are equipped with a natural gas installation.

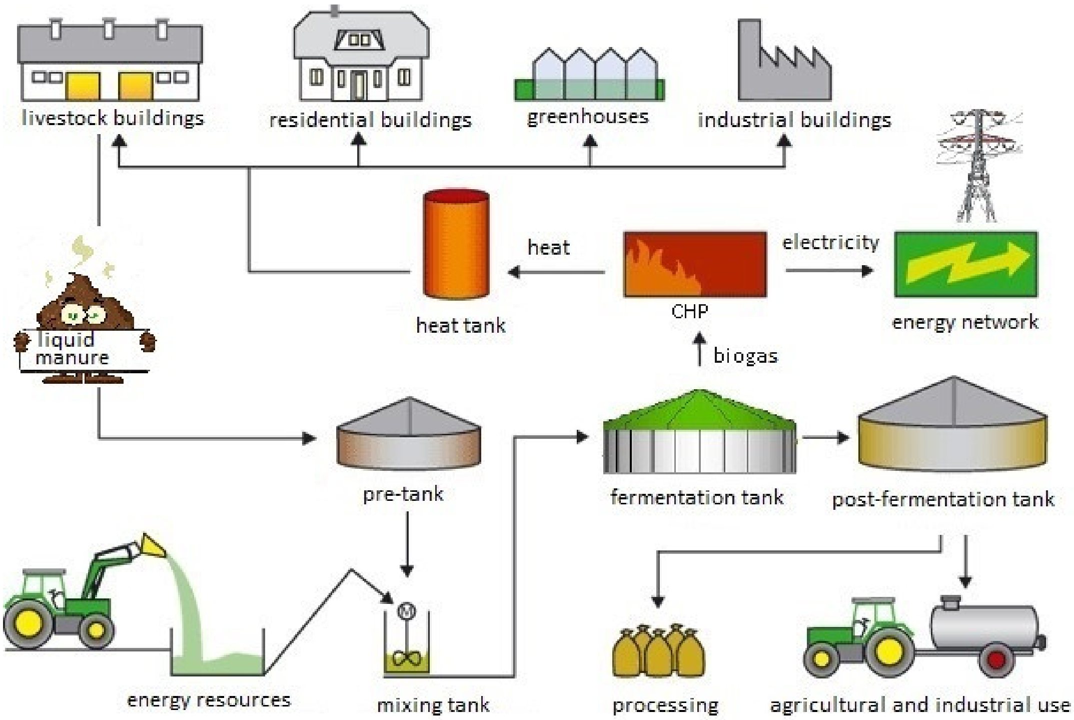

Figure 1. Scheme of waste utilization for green energy production. Source: own elaboration based on [27].

In Poland, the most popular way of using biogas produced in agricultural biogas plants is its processing in a cogeneration engine. Biogas resulting from methane fermentation is purified in a specialized process using, for example, activated carbon as a purification filter. Bog iron ore, which has very good absorption properties, can also be used. The biogas must be treated because the direct use of untreated biogas could cause failures in the cogeneration unit. This is due to the fact that biogas contains compounds and particles that pose a threat to the cogeneration engine. This would result, for example, in clogging of the injectors supplying gas to the combustion chambers, insufficient combustion after the injection itself, corrosion and degradation of the piston and cylinder surfaces, and the deposition of excessive carbon deposits behind the exhaust valve. The purified biogas becomes a suitable fuel for the cogeneration unit [28].

In rural areas where a lot of farm waste, such as slurry or solid waste, is generated, it can be used to produce biogas. Slurry from the livestock building flows by gravity through the channel to the fresh slurry tank. In this tank, the slurry is mixed with a pump and then transported through a pipe to the digester. The digester is fed once a day with daily slurry production. The fermentation process in the chamber is continuous, with cyclic feeding with batches of fresh slurry. Equipping the chamber with an overflow pipeline ensures that the same amount of digested slurry is discharged to the digested slurry tank as it was poured in. Three times a day, the contents of the chamber are mixed with a stirrer. Each mixing takes 10 min. The agitator sucks slurry from the lower part of the chamber through the casing pipe and the heater and transports it to the upper part of the tank, thus mixing it. The discharge pipe allows the digester to be emptied by discharging the slurry into the fermented slurry tank. Both mixing and transport are ensured by the use of a second slurry pump. Both pumps make it possible to discharge slurry through a three-way valve to the slurry tanker. The gas from the chamber is discharged through a pipeline.

Small-scale anaerobic digestion technology is particularly applicable to the European agricultural sector, where the average size of individual farms and land productivity are currently insufficient to meet the raw material requirements of medium and large-scale crops. The scheme of the biogas production installation is shown in Figure 2.

The gas installation is protected against excessive pressure increase by a liquid fuse that discharges excess gas into the atmosphere. The fuse prevents air from entering the network, and its design allows you to regulate the gas pressure. The installation is protected against flashback by means of an installed flame arrester. A dehydrator and desulphurizers are used to purify the gas [28,29].

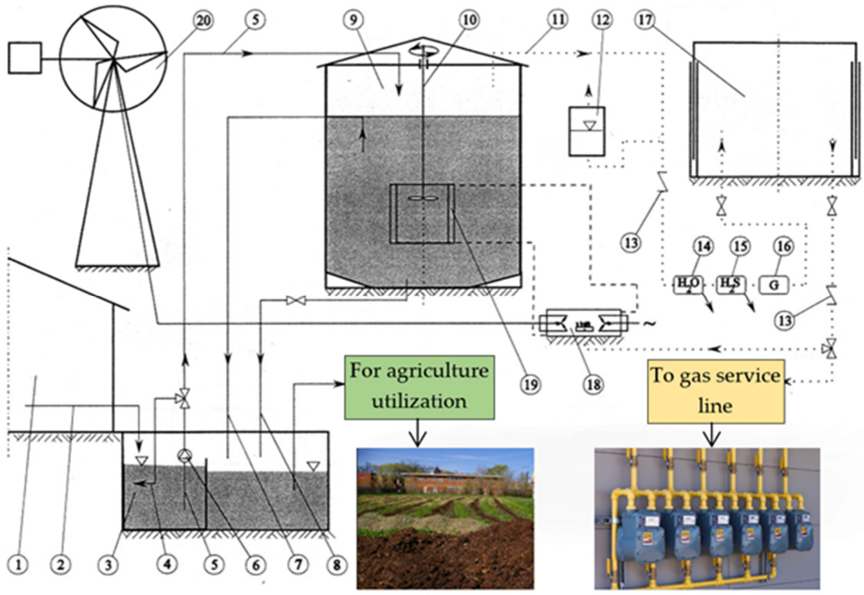

Figure 2. Scheme of biogas installation with fermentation chamber. 1—*Livestock building*, 2—*direct supply pipeline of liquid manure from building*, 3 —*preliminary container*, 4—*mixing pipeline*, 5—*supply pipelines*, 6—*pump*, 7—*overflow*, 8—*drain pipeline*, 9—*fermentation chamber*, 10—*mechanical mixer*, 11—*gas pipeline*, 12—*safety device*, 13—*flame breaker*, 14—*dehydrator*, 15—*desulfuriser*, 16—*gas meter*, 17—*gas container*, 18—*central heating stove*, 19—*heater*, 20—*wind power station*.

The desulphurization process consists in passing gas through the desulphurizing mass covering the shelves of the desulfurizer. The main component of the mass is bog iron ore. The gas meter allows you to control the amount of gas produced. The gas is stored in a bell-shaped steel tank and directed to the household utensils and to the boiler. The boiler operates in two systems: for electricity, switched on at start-up and in the event of a failure, and for biogas. Electricity can be obtained, for example, from a wind farm, as shown in Figure 2. Central heating pipes supply water from the boiler to the heater. The water jacket, wetted by the slurry, supplies the mass with the energy needed to maintain the temperature of 35 °C in the digester. The fermented mass of slurry will be used on the farm as a fertilizer.

The results after 21 working days were as follows: a biogas plant operating on pig slurry produced 2616 m^3, and a biogas plant powered by chicken manure reached 3012 m^3. The energy produced from the obtained biogas, assuming 35% electrical efficiency, amounted to 35 GJ (pig slurry) and 40 GJ (chicken manure) for the monthly billing. During the tests, the content of hydrogen sulphide in biogas was measured. The results were between 600 and 700 ppm, an average result that should be improved in the future.

5. Discussion

The modern economy is characterized by increased demand for energy while paying attention to ecological aspects: zero emissions and environmental friendliness [30]. The energy transformation, apart from large industrial projects, is also reflected in the increased availability of energy services for local communities. This is manifested by the implementation of low-carbon economy initiatives, energy decarbonization, and increasing energy efficiency in rural areas [12]. Agricultural biogas is one of the sources of electricity and heat that can be produced in countries based on agriculture in order to support the energy production system by large power plants. Thanks to the production of biogas, problems associated with the energy crisis can be reduced, especially in rural areas. Energy is an indispensable part of modern society and can serve as one of the most important indicators of socioeconomic development. However, despite technological advances, some three billion people, mostly in rural areas of developing countries, still meet their energy needs for cooking by traditional methods by burning biomass resources (i.e., firewood, crop residues, and animal dung) in traditional crude kilns. Such practices are known to cause significant environmental, social, economic, and public health problems. In order to achieve sustainable development in these regions, access to clean and affordable (renewable) energy is essential. In this context, the upgrading of existing biomass resources (i.e., animal manure, crop residues, kitchen waste, and green waste) to cleaner and more efficient energy carriers (such as anaerobic biogas) has a unique potential to provide clean and reliable energy while preserving the local and global environment. In this way, there is a symbiosis between stakeholders that leads to a circular economy. On the one hand, generated waste such as slurry, manure, manure, peelings, or straw are subject to the process of utilization. As a result of the utilization process, a plant mass is created for which agricultural producers find an additional market. On the other hand, the biogas plant generates energy from a renewable source, increasing local energy security in terms of electricity and heat supplies and introduces safe organic fertilizers to the market [31].

Despite the significant potential to serve developing countries, however, the high cost and lack of expertise in installing and maintaining biogas technology prevent its widespread use in geographically isolated communities. Coordinated efforts from both governmental and non-governmental sectors are absolutely essential to facilitate the upgrading and diffusion of biogas technology to exploit the inherent potential that is currently untapped; it can be said not fully exploited. The intention of this article is to highlight the current state, challenges, and potential of biogas technology in order to encourage further research, development, and dissemination of this concept in developing countries [17].

A good case study example of a biogas plant in a low-income rural area is the village of Ziala in the Satkhira district of Bangladesh. It is well known in the local community for its cow dung management and biogas production. Based on the available raw material, biogas plants produce huge amounts of organic residues and biogas. Cow manure is widely used in plants as part of waste management and biogas production. The residues are used as organic fertilizer and biogas as fuel in the village of Ziala. Therefore, Shaibur et al. (2021) carried out research to observe the effectiveness of the use of cow dung residues produced in biogas plants and their subsequent impact on the socioeconomic profile. The study was based on direct interviews with randomly selected dairy farmers in 2014. Twelve representative biogas plant samples were randomly selected for the interview. The results suggested that a renewable energy transmission system in the form of a biogas plant has successfully converted cow manure into an energy- and nutrient-rich organic fertilizer, reducing the cost of purchasing chemical fertilizers for plant owners. Renewable energy transmission facilities have significantly improved the overall cooking conditions in biogas digesters and reduced the time needed to collect firewood. This makes it easier to manage livestock and preserve forest resources. The biogas plants ultimately contributed to environmental improvement and resource recovery, which ultimately improved the socioeconomic profiles in terms of occupational distribution and education of the participating households. However, some households in the study area did not optimally manage agricultural waste and cow dung. The feces were highly concentrated and, in the absence of proper management, posed a serious threat. This caused degradation of the environment in terms of water and air pollution in the study area. In addition, agriculture is also a source of nitrogen oxides and ammonia, which, when dissolved in water, is a serious problem for organisms living in it [18].

Digestate is a potential biofertilizer and a potential source of income for many biogas plants around the world. Thanks to its fertilizing properties and high yield potential, digestate can be an alternative source of plant nutrients and can be widely used in plant production. The digestate can also be used in the industrial production of biocomposites. According to Ekielski et al. (2021), the addition of digestate has a positive effect on improving the physical and mechanical parameters of some biocomposites, e.g., films (coatings) made of thermoplastic starch [32]. However, returning to the main use of digestate in agriculture, its real impact on soil properties and biomass yield is still untapped. Various post-fermentation products from eight agricultural biogas plants were tested by Jurgutis et al. (2021) for their chemical composition and fertilization potential. Pig manure was dominant in all biogas stations, but it is a raw material with a relatively low energy value, providing 15–27 m^3 of biogas per Mg of biomass used, but it is nevertheless cheap. Because the cost of transporting pig manure is very high, it is recommended to pump it through pipelines to biogas plants and not to transport it by trucks, therefore it is recommended to locate biogas plants very close to breeding farms. In order to pre-treat the waste, it is stored for a certain period of time, usually several dozen days, in anaerobic conditions at a temperature of 38–52 °C. This process causes the fermentation mass to be free from parasites and pathogenic bacteria and weed seeds to be deactivated. The results obtained from the chemical analysis of the digestate indicated that the digestate biomass contained a large amount of nitrogen (up to 73 g kg^{-1} fresh weight) and potassium (up to 25 g kg^{-1} fresh weight). The digestate value was estimated in the range of EUR 2.88–7.89 Mg−1 for liquid digestate and EUR 7.62–13.61 Mg^{-1} for solid digestate based on the market commercial price of nitrogen fertilizers, potassium phosphorus, organic carbon, Cu, Zn, Fe and Mg in the year 2021. The digestate produced in a 1 MW biogas plant is worth EUR 941–2095 per day in addition to revenues from energy sales. The use of digestate on low-fertility soils in the vicinity of the biogas plant allows for the production of up to three times more biomass suitable for biogas production. The use of digestate for the production of semi-natural biomass from grasses in low-fertility soils in the vicinity of a biogas plant can be an alternative strategy for diversifying the portfolio of raw materials for biogas plants [19].

In many countries, biogas plants have been promoted, and special government programs have been dedicated. Governments have established grants, incentives, and policies [33]. However, it is worth analyzing the situation without subsidies and support for this activity. The purpose of the study realized by Bedoic et al. (2020) was to examine the functioning of biogas plants in advanced energy markets after the reduction of energy crops and the withdrawal of biogas plants from subsidy programs for electricity production. Continuous production of electricity and heat in combination with biogas and the sale of electricity on the day-ahead market may be a viable strategy only in the case of cheap substrates. When the break-even point for electricity production in biogas power plants reaches 100 €/MWh_{el}, the sale of electricity on the day-ahead market does not generate a profit. The study showed that a more profitable operational strategy is to combine the operation of a biogas plant on the electricity balancing market with the production of biomethane or to combine a small sugar beet processing plant with a biogas upgrading plant to cover the heat demand in sugar beet processing. The technical and economic analysis showed that the profitability of both alternative operating strategies is seriously dependent on the selling price of biomethane. Under the given market conditions, the selling price of biomethane below 50 €/MWh is not profitable for biogas plants. The developed model can serve as a guideline for biogas plant operators on how to proceed after significant changes in both the production and use of biogas occur [20].

As mentioned, currently, biogas obtained from biogas plants should be characterized by properties that allow it to be also used in industrial networks. Baena-Moreno et al. (2020) conducted research on the potential synergy between biogas upgrading and CO_2 conversion to biomethanol. This novel idea arises as an alternative to the traditional biogas-to-biomethane route, which involves CO_2 separation. The paper presents a technical and economic analysis of the process in order to examine the profitability for potential investors. In total, 15 scenarios were analyzed. Different sizes of biogas plants were tested as baseline scenarios: 100, 250, 500, and 1000 m^3/h. In addition, Baena-Moreno et al. investigated the potential impact of government incentives in the form of subsidies on biomethane (feed-in tariffs and percentage of investment) was investigated. Finally, a sensitivity analysis was developed to investigate the impact of key parameters. The results of the baseline scenarios showed that unprofitable results can be obtained without subsidies. Biomethane subsidies in the form of feed-in tariffs have proven effective for 500 and 1000 m^3/h installations. For a tariff subsidy of €40/MW, biogas plants with a capacity of 500 m^3/h are extremely profitable (net present value of €3,106,000). For plants producing 1000 m^3/h biogas, the €20/MW subsidy as feed-in tariffs gives a similar net present value result. Our results indicate that only a large biogas production can produce biomethanol with a profitable margin of less than 90–100% of subsidized investments. Sensitivity analysis showed that the prices of electricity, natural gas, and biomethanol can significantly affect the overall profitability, translating the expected positive cases into negative scenarios [21].

With climate change and the over-exploitation of fossil fuels, the advantages of bioenergy use are becoming more and more obvious, and many countries and regions around the world are committed to building clean energy biogas plants, as reflected in this literature review. The aim of the article was to identify the problems related to the current use of agricultural waste in the production of biogas and various possibilities for using biogas. Suggestions for the future development of biogas were made by comparing the potential of agricultural waste with the construction of a biogas project. The use of waste can be important in agriculture as well as in industry.

6. Conclusions

The advantage of agricultural biogas plants is that organic waste suitable for methane fermentation is first used to produce biogas, and only then are targeted crops used. The biogas production cycle is, therefore an integrated system for the use of natural resources. First of all, the great advantage of biogas is the profit in the form of renewable energy production, which brings energy, environmental and agricultural benefits. A medium-sized biogas plant can produce 35–40 GJ of energy per month. Secondly, getting rid of organic waste and getting nutrients as a result of production. The post-fermentation mass (undecomposed biomass and minerals) has excellent fertilizing properties. Thanks to this, CO_2 emissions from the production of artificial fertilizers, which globally amount to 600 million tons per year, are reduced. Secondly, getting rid of organic waste and obtaining fertilizing ingredients as a result of production. The post-fermentation mass (undecomposed biomass and minerals) has excellent fertilizing properties.

The advantage of biogas production is also the fact that it reduces the number of bad substances in waste, which translates into a reduction in the amount of soil and water contamination. This reduces the negative impact of contaminated waste on land and water.

Limitations in the conducted research resulted from the short number of biogas plants in which the research was conducted and also due to the fact that the research was not carried out in all seasons of the year.

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