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Biogas Plant Exploitation in a Middle-Sized Dairy Farm in Poland: Energetic and Economic Aspects

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Abstract: Although cow manure is a valuable natural fertilizer, it is also a source of extreme greenhouse gas emissions, mainly methane. For this reason, this study aims to determine the impact of investments in a biogas plant on the energy and economic aspects of the operation of a dairy farm. A farm with a breeding size of 600 livestock units (LSU) was adopted for the analysis. In order to reach the paper's aim, the analysis of two different scenarios of dairy farm functioning (conventional–only milk production, and modern–with biogas plant exploitation) was conducted. The analysis showed that the investment in biogas plant operations at a dairy farm and in using cow manure as one of the main substrates is a more profitable scenario compared to traditional dairy farming. Taking into account the actual Polish subsidies for electricity produced by small biogas plants, the scenario with a functioning biogas plant with a capacity of 500 kW brings €332,000/a more profit compared to the conventional scenario, even when taking into account additional costs, including the purchase of straw to ensure a continuous operation of the installation. Besides, in the traditional scenario, building a biogas plant allows for an almost complete reduction of greenhouse gas emissions during manure storage.

Keywords: biogas plant; energetic optimization; substrates; manure; wheat straw

1. Introduction

1.1. Methane as a Greenhouse Gas

Methane, right after carbon dioxide, is considered to be the greenhouse gas that is the most harmful to the climate [1]. Almost 59% of the world's emissions of this gas are of anthropogenic origin, of which the largest share (40–53%) is agriculture, especially intensive production [2]. In the EU, the share of agriculture in anthropogenic methane emissions is 53%, 26% is methane from waste, and 19% comes from energy production [3]. The reduction of methane emissions slows down negative climate changes and improves air quality [4]. Most of the legal acts concerning climate policy pay mostly attention to limiting carbon dioxide emissions. However, more and more attention is paid to the reduction of methane emissions [5]. The European Green Deal Communication emphasizes that reducing methane emissions related to the energy sector is one of the goals in achieving climate neutrality by 2050 [6]. In turn, the EU strategy to reduce methane emissions emphasizes that biogas production in anaerobic digesters from animal waste (i.e., manure) can be one of the solutions for reducing methane emissions to the atmosphere [7,8].

1.2. Dairy Production as Important Source of Methane Emission

Ruminants are animals whose digestive tracts emit large amounts of methane [4]. A typical high-performance dairy cow produces up to 250 dm^3 of methane daily [9]. Many scientific teams research ways to reduce this emission by modifying the animal's diet or using various additives that reduce the activity of methane in cows' stomachs [10–14]. This is due to the fact that the emission of methane from the digestive system of ruminants reduces the milk yield of animals [15–17]. However, numerous studies show that it is challenging to significantly reduce methane emissions from intensive cattle farming [18–20].

The proper management of livestock manure has a much greater potential to reduce methane emissions, especially in the case of cattle manure [21–23]. It should be emphasized that manure stored in piles is a source of important methane emissions, the scale of which may reach tens of thousands of tons per year in Poland [24]. This emission mechanism is related to the typical practices of farmers who remove manure and form piles without pressing them immediately to remove air from inside the piles—as is done when forming silage corn piles [25,26]. However, there is still some air in a carelessly stacked pile. Cattle manure is an energy material, so bacteria break down easily decomposable chemicals in the presence of oxygen, producing CO_2, water vapor, and a large amount of heat [27,28]. On the one hand, this process creates anaerobic conditions inside the heap, and on the other, it increases the heap's temperature to a level between 35 and 55 °C [29,30]. In this way, anaerobic conditions inside the heap are created, similar to those prevailing inside fermenters in a biogas plant, promoting intensive methane production [31,32]. Therefore, it should be emphasized that in dairy production, the manure removed every day should be immediately transferred to the biogas plant and subjected to the fermentation process there—but under controlled conditions [33–35].

A much lower intensity of methane production occurs from the slurry stored in the tanks [36,37]. This is mainly due to the much lower storage temperature of the slurry than that of the manure in noncompacted piles [38,39]. During storage, slurry stored at a temperature from a few to several degrees Celsius generates methane emissions, but at a level that is many times lower than for farmyard manure stored in piles [40,41].

1.3. Opportunities in Biogas Production

Additionally, the production of biogas in agricultural areas may provide additional income from agricultural activities, which is an opportunity to develop the local economy in rural areas and promote circular economy principles in local communities [42–44]. Biogas is considered a renewable energy source [45,46]. Therefore, its production allows the increase of the share of these sources in the national energy mix, which is the EU's goal as set out in the renewable energy directive (RED II) [47]. A biogas plant can be a significant source of additional income for a farm specialized in dairy production. Energy prices are more stable than prices for agricultural products, including milk [48,49]. Therefore, a biogas plant located next to a dairy farm is a very environmentally friendly and logical solution [50,51]. What is more, perhaps shortly, breeding dairy cows in the European Union will have to be combined with the need to treat manure as a substrate in biogas plants. This is because it is related to the European Commission's activities aimed at reducing greenhouse gas emissions [2,52]. However, currently, methane emissions are not covered by any fee system—as is the case with CO_2 emissions [5]. It is worth emphasizing that the use of manure as input for a biogas plant does not result in a loss of its fertilizing value because all macro- and microelements, except for carbon, will be found in the postfermentation pulp [53,54].

What is more, apart from financial benefits (from the sale of electricity and heat or biomethane), promoting good social attitudes towards the environment, and increasing the share of renewable energy in the energy mix, biogas production can positively affect the quality of the soil [55,56]. The final byproduct of the production of biogas is digestate [57,58]. It is a highly absorbable natural fertilizer, the product of the anaerobic digestion process [59,60]. Digestate from biogas production is considered to be an organic or organomineral fertilizer [61]. Due to the dry organic matter content not exceeding 8%, it can be poured onto fields, just like slurry [62]. Digestate contains phosphorus, nitrogen, and potassium and has a neutral to alkaline pH, making it a good fertilizer [63]. Moreover, the digestion of manure can significantly reduce methane emissions from storages [64]. The barrier to using digestate may be the oversized content of heavy metals and microbiological contaminants, but this case happens mainly when urban sewage sludge is used for fermentation (not considered in the case of agricultural biogas plants). These compounds' content must be checked before using digestate as a fertilizer [65,66].

1.4. Manure and Wheat Straw as Biogas Plant Feedstock

The manure generated in dairy production should necessarily be used as a substrate for biogas plants [67,68]. However, this is not about its average energy value but about avoiding methane emissions during manure storage in heaps [21,31]. After passing through the fermentation process in a biogas plant, manure is processed into a digested pulp, which is already devoid of significant energy value [69]. However, its effect on the soil is friendlier than that of manure or, especially, slurry because of the much lower biological and chemical oxygen demand (BOD and COD) [70,71]. In Poland, due to legal and economic conditions (the level of subsidies for the produced energy in particular), the most optimal way is to build a biogas plant with a capacity of 500 kW [72]. Such an installation is treated as a small biogas plant, and its construction requires only a simplified administrative path (basically the three most important documents). However, feeding a 500 kW biogas plant with only cow manure would require well over 1000 cows on a large scale. It has to be underlined that the term "small" biogas plant, in Polish regulations, means something completely different than the typical understanding in the wider world. In South Asia or Africa, there are millions of tiny biogas plants working with the manure produced by a few cows [73]. However, the climate in these areas creates very favorable conditions for the fermentation process (a high temperature, which excludes the necessity for fermenter heating). In Poland, which is located in Central Europe, it is impossible to exploit biogas plants without a special heating system, while the temperature during wintertime can reach down to −20 °C. That is why only installations with fairly big fermenters (several hundred cubic meters) make technological sense, as their biogas production is sufficient to heat themselves and generate a surplus of energy [74,75].

Meanwhile, in Poland and many EU countries, the most common farm sizes comprise between 100 and 500 cows [76]. Therefore, supplementation with additional biological material is required to ensure a 500-kW biogas plant's continuous operation on a farm of this size. One of the most effective agricultural substrates is straw [77]. Straw has a 2–3-fold higher methane production potential than maize silage, the most popular substrate used by agricultural biogas plants in Europe [78–80]. At the same time, cereals are widely cultivated, thanks to which straw availability is at a high level throughout the country. For this reason, farmers are increasingly using it as a substrate for biogas plants [81]. However, it should be emphasized that the use of straw without an appropriate pretreatment may cause technological problems in biogas plants through the formation of scum, leading up to and including fermentation being stopped [82,83]. Therefore, in order to use straw for biogas plants, it must be very finely shredded; the best techniques for this are to break down lignocellulosic structures at the cellular level, for instance with extrusion, cavitation, or micronization [84–88]. Heat treatment techniques such as Steam Explosion are also very beneficial here [89]. It is worth adding that problems with the formation of scum do not occur in fermentation tanks with a central agitator, such as in the Dynamic Biogas technology [90].

This paper aimed to analyze two scenarios of dairy farm functioning: a conventional one (based mainly on profits from milk production) and a second scenario that included biogas plant exploitation with the usage the cow manure as one of the main substrates, where additional profits from sold energy, heat, and digestate were present. It has to be underlined that the dairy waste (like cheese whey) [91] can also be potentially used as an energetic substrate for biogas plants; however, in the described situation, the distance from the dairy factory was too far for the economic transport of waste for the planned biogas plant.

2. Materials and Methods

In order to reach the paper's aim, the analysis of two different scenarios of dairy farm functioning (conventional—only milk production, and modern—with biogas plant exploitation) were conducted. The main schema of the analytical and calculation procedures are shown in Figure 1.

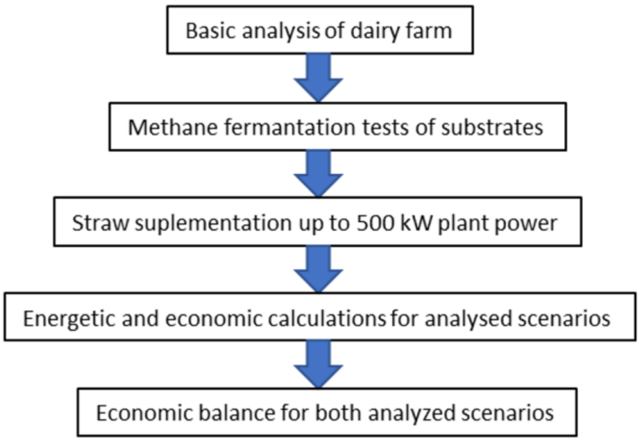

Figure 1. Methodological procedures for the energetic and economic analysis of both scenarios.

The paper's idea is based on a real investment planned to be realized in one of the Poznan University of Life Sciences (PULS) experimental farms. In this farm, dairy production from 600 cows is realized, and the investment for building a biogas plant with 500 kW of electric power is planned for 2021. At the end of 2019, PULS already finished a similar biogas plant at Przybroda experimental university farm (25 km west of Poznan) (Figure 2). However, the Przybroda biogas plant mainly uses biowaste (including food waste and waste from the agro-food industry) as its main substrates.

Figure 2. 500 kW biogas plant at Przybroda PULS experimental farm.

The investment procedure made in the case of the biogas plant building should be based on strong economic and energetic arguments. It has to be underlined that the decision about the construction of biogas plants is usually related to a cost of several million euros. That is why this decision should be taken while considering several steps that let one reach the proper choice. The good practice is to follow the way that is shown in Figure 3.

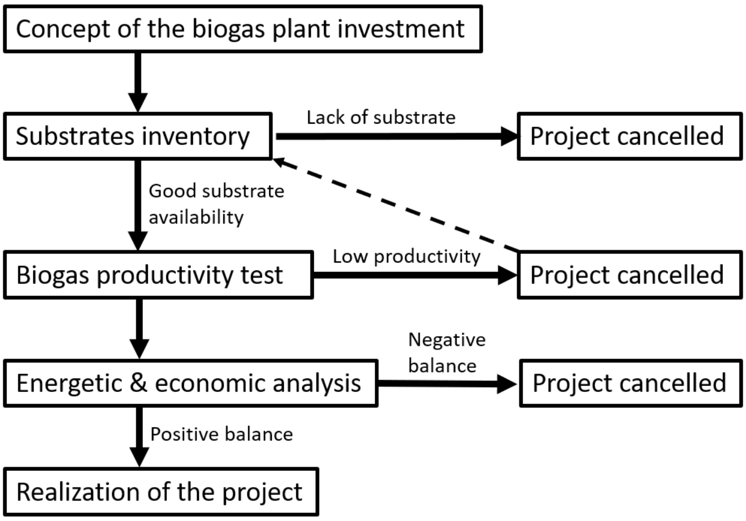

Figure 3. The flowchart of the proper way for making decisions for biogas plant investment.

2.1. Biogas Production Efficiency from Substrates

The biogas production efficiency analysis from substrates (manure and straw) was made in the Ecotechnologies Laboratory at Poznan University of Life Sciences, the biggest Polish biogas laboratory. The test methodology was done within German norms DIN 38414/S8 [92] and VDI 4630 [93], the most popular analytical procedure used in the European biogas laboratories. The Ecotechnologies Laboratory was the first Polish biogas laboratory that passed the quality proficiency test organized by the German organizations Verband deutscher landwirtschaftlicher Untersuchungs- und Forschungsanstalten (VDLUFA) and Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL).

The fermentation process runs in the glass reactors (volume 2 dm^3), well-closed with a weck system. The reactors are maintained at a stable temperature (39 °C, ±1 °C) by their placement inside the aquarium with heat water. The samples (about 50 g of organic dry matter) are put inside reactors (always in three replications) and then filled with inoculum. The blank samples (in three replications as well) are only filled with inoculum. Inoculum is produced from the liquid part of the digestate obtained from a typical biogas plant. The produced biogas goes to the plexiglass cylinder, where its volume is measured every 24 h. The gas composition (CH_4 0–100%, CO_2 0–100%, O_2 0–25%, H_2S 0–10,000 ppm, and NH_3 0–1000 ppm) is measured using the special portable tool GA5000. This instrument is calibrated each week using the gases to calibration (CH_4 65%, CO_2 35%, H_2S 500 ppm, and NH_3 100 ppm) supplied by Linde Gas company. The obtained results for each material are reduced by the production from the blank samples and then recalculated to be expressed as biogas and methane production from 1 Mg of FM (fresh matter) (as well as of TS and VS) of the analyzed sample.

The final results of the methane production efficiency from the substrates analyzed in laboratory tests sent from the Ecotechnologies Laboratory to the contractors are always expressed in CH_4 m^3 from 1 Mg of FM. This value is indispensable for further energetic calculations of planned biogas plant exploitation.

2.2. Energetic and Economic Calculations

The investment plan is to build the biogas plant with 500 kW of electric power in Dynamic Biogas technology. The reason for this size is related to Polish law regulations. Whole administrative procedures are simplified in building a biogas plant with a maximum electric power of 0.5 MW. Furthermore, this size is enough to reach a reasonable profit from electric energy production.

The electric energy (E_e) production from methane produced yearly from used substrates was calculated as follow:

$$Ee = VCH_4 \cdot WCH_4 \cdot \eta e \quad [MWh] \tag{1}$$

where:

VCH_4—volume of methane produced from digested substrates [m^3];

WCH_4—energetic value of 1 cubic meter of methane [9.968 kWh m^{-3}];

ηe—electric efficiency of CHP unit [0.4].

A similar equation should be used to calculate the heat (thermal energy, E_t) amount emitted from the cogeneration unit (CHP):

$$Et = VCH_4 \cdot WCH_4 \cdot \eta t \quad [MWh] \tag{2}$$

where:

VCH_4—volume of methane produced from digested substrates [m^3];

WCH_4—energetic value of 1 cubic meter of methane [9.968 kWh m^{-3}];

ηt—thermal efficiency of CHP unit [0.45].

The calculation of biogas plant electric power (P_e) is based on the electric energy amount produced during the whole year and the working time of CHP. This equation is presented below:

$$Pe = Ee/t \quad [MW] \tag{3}$$

where:

Ee—amount of electric energy produced yearly [MWh];

T—working time of CHP during the whole year of exploitation [8400 h].

The amount of heat can also be expressed in GJ, which is the most common unit that is used in reality by enterprises and people. This amount can be easily calculated because 1 MWh is equal to 3.6 GJ. As in the case of electric power (P_e), a similar equation was used for thermal power (P_t) calculations:

$$P_t = E_t/t \quad [MW] \tag{4}$$

where:

Et–amount of heat produced yearly [MWh];

T–working time of CHP during the whole year of exploitation [8400 h].

It should be underlined that in a typical biogas plant, the real working time (7200–8100 h/a) is firmly lower than the 8400 h/year value fixed before. This is related to many exploitation problems and breaks of biogas production by, i.e., mixing system failures and other mechanical damages. However, the biogas plants working in Dynamic Biogas technology have a unique construction of steel fermenters (with a central, vertical mixing system working with only one mixer that is easily exchanged) and can reach up to 8500 working hours per year in reality.

The investment cost for building the 0.5 MW biogas plant in DB technology is 9 million PLN (€1.970 million with a currency rate of €1 = 4.56 PLN). This means that the depreciation cost (for a 15-year period of exploitation) is €131,580/a.

3. Results

3.1. Basic Characterization of Analyzed Dairy Farm

The analyzed farm has over 1000 ha of planted area and a herd of 600 dairy cows (breeding size of 600 livestock units (LSU)), which produce milk at a high level of 11,000 L/LSU/a. The milk is delivered to the dairy for 0.29 €/L. The sale of milk is one of the primary income sources for the farm, as it amounts to €1.925 million (Table 1).

Table 1. Characterization of the analyzed dairy farm.

Parameter	Unit	Value
Price of milk	€/L	0.29
Milk production	L/LSU/a	11,000
Number of cows	LSU	600
Income from the sale of milk	€1000/a	1925
Manure weight	Mg/a	9855

After being removed from breeding buildings, cow manure is stored in piles on concrete platforms and spread into the field three times a year for fertilization. The total mass of produced farmyard manure is 9855 Mg per year. It should be emphasized that in the current situation, manure stored for several months a year is a source of uncontrolled methane emissions, which in the future may become a financial problem for the farm if the European Commission pushes the taxation of CH_4 emissions, on an equal basis as CO_2 currently, through.

3.2. Methane Productivity Analysis

The basic parameters, such as dry matter content (TS), organic dry matter (VS), methane content, biogas, and methane yield of substrates, used for the fermentation tests are presented in Table 2.

Table 2. The basic parameters and biogas yield of the tested materials.

Substrate	TS	VS	C:N Ratio	Biogas	CH_4 Content	CH_4
	[% FM]	[% TS]		[m^3/Mg FM]	[%]	[m^3/Mg FM]
Cow manure	21.56	85.62	21:1	79.90	56.37	45.04
Wheat straw	92.67	96.96	95:1	468.49	56.72	265.72

The results of TS show the big difference between both materials. Farmyard manure contains mostly water (over 78%) and more than 15% ash, so the methane productivity from one ton of fresh matter (45.04 m^3 /Mg FM) is almost six times lower when compared to the wheat straw result (265.72 m^3/Mg FM). That is why, from a biogas plant exploitation point of view, the usage of straw for installation feeding has a much higher profitability when compared to manure. The biogas obtained from the fermentation of wheat straw and manure had a similar methane content: 56.7 and 56.4% methane, respectively.

The fermentation charts for manure and wheat straw are presented in Figures 4 and 5. It has to be underlined that the samples of manure and straw had a different initial mass, so the results presented in the figures cannot be directly compared. However, for comparison, the biogas and methane productivities calculated in m^3 from 1 Mg of both materials are presented in Table 2. Moreover, Figures 4 and 5 are important for presenting the dynamic of the gas production and fermentation time.

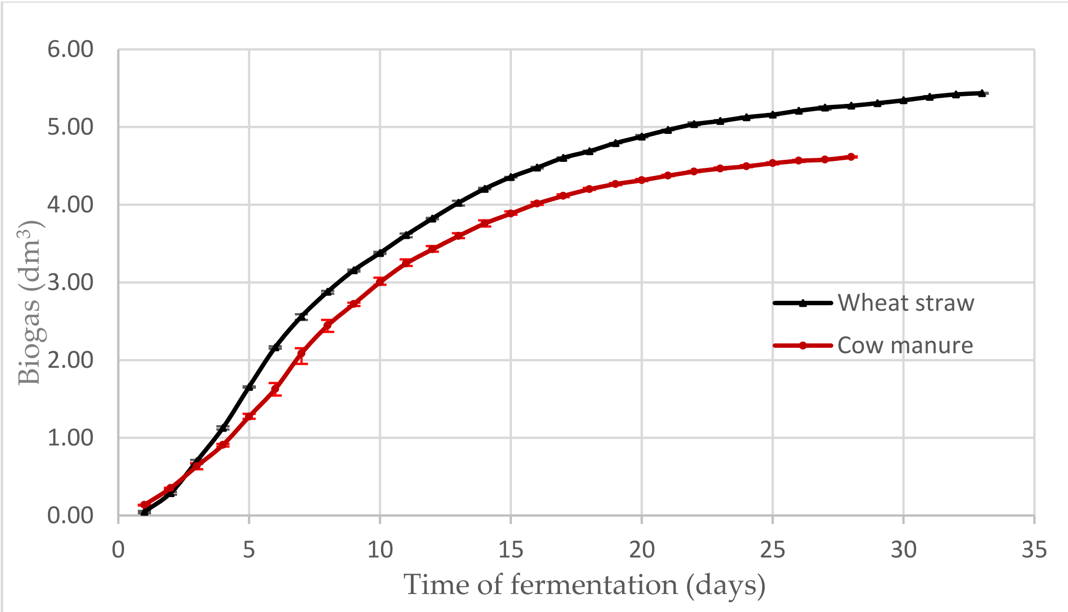

Figure 4. Production of biogas during the samples' fermentation process (daily measurements) for both materials, with error bars (the initial sample masses were different).

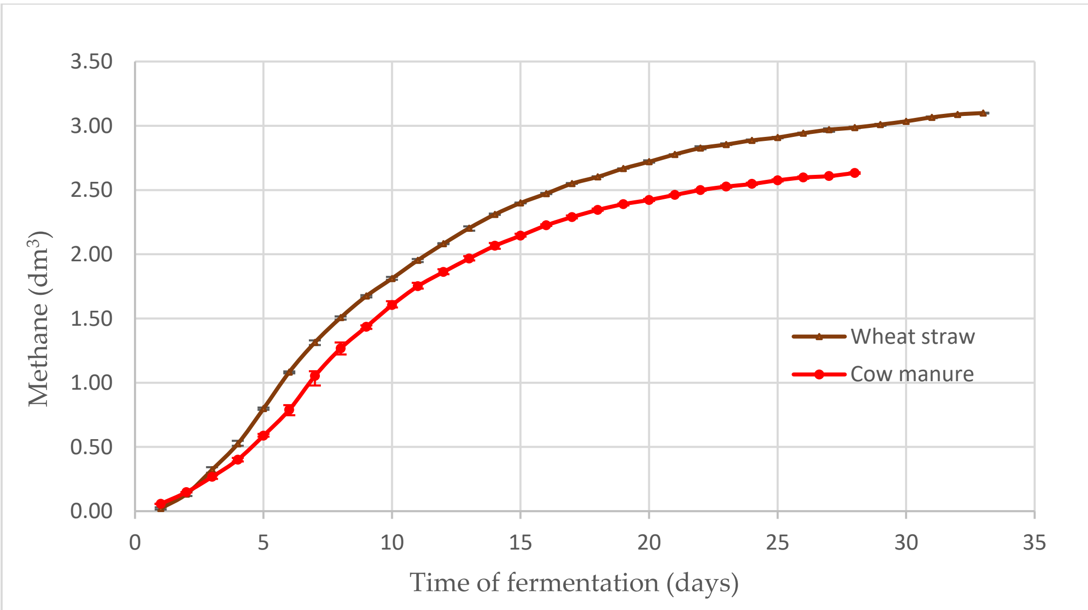

Figure 5. Methane production during the samples' fermentation process (daily measurements) for both materials, with error bars (the initial sample masses were different).

The runs of fermentation show that cow manure is digested in a shorter time (HRT (Hydraulic Retention Time) = 28 days) than wheat straw (33 days). This phenomena is also visible in the periods for 80% and 90% of the total methane production (Figure 6).

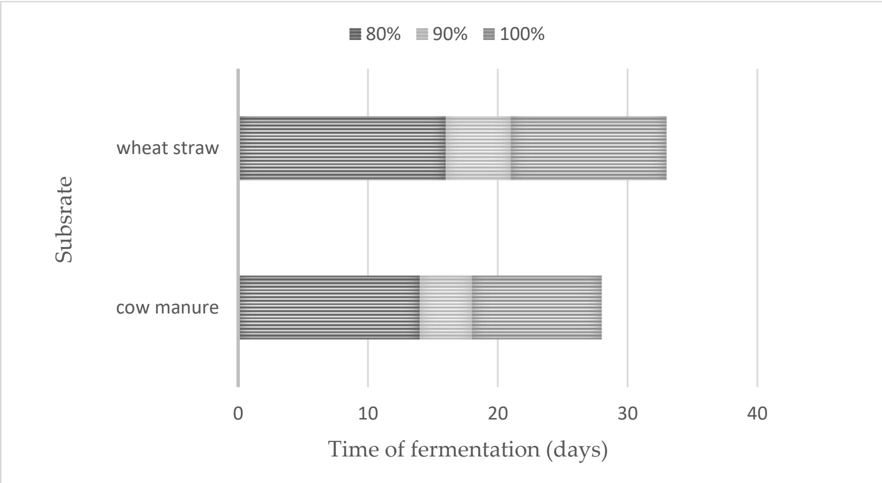

Figure 6. Time required for 80, 90, and 100% of total methane production for the analyzed materials.

80% of total methane production was reached by cow manure on the 14th day; however, wheat straw needed 16 days to reach the same level (two days later). Those differences between manure and straw are bigger for 90% of the total production (three days), and the biggest difference is for the end of fermentation (five days).

3.3. Energetic and Economic Calculations

In the energy calculations, the first stage included the calculation of the electric power of the biogas plant, while only assuming work that used manure as a substrate. On this basis, it has been calculated that the production of methane from manure will amount to over 443,000 m^3 annually, which will allow for the production of 1770 MWh of electricity by a 0.211 MW installation (Table 3).

As this capacity is less than half of the planned installation (500 kW), it was decided to obtain the missing capacity (0.289 MW) by using 2300 Mg of wheat straw (Table 3).

Table 3. Energetic aspects of the biogas plant in the analyzed dairy farm.

Parameter	Unit	Value
CH_4 yield of manure	m^3/Mg	45.04
Amount of methane	m^3/a	443,869
Electric energy	MWh/a	1770
Electric power of the installation	MW_e	0.211
Additional substrate: wheat straw		
The mass of straw	Mg/a	2300
CH_4 yield of straw	m^3/Mg	265.72
Amount of methane	m^3/a	611,156
Electric energy	MWh/a	2437
Electric power of the installation	MW_e	0.289
Total amount of methane	m^3/a	1,055,025
Total electric energy	MWh/a	4207
Total electric power	MW_e	0.500
Electricity price	EUR/MWh	158.3
Electricity value	EUR/a	666,044
Amount of heat	MWh/a	4732
Amount of heat	GJ/a	17,037
Heat power	MW	0.563
Price for heat	EUR/GJ	8.77
Heat value	EUR/a	134,500

Ultimately, the designed installation will generate 1,055,025 m^3 of methane, which, with a CHP unit electrical efficiency of 40%, allows for the production of 4207 MWh of electricity. When related to the 8400 h of operation of the cogeneration unit, this amount of energy allows 500 kW of electric power to be reached for the planned installation.

Since the current price (including subsidies from the state) for electricity for a 50–500-kW biogas plant in Poland is 158.3 €/MWh, the generated energy will bring revenues of over €666,000 per year.

The amount of heat, calculated according to a methodology similar to that of electricity, is over 17 TJ. When calculating the heat price, the price of heat produced from Poland's most popular energy carrier, i.e., hard coal, was used. In Poland, the value of heat generated from coal is €8.77/GJ. On this basis, the revenue from the sale of heat can be calculated, amounting to €134,500 per year (Table 4).

Table 4. Economic balance of the analyzed dairy farm in a conventional scenario (milk production) and in a scenario with milk production and biogas running.

Parameter	Standard Scenario	Biogas Plant Scenario
	Profits [kEUR/a]	
Sold milk	1925	1925
Manure as fertilizer	259	
Digestate as fertilizer		74
Electricity production		666
Heat		135
	Costs [kEUR/a]	
Straw cost		−76
Depreciation		−132
Service costs and others		−77
Balance	**2184**	**2516**

The total (simplified) economic balance of the dairy farm operation in two scenarios (traditional and in the version with a biogas plant processing cow manure and straw) shows a significant advantage of the second variant. The total profit in scenario II (€2.516 million) is €332,000 higher than in the traditional scenario. Considering the cost of building a biogas plant (€1.970 million), this means that this installation will be paid back after six years of operation.

The described situation may change even more favorably for scenario II if the European Commission introduces taxes for methane emissions, similar to the current situation in the case of carbon dioxide. It should be taken into account that agriculture is a source of high methane emissions, and especially large amounts of methane are produced from heaps of cattle manure. The necessity to pay for emissions of methane—a greenhouse gas that is 21 times more powerful than CO_2—will significantly worsen the profitability of scenario I (traditional). On this basis, it can be assumed that in the future, the construction of biogas plants at medium and large dairy farms will be necessary due to the reduction of uncontrolled methane emissions from stored manure.

4. Discussion

The paper describes an energetic and economic analysis of a dairy farm and small biogas plant coupling in order to increase farm profitability and decrease the uncontrolled methane emission from manure stored in heaps. However, some doubts may relate to the term "small" biogas plant, as in the described farm the planned installation has 500 kW of electric power and cannot be sufficiently fed with manure produced from 600 cows. In fact, when compared to the most popular biogas plant size in India and Southeast Asia (fermenters with a volume of only several cubic meters even, often located underground), this is a huge difference [73,94]. The main reason for this considerable difference in the definition of a small biogas plant is related to climate conditions. In Poland, temperatures reaching even −20 °C in wintertime make it almost impossible to build small biogas plants like those in Asia because all constructed installations should be equipped with a heating system that allows the temperature inside fermenters to be kept at the level of 38–42 °C [95,96]. Some trials in Poland, involving the construction of small biogas plants with a fermenter volume of 20–60 m^3 and an installed power of 8–12 kW, showed that those installations were not able to produce enough biogas during wintertime to heat themselves and stabilize the temperature inside the fermenters. Furthermore, this is due to the high investment costs of operating such micro biogas plants, and, as a solution to this situation, Polish legislation defines a "small" biogas plant as an installation with installed electric power between 50 to 500 kW [97,98].

The usage of manure as a substrate for biogas plants is mentioned by many scientists as the best solution from an energetic, economic, and environmental point of view [33,99,100]. This can provide additional profit to animal farms (as was calculated in this paper) and can also reduce uncontrolled methane emissions to the atmosphere from manure stored in piles. What is especially interesting for human health is that anaerobic digestion can also destroy the antibiotics that are present in manure [101]. The massive usage of antibiotics in animal production and the subsequent uncontrolled stream of solved medicaments to the environment via animal (and human) excrements is the main reason for the creation of "super-bacteria"—resistant to all known antibiotics.

Some studies underline that (in general) animal manures should be treated by anaerobic digestion; however, these materials have a relatively weak biogas potential in order to guarantee a high productivity of biogas plants [102,103]. This was also the case in our study because whole manure production could cover less than half of the power in the planned installation. That is why the usage of additional substrates is required [80,104]. One of the most popular substrates is straw, which is easy to collect and has a high productivity. Many researchers have underlined the high value of different straws used for biogas feeding, like maize straw [77,105] or cereals [106]. In the described study, we need an additional 2300 Mg/a of wheat straw to keep the highest productivity of the planned biogas plant. It has to be underlined that straw usage for biogas plant feeding does not generate a conflict between food and biofuels production as is the case for maize silage usage. This is because straw is treated as an agricultural byproduct and not as the main yield.

The concept described in this paper is based on using only manure and straw for the feeding fermentation process. The reason for this concept is that both materials are produced on farms. However, it has to be underlined that the codigestion of different biowastes can generate a synergy effect and increase the total biogas production on a level that is higher than the sum of biogas generated separately by each substrate [107,108]. An excellent way to increase biogas productivity is the usage of dairy waste (i.e., cheese waste), brewery waste, and other materials (sometimes specific materials like biochar) [109,110]. In the described case, however, the dairy factory's distance was too big for the economic transport of dairy waste to the planned biogas plant.

5. Conclusions

Based on the research and results obtained, the following conclusions were formed:

1. Investment in a biogas plant operating at a dairy farm and using cow manure as one of the main substrates is a more profitable scenario than traditional dairy farming.
2. Currently, in Polish conditions, a scenario with a biogas plant operating with a capacity of 500 kW brings 332,000 €/a more profit than a conventional scenario (only milk production), even when taking into account additional costs, including the purchase of straw to ensure the continuous operation of the installation (manure from 600 cows will not provide substrate coverage).
3. In the analyzed case, the cost of building a biogas plant will pay off in less than six years. However, it is important to underline that this concerns the biogas plant with a power of 500 kW working with cow manure and wheat straw. Smaller-scale installations, as well as other substrates, can change this revenue time.

4. The economic advantage of the dairy farm scenario with a biogas plant over the conventional variant will be even more significant if the European Commission introduces charges for methane emissions from agriculture (which will affect particular dairy farms that store manure in piles).
5. It should be necessary to develop and conduct energetic and economic analyses for scenarios based on smaller size installations and alternative substrates (dairy waste, food-industry waste, etc.).

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