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The Economic Efficiencies of Investment in Biogas Plants—A Case Study of a Biogas Plant Using Waste from a Dairy Farm in Poland

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Abstract: High investments and low economic efficiency of agricultural biogas plants operating on farms are two of the main barriers to the development of the biogas plant sector. Identification of economic and financial problems related to the operation of such facilities allows for the reduction of entry barriers for private investors, especially farmers. The aim of this research was to analyze the economic efficiency of investing in an agricultural biogas plant operating at a dairy farm. For the analysis, the case study method was applied. The economic efficiency of investment in a biogas plant was assessed using six different cash flow options. The NPV (net present value) and IRR (internal rate of return) methods were applied to assess the economic efficiency of the investment. It was found that the investment project for an agricultural biogas plant with a capacity of 0.499 MW located at a dairy farm required a subsidy of approximately 40–60% of the value of to ensure satisfactory economic efficiency. It has been shown that a particularly important aspect in assessing the economic efficiency of an investment in an agricultural biogas plant is the use of an economic calculation that takes into account the valuation and quantification of all positive external effects of such projects.

Keywords: biogas plant; economic efficiency; investment; dairy farm; case study; energy security

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1. Introduction

The advancement of renewable energy sources represents a crucial aspect of enhancing national energy security and mitigating the detrimental effects of energy production on the natural environment [1,2]. The "Energy Policy of Poland until 2040", developed by the Ministry of Energy and the Environment, posits the limitation of the adverse impact of the energy sector on the natural environment. This objective is to be achieved, in part, through the accelerated development of renewable energy sources (RESs). It is anticipated that by 2030, renewable energy sources (RESs) will account for at least 23% of gross final energy consumption and that greenhouse gas (GHG) emissions will have decreased by 30% compared to 1990 levels [3]. Agricultural biogas plants are one of the specific sources of energy that will contribute to this reduction. Biogas production has become a common practice in many countries [4,5]. Many factors determine the success or setbacks of this method of energy production. These are economic, technological, and institutional factors [6–8]. Positive external effects related to the operation of agricultural biogas plants that allow for the reduction of environmental pollution are also important. This is particularly significant in terms of the possibility of using organic residues from agri-food processing and organic waste of farm origin, such as manure and crop residues, to generate renewable energy [9,10]. Besides biogas, an agricultural biogas plant produces digestate. The utilization of digestate as a soil amendment represents the most environmentally beneficial option [11], and furthermore, it has a favourable impact on economic outcomes.

The generation of energy from agricultural biogas plants is a popular method across European countries, especially those characterized by intensive animal production. The largest producer of biogas is Germany, followed by Italy, but also Denmark, Switzerland, Austria, and the Czech Republic [10,12–15]. In the European Union (EU-27), the primary energy output produced from biogas in 2022 (15,763 Mtoe) was more than twice as high as in 2010 (6996 Mtoe) [16], and Kampman et al. [17] posited that another doubling could be feasible by 2030. The development of this sector may encounter many technical, social and cultural, market, regulatory and institutional, political, and environmental, and especially economic and financial barriers [18,19]. In the area of economic and financial barriers, the attention is drawn to high investment costs and long payback periods, especially in the case of small investments, high investment risk, high operating costs, and low profitability [8,18,20,21]. In addition, attention is also paid to market barriers [18,22]. In the literature on the subject, the issue of economic efficiency of operation and investment in agricultural biogas plants is relevant [23]. Research draws attention to the low profitability of agricultural biogas plants [21,24–26] and the costs of substrate transport and their impact on the profitability of energy production [27–31]. In addition, there is a substantial body of literature on medium- and large-scale biogas projects [32–36]. Moreover, it is emphasized that investments in agricultural biogas plants are very sensitive to changes in market conditions and energy policy [37]. This generates a higher level of investment risk and consequently results in the need to obtain a higher rate of return on investments, which in many cases may lead to the lack of economic justification for their implementation. Therefore, such investment projects may require support from public funds. In the case of investments in agricultural biogas plants, an important aspect is also the identification of social and ecological benefits, which are significant from the point of view of public interest.

Agricultural biogas plants in Poland are typically situated in close proximity to large animal farms, utilizing the otherwise noxious waste products of slurry and manure as their substrate [38–40]. Investment in this type of business activity must be based on rational economic calculation. To the best of our knowledge, there is a lack of research focusing on aspects of assessing the efficiency of investments in agricultural biogas plants, especially small ones located on dairy farms, identifying factors determining the profitability of this type of investment, and research on analyzing the current economic and financial situation of these facilities. On the one hand, it is necessary to identify the economic benefits and costs associated with the operation of such a project, which allows reducing the risk of failure and may be a factor encouraging farmers to make this type of investment. On the other one, a detailed analysis of the factors determining the economic efficiency of investments in biogas plants will allow the preparation of appropriate policy tools for the development of this energy production sector. For this reason, the presentation of the results of already operating biogas plants provides interesting conclusions for both politicians and future investors. For this reason, the aim of this research is to analyze the economic efficiency of investing in an agricultural biogas plant operating on a farm engaged mainly in the production of dairy cattle. The case-stage method was applied in this study.

2. Development of Agricultural Biogas Plants in Poland

The "Energy Policy of Poland until 2040", developed by the Ministry of Energy and the Environment, posits the necessity of limiting the detrimental impact of the energy sector on the natural environment. This objective is to be achieved, in part, through the advancement of renewable energy sources. Poland has significant potential for using agricultural production to generate energy [41–44]. It can be argued that a particularly important role is played by agricultural biogas in the process of enhancing the contribution of the agricultural sector to the production of renewable energy. It is noteworthy that Poland possesses considerable and untapped potential for the production of biogas and biomethane using available substrates [45,46].

The development of agricultural biogas plants in Poland commenced in 2005 when legislative solutions pertaining to energy and environmental protection law were introduced. The amendment established public support systems dedicated to renewable energy sources, thereby implementing EU law into the legal system (Directive 2001/77/EC). This was followed by the establishment of the first agricultural biogas plant [44]. In 2023, there were 119 biogas producers with 143 installations (Figure 1). Based on these installations, 795.61 GWh of electricity and 374.09 million m3 of agricultural biogas were generated in 2023 (Figure 2). The rise in the generation of agricultural biogas and electricity can be attributed to two factors. Primarily, this can be explained by an increase in the number of agricultural biogas plants in Poland. Secondly, there has been a notable rise in investment interest in this particular area [47]. However, the number of biogas plants in Poland compared to the production capacity of the development plans adopted by the public administration should be considered very small [44]. In the adopted program for the development of agricultural biogas plants in Poland, approximately 2000 agricultural biogas plants (with a total capacity of approximately 250 kWe) were to be in operation by 2020 [48]. For instance, there are 11,269 biogas plants in Germany, 1710 in Italy, 890 in France, 578 in the Czech Republic, and 423 in Austria [49].

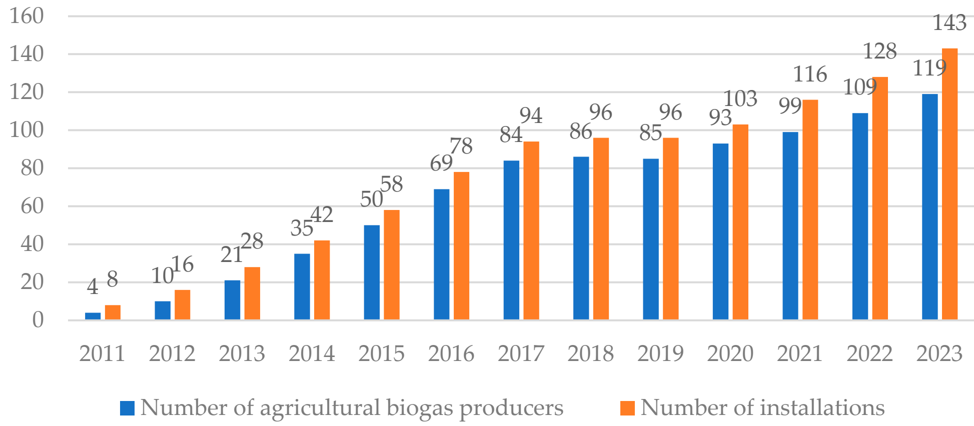


Figure 1. Number of agricultural biogas producers and number of installations in Poland. Source: [50].

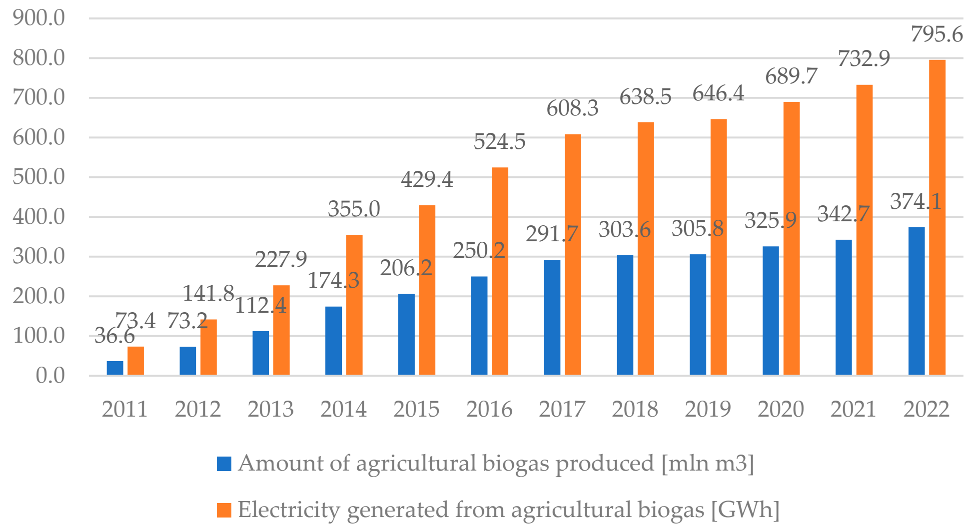


Figure 2. Amount of agricultural biogas produced, and amount of electricity generated from agricultural biogas in Poland. Source: [50].

In the structure of biogas plants, the largest share is taken by biogas plants with a capacity of 0.5–1 MW (39.5%), followed by biogas plants with a capacity below 0.5 MW (31.5%) (Figure 3). In turn, the installed capacity of biogas installations is mainly concentrated in biogas plants above 1 MW (Figure 4). These data indicate that the development of small agricultural biogas plants (below 1 MW) in Poland is in the initial phase. The development of small installations is mainly determined by exogenous factors, i.e., applicable legal regulations and financial support from public sources [51–53]. The low importance of the biogas sector in Poland is also indicated by its share in the total installed renewable energy capacity, which is low (Figure 5). In 2023 it was about 2%. Wind energy and photovoltaic installations are the renewable energy sources mainly developed in Poland.

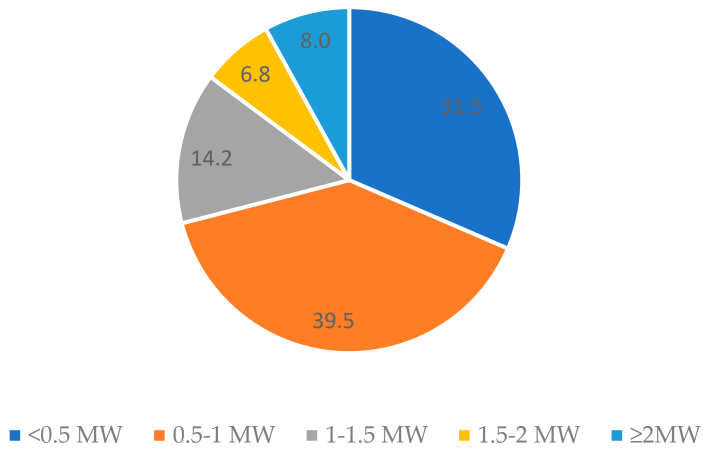


Figure 3. Structure of biogas plants according to installed capacity in 2023 in Poland. Source: [50].

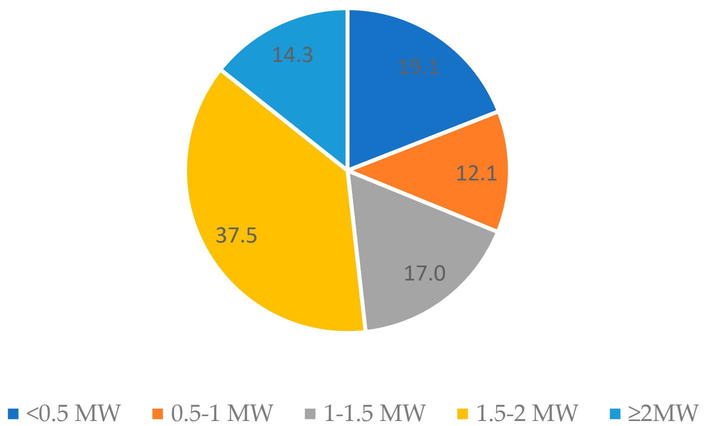


Figure 4. Structure of installed capacity in biogas plants in 2023 in Poland. Source: [50].

The substrate employed in the technological process represents a crucial factor that influences the economic efficiency of a biogas plant. The majority of biogas plants in Poland and Europe are based on NaWaRo technology or related solutions [44]. In the nascent stages of development, agricultural biogas plants were predominantly constructed in proximity to large hoggery farms. This strategic location enabled the utilization of copious quantities of agricultural substrates, including slurry and maize silage, which served as the basis for the input for NaWaRo technology [48]. For this reason, in 2011–2012 the share of slurry and maize silage was high (Table 1). In the following years, the structure of the substrate used changed. The importance of waste from the agri-food industry is increasing. This is attributable to the fact that a considerable number of new agricultural biogas production plants commissioned in Poland are situated at agri-food processing facilities [54]. This process should be considered beneficial since the biogas plant acts as a bio-waste utilizer. Moreover, it does not adversely affect food security [55]. Supplying biogas plants with crops grown for food can be controversial because of the competition for land between energy and food crops. This also increases the risk of intensification of agricultural production and the risk of creating monocultures.

Table 1. Structure of substrates used for agricultural biogas plants in Poland from 2011–2022.

Substrates	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
After-distillery stock	6.5	16.0	22.5	16.8	17.7	14.8	20.1	21.0	20.6	20.7	19.0	18.8
Slurry	56.7	36.9	29.0	26.9	24.1	24.1	21.3	18.9	18.5	17.3	16.4	16.4
Food processing waste	1.6	0.5	0.4	1.5	0.9	0.9	0.9	1.7	3.0	7.9	11.4	13.7
Fruit and vegetable residues	2.3	9.6	17.3	16.7	19.9	20.6	19.9	19.3	19.4	15.4	14.9	13.6
Maize silage	23.2	26.8	17.5	19.7	16.7	13.6	12.4	12.1	10.6	11.3	11.3	10.8
Technological waste from the agri-food industry	0.0	0.0	0.0	1.1	2.5	4.1	4.2	4.5	4.7	5.1	5.3	5.4
Beet pulp	1.5	4.0	6.5	8.9	7.6	6.9	7.4	7.3	6.4	4.8	4.2	4.0
Waste from dairy industry	0.4	1.4	0.8	1.0	1.9	2.8	2.0	2.7	3.2	3.0	2.7	3.0
Expired food	0.0	0.0	0.0	0.3	0.4	0.9	0.9	1.8	2.5	2.7	3.0	2.8
Post-slaughter waste	0.0	0.1	0.4	0.3	0.5	0.6	0.4	1.7	2.6	1.9	1.8	2.2
Manure	2.5	2.9	1.8	1.7	1.8	2.5	2.2	2.1	2.1	2.1	1.9	1.7
Waste plant mass	0.0	0.0	0.3	0.5	0.3	1.0	0.6	1.4	1.1	2.0	1.5	1.3
Fruits and vegetables	0.0	0.0	0.0	0.2	0.7	0.8	1.2	1.0	0.8	0.8	1.2	0.9
Cereal and cereal waste	0.3	0.1	0.0	1.1	0.4	0.6	0.6	0.3	0.2	0.4	0.9	0.8
Bird droppings	0.0	0.3	0.7	0.6	0.6	0.8	0.6	0.6	0.5	0.6	0.6	0.8
Fats	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.6	0.6	0.7
Sludge from the processing of plant products	0.0	0.0	0.3	0.2	0.0	0.0	0.0	0.3	0.4	0.5	0.9	0.6
Grass and cereal silage	2.8	0.1	0.1	0.8	0.4	0.5	0.7	0.6	0.6	0.6	0.6	0.6
Green forage	0.0	0.4	1.0	0.4	0.7	1.8	2.5	1.0	0.8	0.9	0.6	0.3
Other	2.2	0.8	1.5	1.4	2.7	2.6	2.0	1.4	1.5	1.5	1.2	1.5

Source: [50].

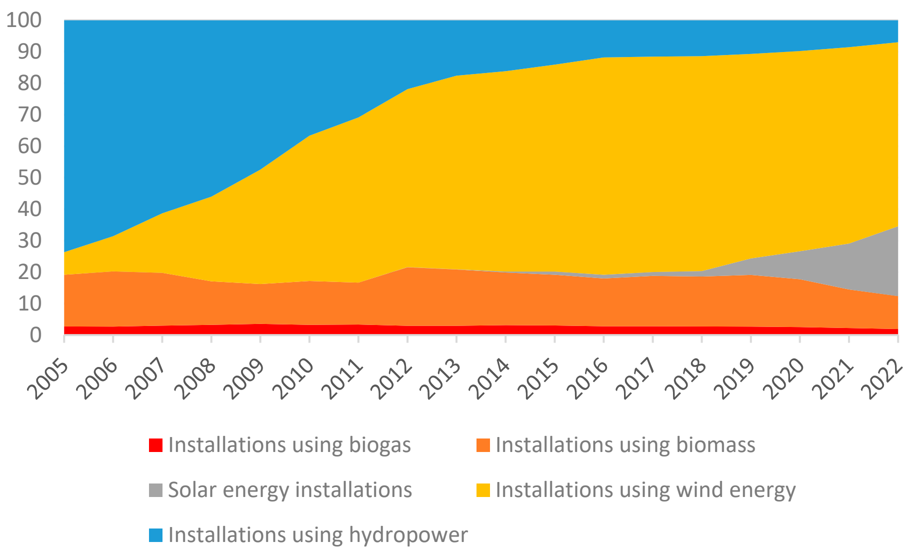


Figure 5. Structure of installed renewable energy capacity in Poland [%]. Source: [56].

3. The Factors Influencing the Development of Agricultural Biogas Plants

3.1. Political Frames

The development of agricultural biogas plants is determined by a wide group of factors including economic, environmental, technological, political, and social ones. The considerable number of variables that influence the functioning of the renewable energy sector, and the fluctuations in these variables over time, result in uneven development of this sector. These factors can be divided into exogenous and endogenous. Undoubtedly, political decisions, which determine the level of electricity prices, are one of the most important factors that affect the profitability of investments in agricultural biogas plants.

Electricity prices affect the sales revenues obtained by biogas plants, which translates into the level of profit obtained and consequently the profitability of the investment project.

In Poland, since 2005 there have been changes in the forms of support for agricultural biogas plants. The initial support model, which was introduced in 2005, was the system of certificates of origin, otherwise known as “color certificates”. This model was developed in response to the need to align Polish legislation with the directives set forth by the European Union (Directive 2001/77/EC). Following the implementation of the certification system in 2005, biogas plants were granted the right to apply for a “green” (basic) certificate, as well as high-efficiency cogeneration (“yellow” or “purple”) certificates in the majority of cases. In the first years of operation, prices of energy certificates remained at the level of PLN 250/MWh (USD 68–103) of electricity generated from renewable sources. The introduced system of “colored certificates” in the first years of its operation provided producers of energy from renewable sources with the opportunity to receive over PLN 250 (USD 68–103) for each MWh of electricity generated. At the same time, a system of substitute fees was implemented, which prevented excessive increases in prices for certificates of origin. If the prices of “color certificates” were too high, the producers of energy from conventional sources could fulfill the obligation to achieve a specific share of renewable energy sources in the energy produced by paying an administratively determined fee for each year; a substitute fee. For a long period, the price level of green certificates and substitution fees was similar, which provided energy producers with stable conditions. However, the situation changed radically in 2012 when there was a large oversupply of “color certificates” on the market and a collapse in their prices. As a consequence, this led to a slowdown in the development of the renewable energy market [44,57].

The situation improved in 2016 as a consequence of the introduction of certificates of origin that were specifically designed for energy derived from agricultural biogas (the so-called blue certificate). Blue certificates are applicable to agricultural biogas plants. They confirm the production of electricity by this type of plant. They were introduced with the aim of supporting existing agricultural biogas plants. It is the responsibility of electricity sellers to obtain and present for redemption these certificates in a proportionate manner relative to the quantity of energy sold. The level of the redemption obligation directly affects the demand for blue certificates. The price quotations of “blue” certificates remained at a relatively stable level throughout the entire period of their operation (at the level of the substitute fee of PLN 300.03—approximately USD 80). In 2016, a new support system was also introduced: renewable energy auctions organized by the Energy Regulatory Office. Both existing installations and those launched after 1 July 2016 were eligible to participate, but new installations were no longer eligible to receive support in the form of certificates. In order to guarantee equitable conditions for fair competition, a system of “baskets” was implemented, wherein entrepreneurs operating facilities with analogous technological solutions contend with one another. This approach circumvents the issue of competition between technological solutions with disparate labor and cost intensities. The auction was also divided according to the size of the installation (with a capacity of more and less than 1 MW). The auction system also assumes the so-called reference price, i.e., the maximum price at which electricity can be sold (in 2016 it was PLN 550/MWh—approximately USD 139/MWh). Furthermore, the winning auction price is subject to annual indexation in accordance with the price index of consumer goods and services. The support period is planned for a maximum of 15 years [44]. This solution allows owners of renewable energy installations to sell the electricity generated by their facilities in one of two ways. Firstly, they may sell at auctions that are announced by a government agency. Secondly, they may choose to sell on the wholesale market and obtain green certificates. Green certificates can be sold and supplement revenues from energy sales on the wholesale market. Feed-in tariffs are applied to biogas plants that win auctions [21]. The first renewable energy auctions were met with a lack of enthusiasm by agricultural biogas producers. The primary factors contributing to the low level of interest in the auctions among the proprietors of agricultural biogas plants include the anticipated contractual penalties, for example, for producing less than 85% of the declared energy, and the necessity of settling public aid received at the investment stage [44,58].

Another significant change in the operation of agricultural biogas plants took place in 2018. The most significant aspect of this change for agricultural biogas plants was the introduction of feed-in tariffs (FiTs and FiPs) for biogas plants with an installed capacity of less than 1 MWh. Feed-in tariffs are a state policy mechanism designed to accelerate investment in renewable energy sources. This mechanism allows long-term contracts to be offered to renewable energy producers. Feed-in tariffs (FiTs) constitute a mechanism that encompasses installations with an installed capacity of less than 500 kW. The FiT system is constituted by a contractual agreement between a generator and an obligated seller for the sale of electricity at a fixed price, which is 90% of the reference price. The Feed-in Premium (FiP) mechanism is applicable to installations with a capacity of at least 500 kW and no more than 1 MW. The FiP scheme is based on subsidies to the market price, whereby 90% of the value of the so-called negative balance is covered. This is defined as the difference between the reference price announced for the installation and the market average value of electricity sales. In 2021, the government adopted a draft amendment to the RES Act extending support in the form of auction systems and feed-in tariffs [44]. At this time, there are approximately 20 instruments of varying types currently in use in Poland, which are directed towards a number of different stakeholder groups. Those who own biogas plants have the option of utilizing one of several support instruments, including feed-in tariffs (FIT), feed-in premiums (FIP) and green certificates [59]. Legislative changes to renewable energy support systems affect the level of profits generated by biogas plants currently operating in Poland, but also clearly affect the profitability of investment in this type of installation.

3.2. Determinants of the Profitability of Investments in Agricultural Biogas Plants

Factors shaping the profitability of investments in agricultural biogas plants are the result of the impact of external factors related to energy policy and the policy supporting the development of the renewable energy sector, as well as factors related to the agricultural biogas plant project itself, the technology used, and the location of the plant in relation to the raw material base. The current low level of development of agricultural biogas plants in Poland requires an in-depth analysis of the economics of their operation and the identification of factors influencing the increase in interest in this type of investments.

The literature on the subject draws attention to the high level of investments related to the construction of agricultural biogas plants. This factor is a clear barrier limiting the development of this sector. Therefore, especially in the nascent stages of the agricultural biogas market's development, the need for financial support from public sources was indicated [37,38,59–61]. Such support reduces the financial risk of the investment and improves the economic efficiency of the investment project. The problem with various forms of public support addressed to private entities is the need to justify them to the public (taxpayers). Attention should be paid here to the social benefits associated with the operation of this type of installation. The following can be mentioned here: a reduction in CO_2 emissions [22,62], a possibility of waste disposal [63,64], a reduction in the excessive consumption of fossil fuels, and an increase in the supply of fuels from renewable sources that will allow for balancing supply and demand at a price level acceptable to consumers, have a positive impact on increasing energy security [65,66], and contribute to improving the economic situation and vitality of rural areas [67]. These benefits should be considered in the context of public goods and analyzed through the prism of social well-being.

The basic revenues derived by agricultural biogas plants come from produced electrical power as well as obtained certificates of origin, received surplus process heat, post-fermentation pulp in the form of a fertilizer, and payments for utilizing noxious and organic waste [38]. The revenues of enterprises running agricultural biogas plants depend mainly on the sales price of electricity and the prices obtained for certificates [21]. In turn, the operating costs of this type of facility depend on the production technologies used and the prices of production factors. While the prices of production factors (capital and labor) are relatively the same for all enterprises, the costs of used substrates for biogas production will depend on their availability and prices. The level of sales revenues depends on the electricity sales system adopted by the company. Owners of renewable energy installations can sell the electricity generated at auctions convened by a government agency, or alternatively they may elect to sell on the wholesale market and obtain green certificates. Feed-in tariffs (FiTs) are applied to biogas plants that win auctions [21]. In the case of feed-in tariffs (FiTs), the risk of running a business is lower, and guaranteed prices for energy from biogas under FiTs contribute to improving economic efficiency. Due to guaranteed energy prices for biogas, which results in a relatively stable level of income, sources of improvement in the economic efficiency of biogas plants should be sought in the area of production technology and production costs.

Analyses regarding improving the efficiency of agricultural biogas production cover many aspects. Attention is drawn to the importance of the substrate used in production. Due to the fact that most agricultural biogas plants are located near large farms, the importance of cattle manure, pig slurry, and other waste from agricultural production as a substrate with great potential for the production of biogas and digestate is indicated [47,62,64,68–71]. A biogas plant located close to the source of substrate acquisition and with easy access to it reduces the costs of transport and purchase of the substrate, but also allows for continuity of production and full use of the installed capacity [72–76]. For this reason, biogas plants located near the source of such substrates as well as on farms, especially those with animal production [8,77], have lower unit production costs [78–80]. The impact of the location of agricultural biogas plants on the efficiency of their operation is also often the subject of scientific research, not only due to the economic efficiency calculation, but also due to the concept of their dispersion or centralization, as well as the scale of production [6,81]. It seems that the impact of agricultural biogas production technologies on economic efficiency is of decisive importance [82]. The development of technology is mainly expected to increase the efficiency of biogas production from substrates and reduce investment costs per unit of installed capacity [83].

4. Materials and Methods

This research used the single case study method. The case-stage method, despite criticism, has been popularized and used in social sciences since the 1980s. [84]. A case study, classified as a qualitative method, differs from quantitative methods in terms of the size of the research sample. The advantage of employing large samples is the breadth of data that can be obtained, whereas the disadvantage is that the depth of analysis is limited. In a case study, the situation is the opposite. It is essential that both approaches be employed in order to ensure the sound development of social science [85]. The use of the case-stage method in research allows for the analysis of phenomena in their natural context [84], but also provides the opportunity to use case studies for theorizing [86]. The case studymethod is also a common method used to analyze the economic efficiency of agricultural biogas plants [9,35,87–89]. In studies of this type, it is emphasized that this method allows an analysis of the functioning of sample agricultural biogas plants in order to optimize future technological solutions and develop appropriate policy tools for the development of this sector. This study is a look at the problem of operating this type of facility from the point of view of the stakeholders—farmers interested in this type of investments and politicians creating appropriate policy tools for the development of biogas plants.

The analysis of the economic efficiency of the investment was carried out on the example of an agricultural biogas plant with a capacity of 0.499 MW located on a farm dealing mainly with dairy cattle breeding. The total area of the farm is 1500 ha, of which 75% is meadows and pastures. The analysis used the financial statements of the biogas plant for the years 2015–2023, i.e., starting from the first year of operation of the investment. The choice of this type of biogas plant was dictated by the fact of their large share in the structure of biogas plants in Poland (Figure 3) and that the literature draws attention to the need to carry out economic analyses for this type of biogas plant [47].

In order to analyze the profitability of investing in a biogas plant, financial information about the completed project was used. This information concerned realized net cash flows for the audited period and the level of investment. The analysis is ex post and covers the period from the commencement of the investment until 2023.

The investment profitability was assessed using the net present value (NPV) and internal rate of return (IRR) methods. To assess the profitability of the investment, economic results at current prices were used. This approach will avoid the selection of appropriate indicators to adjust prices, but it also results from the ex post approach of this research. The NPV method is commonly used for ex ante analysis, i.e., before making an investment decision. The ex post approach used in this work allows the assessment of investment profitability according to the actual cash flows obtained, and not the expected cash flows. In our opinion, this approach allows for the knowledge of the existing reality, which can be used in the process of assessing similar projects implemented in the future. This has an educational and practical dimension.

NPV may be regarded as a measure of the pure economic benefits of the project, representing the total present value of the net cash flow [35,90]. A positive or equal zero net present value (NPV) indicates that the project is profitable. The formula for calculating the net present value (NPV) can be expressed as follows:

$$NPV = \sum_{t=0}^{n} \frac{NCF_t}{(1+i)^t}$$

where: NPV—net present value, NCF_t —cash flows in particular years, i—interest rate, t = 0, 1, 2, . . ., and n—another year of the calculation period.

In the analysis of economic efficiency, the interest rate i = 8% was assumed, which includes 4% as the risk-free rate (the risk-free rate is assumed to be equal to the average interest rate on government bonds) and 4% as the risk premium (the risk premium assumed by the investor).

This research also calculated the internal rate of return (IRR) according to the following formula:

$$IRR = i_1 + \frac{NPV_1(i_2 - i_1)}{NPV_1 + |NPV_2|} \quad (1)$$

where: i_1—the interest rate for which the NPV is positive but close to zero; i_2—the interest rate for which the NPV is negative but close to zero; NPV_1—NPV value calculated for i_1; and NPV_2—NPV value calculated for i_2.

The internal rate of return (IRR) of a project is the discount rate that ensures that the net present value (NPV) of the inflows is equal to the cost. This is tantamount to requiring that the net present value be equal to zero. The internal rate of return (IRR) represents an estimate of the project's rate of return.

5. Results

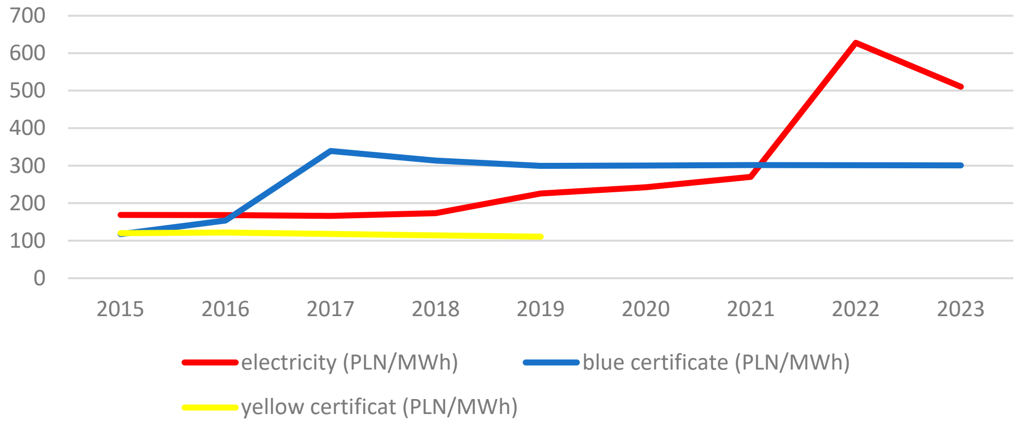
5.1. Economic Results and Technical Efficiency of the Tested Biogas Plant

Maximizing the level of revenues from the operating activities of biogas plants and the consequences of the operating profit are crucial tasks for plant operators. In the analyzed period, the biogas plant achieved the highest revenues in 2017, 2022 and 2023 (Table 2). However, in 2022 and 2023, this was related to the high level of electricity prices (Figure 6A,B) and high efficiency (Figure 7). In turn, in 2017 it was due to the compensation received by the biogas plant (Figure 7). It is also worth paying attention to the structure of the revenues obtained. In 2016–2021, the majority of revenues came from the sale of certificates of origin (blue certificates for electricity production in biogas plants and yellow certificates for cogeneration were issued for energy produced in units below 1 MW), while in 2022–2023 and 2015 it was the sale of electricity. This analysis indicates that in the period of low electricity prices (170–250 PLN/MWh; 43–70 USD/MWh), the main source of income is certificates of origin (blue certificate—approximately 300 PLN/MWh; approximately 80 USD). The most important element of the profit and loss account is the level of generated net profit. The profitability of every economic venture depends on the value of net profit. In the analyzed period, the analyzed biogas plant achieved profit only in 2022 and 2023, losses were recorded in the remaining period (Table 2). The analysis additionally took into account the estimated value of the digestate, and the value of electricity transferred to the farm. This was treated as a benefit provided by the biogas plant to the farm, allowing the farm to reduce the costs of fertilization and electricity. The share of electricity transferred to the farm is approximately 15–18% (Figure 8). Taking this type of benefit into account, the economic calculation looks more favorable. However, the losses generated in 2015, 2016, and 2018 were so large that only the accumulated profit in 2022 reached a positive value. These data indicate that this type of biogas plant may have financial problems, especially in conditions of low energy prices. It is similarly important to acknowledge that the operation of a biogas plant in conjunction with a farm may potentially jeopardize the financial stability of the farm.

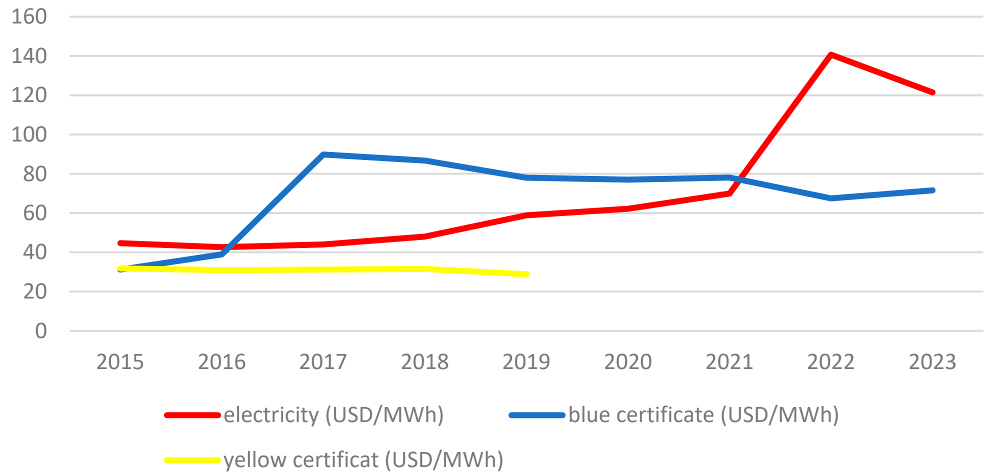
Table 2. Economic results of the tested biogas plant (thous. PLN/thous. USD *).

Specification		**Year**								
		2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Revenue	thous. PLN	1603.3	2672.8	4569.9	3787.4	3862.6	3776.7	3634.7	4652.7	4565.9
	thous. USD	425.3	677.8	1209.7	1048.2	1006.0	968.6	940.9	1043.0	1086.6
Including:										
Sale of electricity	%	51.9	35.4	26.7	29.5	36.6	37.6	42.8	65.3	58.1
Sale of certificates	%	48.1	64.6	73.3	70.5	63.4	62.4	57.2	34.7	41.9
Total costs	thous. PLN	2606.2	3342.1	4762.0	4234.7	4127.2	4099.7	3977.4	4198.7	4227.6
	thous. USD	691.3	847.6	1260.6	1171.9	1074.9	1051.4	1029.6	941.3	1006.1
Net profit	thous. PLN	−1002.9	−669.2	−192.0	−447.3	−264.6	−323.0	−342.8	454.0	338.3
	thous. USD	−266.0	−169.7	−50.8	−123.8	−68.9	−82.8	−88.7	101.8	80.5
Energy for the needs of a farm	thous. PLN	130.0	114.9	46.7	44.7	54.9	55.3	68.1	166.6	120.9
	thous. USD	34.5	29.1	12.4	12.4	14.3	14.2	17.6	37.3	28.8
Fertilizing value of digestate	thous. PLN	115.2	188.2	308.1	222.0	271.1	316.7	293.1	346.5	450.7
	thous. USD	30.6	47.7	81.6	61.4	70.6	81.2	75.9	77.7	107.3
Net profit adjusted for energy for farm needs and the value of digestate	thous. PLN	−757.8	−366.1	162.8	−180.6	61.4	49.0	18.4	967.1	909.9
	thous. USD	−201.0	−92.8	43.1	−50.0	16.0	12.6	4.8	216.8	216.5
Cumulative net profit adjusted for energy for farm needs and the value of digestate	thous. PLN	−757.8	−1123.9	−961.1	−1141.7	−119.2	−70.2	−51.8	985.5	1895.4
	thous. USD	−201.0	−285.0	−254.4	−316.0	−31.0	−18.0	−13.4	220.9	451.1

* The United States dollar (USD) values have been calculated using the average Polish zloty (PLN) to USD exchange rate. Source: own study.



(**A**)



(**B**)

Figure 6. (**A**) Obtained prices for electricity and certificates of origin (PLN/MWh). Source: own study. (**B**) Obtained prices for electricity and certificates of origin (USD/MWh—The United States dollar (USD) values have been calculated using the average Polish zloty (PLN) to USD exchange rate). Source: own study.

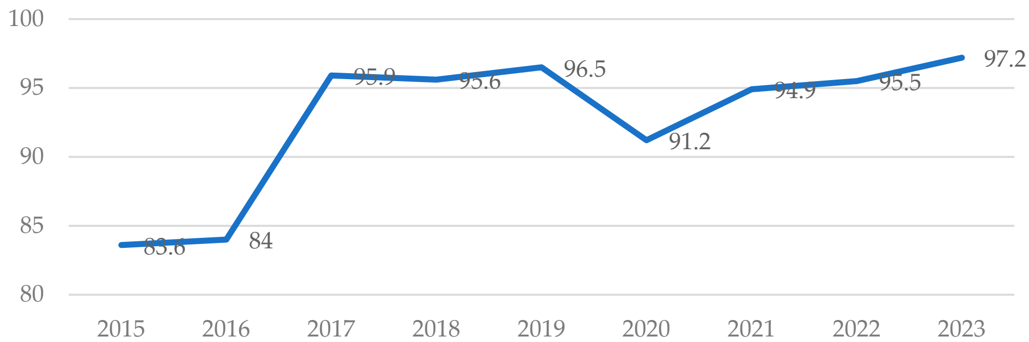


Figure 7. Plant utilization factor of the tested biogas plant (%) (biogas plant efficiency calculated as its operating time in a given year divided by the maximum possible operating time in a year, i.e., 24 h × 365 days = 8760 h). Source: own study.

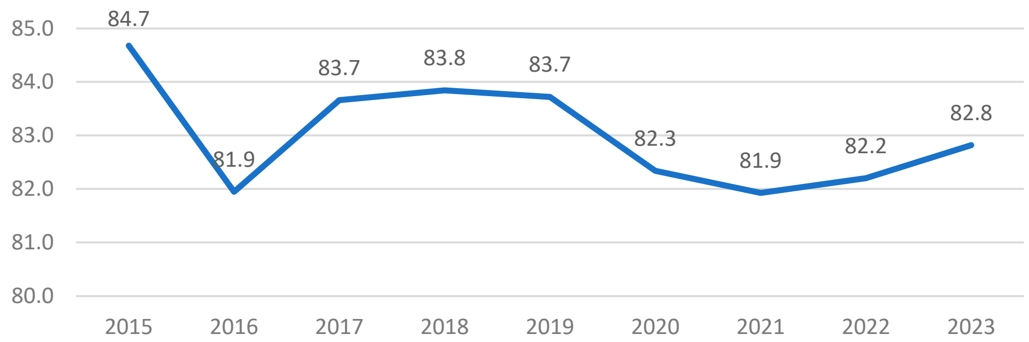


Figure 8. Percentage of energy sold of the total produced energy (%). Source: own study.

5.2. The Structure of the Substrates Used in the Tested Biogas Plant

For the proper functioning of the biogas plant, it is necessary to provide an appropriate amount of biomass. In the case of agricultural biogas plants operating on farms, the natural element is the use of biomass from the farm. In the case of the researched agricultural biogas plant, favorable changes took place in the analyzed period. In the last two years, the share of substrates from agricultural farms has increased significantly (Table 3). This increases was mainly in cow manure and slurry, which increased from 28.6%, in 2020, to 62.1%, in 2023, of the total amount of substrate used. It was complemented by maize silage, whose share was not large, but required for technological reasons. Such a small share of biomass grown on agricultural land should be considered beneficial and does not constitute a threat to food security in the country. With the high consumption of biomass produced on farms for the production of electricity, there may be concerns about food security as a result of a reduced supply of agricultural raw materials for food production. A large share of waste from the agri-food industry was also recorded. This indicates an important function of agricultural biogas plants related to the utilization of waste mass. It is worth paying attention to the fact that the use of cow manure and slurry helps reduce the negative impact of agriculture on the natural environment [22,91–94]. In addition, using one's own substrate reduces the costs of transporting the substrate, which has a positive effect on reducing operating costs.

Table 3. Structure of substrates used in the investigated agricultural biogas plant from 2016–2023.

Substrates	2016	2017	2018	2019	2020	2021	2022	2023
Substrates from the farm								
Slurry	28.5	12.5	10.4	17.4	7.8	14.8	28.1	33.9
Cow manure	23.3	25.1	31.6	15.8	20.8	25.9	26.8	28.2
Maize silage	3.2	1.5	2.9	0.2	1.6	2.1	9.0	7.4
Grass and cereal silage	0.0	0.0	0.0	1.8	4.5	2.0	0.5	4.0
Cereal and cereal waste	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
Total substrates from the farm	**55.0**	**39.1**	**44.9**	**35.2**	**34.7**	**45.3**	**64.4**	**73.5**
Food processing waste; technological waste from the agri-food industry; fruit and vegetable residues	30.0	34.1	32.8	43.4	43.9	39.2	30.9	18.4
Beet pulp	15.0	19.0	12.0	10.6	10.5	8.1	0.8	4.4
Waste from the dairy industry	0.0	7.8	10.2	10.8	10.5	7.4	3.8	3.7
Other	0.0	0.0	0.1	0.0	0.4	0.0	0.1	0.0
Total substrates from outside the farm	**45.0**	**60.9**	**55.1**	**64.8**	**65.3**	**54.7**	**35.6**	**26.5**

Source: own study.

5.3. Economic Efficiency of Investment in the Tested Agricultural Biogas Plant

The analysis of the economic efficiency of the investment in the tested biogas plant was carried out taking into account various operating options. Four options have been identified:

W1: the investments do not include subsidies from public funds and the revenues do not include benefits for the farm in the form of electricity and digestate.

W2: the investments do not include subsidies from public funds, but include benefits for the farm in the form of electricity and digestate; the value of electricity was valued according to market prices and the value of digestate according to production costs.

W3: the investments include subsidies from public funds, but do not include benefits for the farm in the form of electricity and digestate.

W4: the investments include a subsidy from public funds and benefits for the farm in the form of electricity and digestate; this is the actual picture of the operation of the biogas plant resulting from the financial report.

Taking into account hypothetical options W1–W3 allows us to draw attention to the importance of policy supporting the development of this type of installation and the importance of benefits for agricultural farms. The analysis of economic efficiency was carried out for an incomplete period of operation of the agricultural biogas plant; therefore, in the last analyzed year, the economic calculation included the liquidation value, calculated as the difference between the initial value of investments and the value of depreciation write-offs.

In the economic efficiency calculation of the investment, the actual value of the investment was assumed (PLN 10,735.7 thousand; USD 2847 thousand), and the value of the subsidy was obtained (PLN 3800 thousand PLN; USD 1007 thousand). The investments were carried out within one year—2014. The subsidy was obtained in 2015, and the first year of operation of the investment was 2015. The analysis was carried out for the period 2014–2023. The presented analysis used financial data in accordance with the accounting standards used in the examined enterprise.

The analysis conducted indicates that none of the analyzed options ensured the profitability of the investment project (Table 4). It is also worth paying attention to scenario W2 and W3. More favorable NPV and IRR values were achieved for the W3 option compared to the W1 option. This indicates the great importance of support from public funds for such investments. The lack of such support, while taking into account the benefits for the farm (option W2), also ensured a lower level of NPV and IRR compared to the W1 option.

Table 4. Analysis of the economic efficiency of investment in the agricultural biogas plant for the years 2014–2023 (options W1-W6).

Specification		W1	W2	W3	W4	W5	W6
NPV	thous. PLN	−6346.1	−4304.9	−2828.2	−786.6	−407.1	−392.6
	thous. USD *	−1683.3	−1141.9	−750.2	−208.6	−108.0	−104.1
IRR (%)		−3.07	0.83	2.04	6.42	7.05	5.33

* The United States dollar (USD) values have been calculated using the average Polish zloty (PLN) to USD exchange rate. Source: own study.

In the analysis carried out, it should also be noted that the economic results obtained in the tested biogas plant were intensified by exceptionally high and favorable energy prices for 2022–2023 (627.8 PLN/MWh; 140 USD/MWh in 2022 and 510.2 PLN/MWh; 121 USD/MWh in 2023) (Figure 6A,B). This situation will no longer occur in 2024. For this reason, it was decided to analyze the economic efficiency of the tested biogas plant by selecting the period most typical for economic conditions for the analysis. It was assumed that these would be average values for the years 2019–2021, characterized by a relatively stable level of electricity prices. This option was designated as W5. It includes a subsidy to finance investments and the estimated value of benefits for the farm. The analysis was carried out for the years from 2014 to 2023. In this option, the investment project is also unprofitable; the internal rate of return (IRR) was 7.05% (Table 4). Additionally, option W6 was also presented, which, like option W5, takes into account a typical period of economic conditions, but does not include investment subsidies. This option also turned out to be unprofitable, but more advantageous than options W1, W2, W3, and W4. This analysis indicates the importance of economic conditions (energy prices and substrate costs) and public aid in investment activities.

Next, this research estimated the level of public aid required to ensure profitability (NPV $\geq$ 0) for the presented options (only options with public aid were taken into account) (Figure 9). The failure to take into account the benefits for the farm in the investment profitability calculation (option W3) indicates the need to ensure over 60% of the share of non-returnable financing in investments. The other two options, W4 and W5, taking into account the estimated benefits for the farm, indicate a much lower level of public financing. Therefore, an important issue is to correctly estimate the benefits generated by a biogas plant for a farm.

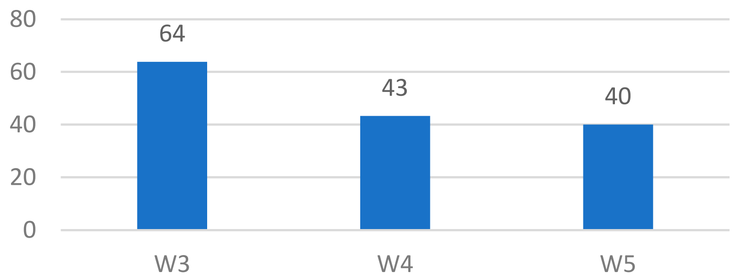


Figure 9. The minimum level of public aid in investments to ensure the profitability of the investment project (%). Source: own study.

Next, it was decided to estimate the benefits generated by the biogas plant for the farm and the surroundings. These benefits were related to digestate production, electricity production, and heat production. The value of the digestate was estimated according to a different method than the one used on the farm. The content of the basic components of the digestate was taken into account: nitrogen, phosphorus, and potassium (NPK). The biogas plant commissions tests for the NPK content in the digestate. The digestate was valued according to market prices of mineral fertilizers. To value the electricity consumed by the farm, market prices of electricity obtained by the biogas plant were used, i.e., the method used in the previous biogas plant assessment was followed. The value of heat produced was estimated according to the market price of 1 GJ of heat. However, the farm does not fully use the heat produced. The farm's heat is used for its own needs to heat farm and office buildings and to dry agricultural produce. Part of the produced heat could be used to heat a housing estate located near the farm (it is possible to provide heat to approximately 100 families) and to dry grain. However, this requires the construction of special infrastructure enabling the transfer of heat from the biogas plant to the housing estate and investment in a grain dryer. Table 5 presents the economic results of the tested biogas plant, taking into account the above-mentioned estimated additional benefits. Two options were presented. The first option (W7) takes into account only the value of thermal energy used by the farm, the second option (W8) presents the economic results of the biogas plant taking into account the full use of thermal energy, both for the needs of the farm and its sale. Taking into consideration the full benefits created by the biogas plant at market prices allows for the generation of net profit throughout the analyzed period, contrary to the economic calculation presented in Table 3.

For these two options of economic calculation, taking into account benefits for the farm (options W7 and W8), the investment profitability was analyzed. Both the options without public aid (W7A and W8A) and the options with public support (W7B and W8B) are presented. The analysis shows that such a project is profitable and does not even require support from public funds (Table 6).

Table 5. Economic results of the tested biogas plant (thous. PLN/thous. USD *).

Specification		2015	2016	2017	2018	2019	2020	2021	2022	2023
Option W7										
Net profit	thous. PLN	−1002.9	−669.2	−192.0	−447.3	−264.6	−323.0	−342.8	454.0	338.3
	thous. USD	−266.0	−169.7	−50.8	−123.8	−68.9	−82.8	−88.7	101.8	80.5
Energy for the needs of the farm	thous. PLN	130.0	114.9	46.7	44.7	54.9	55.3	68.1	166.6	120.9
	thous. USD	34.5	29.1	12.4	12.4	14.3	14.2	17.6	37.3	28.8
Value of the digestate	thous. PLN	638.5	605.4	583.5	574.4	628.0	614.5	769.9	1616.6	988.2
	thous. USD	169.4	153.5	154.5	159.0	163.6	157.6	199.3	362.4	235.2
Value of heat actually used on the farm	thous. PLN	240.0	386.0	369.2	460.9	464.0	379.0	385.4	579.0	930.5
	thous. USD	63.7	97.9	97.7	127.6	120.8	97.2	99.8	129.8	221.4
Net profit adjusted for farm benefits	thous. PLN	5.5	437.0	807.4	632.8	882.3	725.9	880.6	2816.2	2377.9
	thous. USD	1.5	110.8	213.7	175.1	229.8	186.2	228.0	631.3	565.9
Option W8										
Net profit	thous. PLN	−1002.9	−669.2	−192.0	−447.3	−264.6	−323.0	−342.8	454.0	338.3
	thous. USD	−266.0	−169.7	−50.8	−123.8	−68.9	−82.8	−88.7	101.8	80.5
Energy for the needs of the farm	thous. PLN	130.0	114.9	46.7	44.7	54.9	55.3	68.1	166.6	120.9
	thous. USD	34.5	29.1	12.4	12.4	14.3	14.2	17.6	37.3	28.8
Value of the digestate	thous. PLN	638.5	605.4	583.5	574.4	628.0	614.5	769.9	1616.6	988.2
	thous. USD	169.4	153.5	154.5	159.0	163.6	157.6	199.3	362.4	235.2
Value of heat	thous. PLN	683.0	632.7	698.3	733.0	672.9	885.0	884.5	1249.7	1955.8
	thous. USD	181.2	160.5	184.8	202.9	175.3	227.0	229.0	280.2	465.4
Net profit adjusted for farm benefits	thous. PLN	448.6	683.8	1136.5	904.8	1091.2	1231.9	1379.7	3486.9	3403.2
	thous. USD	119.0	173.4	300.8	250.4	284.2	315.9	357.2	781.7	809.9

* The United States dollar (USD) values have been calculated using the average Polish zloty (PLN) to USD exchange rate. Source: own study.

Table 6. Analysis of the economic efficiency of investment in the agricultural biogas plant for the years 2014–2023 (options W7A-W8B).

Specification		W7A	W7B	W8A	W8B
NPV	thous. PLN	1574.6	5093.2	4285.2	7803.7
	thous. USD *	417.7	1350.9	1136.6	2069.9
IRR (%)		10.43	17.41	14.36	21.87

* The United States dollar (USD) values have been calculated using the average Polish zloty (PLN) to USD exchange rate. Source: own study.

6. Discussion

One of the barriers to the development of agricultural biogas plants is their low economic efficiency of investment. The reasons for low economic efficiency are mainly related to the following aspects: high investment costs [23,95–97] and the lack or insufficient level of subsidies for this type of investment [23,95,98]. The analysis carried out in this paper showed that investment in a biogas plant was highly capital-intensive, which had been confirmed by previous research [37,99]. This makes it difficult to achieve an appropriate level of economic efficiency that satisfies investors. Reaching an appropriate level of economic efficiency may require not only public aid, but also preparation of special forms of financing for this type of investment [100]. It is reasonable to posit that a significant proportion of existing and currently constructed biogas plants in Poland would likely not have come into being without the provision of public financial assistance [38]. Our own research showed that the profitability of this type of agricultural biogas plant depended on public support, but also on the possibility of full use of the energy and heat produced. For the success of such a project there must be a wide range of enabling factors. One of them is obtaining funding from public funds. Without support, such an investment may not be profitable. This confirms the importance of financial tools in the development policy of the renewable energy sector. Similar results were also obtained in the study by Klimek et al. [37], where investing in biogas plants without government subsidies is unprofitable. These authors indicate that the required level of subsidies in investments should be as much as 60–70%. The literature on the subject often emphasizes that the possibility of obtaining subsidies, grants, tax breaks, etc. is a motivating factor to undertake this type of activity [101–107]. This research also concluded that if it was not possible to fully use the obtained production, investment in a biogas plant requires a subsidy of 40–60% of funding. In turn, the analysis of the economic efficiency of the operation of an agricultural biogas plant conducted by Akbulut [89] shows that success of such an investment project is characterized by a positive NPV. In this case, the analysis was carried out taking into account the income from milk sales obtained on the farm. This approach to the problem of investment efficiency in agricultural biogas plants fits into the holistic systems approach in the analysis of farm organization [108]. This allows capturing the impact of an agricultural biogas plant on the economic and financial situation of the entire farm but may artificially inflate economic results. The question arises whether, without a biogas plant, an agricultural farm with only agricultural production would achieve better economic results. In the case of our own research, it is clearly visible that the loss generated by the biogas plant will burden the economic result of the farm. However, it should also be noted that the method of calculating the economic result adopted in the examined biogas plant and farm does not fully reflect the benefits obtained for the farm. Estimation of the full benefits at market prices will allow one to obtain satisfactory results. Moreover, it should be noted that the success of such a project requires public infrastructure related to the possibility of selling the produced heat to households. Without such infrastructure, such an investment does not use its full potential. The development policy for this type of investment project should not only take into account support for farmers, but the support must also cover other investments located in the vicinity of agricultural biogas plants.

In our opinion, in the economic efficiency calculation, treating a biogas plant operating within a farm as a separate unit will allow a more accurate assessment and capture of all connections with the farm and the social environment. The weakness of this approach is the need to evaluate the benefits for the farm in the form of digestate and the electricity supplied, as well as the need to evaluate the costs related to the raw materials delivered from the farm. This approach fits into the analytical model of economic efficiency assessment, where such an assessment is carried out separately for individual farm activities. Both approaches, holistic and analytical, have their advantages and disadvantages. They can result in different conclusions. This is a methodological problem that indicates the complex nature of efficiency assessment in agriculture resulting from the interrelationships of individual parts of a farm. The systems approach demonstrates that each component of the farm can exert an influence on the behaviour of the other parts of the farm. Furthermore, the nature of this influence is also contingent upon the state of other components within the system. This implies that the system should not be conceptualized as a collection of discrete components, but rather as a unified entity. It is difficult to understand the functioning of the whole by analyzing only the individual components [109]. The analytical approach is founded upon the isolation of the phenomenon under study, which is then subjected to analysis within this isolated context. However, this analysis is deficient in regard to feedback, which is the foundation of the internal relations between the components of the system [110]. The analytical approach will allow a deeper insight into the conditions for the functioning of individual parts of the entire facility. However, one should be aware of the mutual connections and couplings between the individual components of the entire system (the internal couplings in the system) and the system's surroundings. In the analytical approach, there is also a need, and at the same time difficulty, to monetize benefits and costs that are not strictly accounting in nature, as in the case of biogas plants: the value of digestate, costs of raw materials obtained from the farm, but also benefits related to public goods. Such an attempt was made in our research. It turns out that a full valuation of the benefits allows for a more precise assessment of such an investment project.

For this reason, when making an economic calculation of the operation of an agricultural biogas plant, attention should also be paid to intangible benefits [38]. They are difficult to estimate, but their identification and estimation are an important issue necessary to be included in the profitability calculation of such investments, especially from the point of view of the policy supporting the development of agricultural biogas plants. Estimation of positive external effects allows for overcoming socio-cultural, environmental, and political barriers. Social and cultural barriers are related to the reluctance and concerns of local communities about the impact of biogas on their comfort of life, adverse perception of technology, and cultural and religious beliefs with stigmatization as users' literacy and education about the use of biogas are still low [23,111]. Environmental barriers are mainly related to concerns about the negative impact of biogas plants on the natural environment, in particular: noise and odor pollution, high volume of water requirement, inadequate water access, and pollution (air, water and land) [111]. Political barriers include the lack of institutional solutions, the lack of a clear policy for the development of this type of installation, and a lack of promotion of this type of installation [112,113]. These types of barriers can be eliminated or their impact can be limited by correctly quantifying the costs and benefits of operating biogas plants, taking into account the full calculation, not only the calculation in the economic sense, but in a holistic approach, taking into account the full range of both private and public benefits.

The literature suggests that biomethane offers a range of models for a circular bioeconomy that are in line with the Sustainable Development Goals (SDGs). The importance of biomethane–biogas production as an alternative option for decarbonizing many sectors of the economy is pointed out. This would reduce global emissions and contribute to the management of increasingly large amounts of organic waste [114–118]. The following effects, which are part of a closed-loop bioeconomy, can be observed at the facility under analysis: the utilization of organic waste for energy production and the use of digestate for crop fertilization. This is of particular importance to the agricultural sector, where large quantities of reusable agricultural waste are generated. The reduction of environmental pollution and the creation of added value for farmers and other stakeholders are two key benefits of this process [114,119,120]. It is additionally noteworthy that biogas production aligns with a model of sustainable rural and agricultural development. The utilization of local resources and the transformation of organic waste materials into marketable products facilitate an increase in income in the agricultural sector and for local workers [114]. Furthermore, agricultural biogas plants offer a potential avenue for achieving global sustainable development goals, including poverty reduction, ensuring access to affordable, reliable, sustainable and modern energy for all, substantially increasing the share of renewable energy in the global energy mix, economic growth, increasing industry value added by small enterprises, and responsible production and consumption [114]. The realization of these objectives is of particular importance with regard to social welfare and should be a significant argument for politicians in the creation of models for the development of this economic sector.

The analysis of economic results carried out for the tested biogas plant indicates a high sensitivity of the generated profit to changes in market and political factors related, in particular, to energy prices and certificate prices [21,37]. The influence of market and political factors can be clearly seen in our own research, where low electricity prices clearly influenced the low level of profit or even loss generated by the tested biogas plant. The literature on the subject also emphasizes that obtaining renewable energy from other sources such as solar, hydro, and wind is also cheaper than biogas [23,112,121,122]. This may also be a factor negatively affecting the development of biogas plants.

The results of our research indicate the problem of economic efficiency of small agricultural biogas plants located on farms. In order to resolve this issue, it is necessary to explore the potential of institutional solutions that are related to government incentives. These include feed-in tariffs, long-term financing, capital grants, viability gap funding, and tipping fees for waste collection and handling [23]. With the lack of appropriate policy tools for the development of agricultural biogas plants, especially those operating on a small scale, such projects are characterized by a lack of profitability, which discourages private investors.

7. Conclusions

The analysis carried out is a valuable case study in the context of the need for the development of renewable energy in Poland, in particular those based on dispersed agricultural biogas plants operating on dairy farms. It has been shown that this type of investment requires public support, as well as a kind of regulatory "protection", which would ensure relatively stable conditions in terms of the possibility of selling the produced energy and energy certificates at relatively stable prices.

The low economic efficiency of the investment in the researched agricultural biogas plant and the inability to fully use the potential production indicate the need to use solutions supporting this type of investment project. Especially in the investment phase, private investors (mainly farmers) may face a serious capital barrier that is difficult to overcome. In such a situation, the development of appropriate policy instruments for the development of agricultural biogas plants operating on farms is an important factor in stimulating the development of such a sector. An important solution is the use of non-returnable investment subsidies from public funds, allowing them to cover at least 40–60% of investments. Such support allows overcoming entry barriers for small private players/developers. Moreover, support also requires the construction of appropriate technical infrastructure, enabling the transmission and full use of the obtained production.

The use of interventionist instruments in the development policy of agricultural biogas plants requires justification. Such arguments can be sought in the area of social benefits related to increased energy security, environmental benefits related to the reduction of greenhouse gas emissions, or a positive impact on the vitality of rural areas. In the tested agricultural biogas plant, the following positive effects can be noted: a reduction of methane emissions, an elimination of nuisance odor associated with fertilization with manure, there is no associated seepage of harmful nitrites and nitrates into groundwater, the possibility of using heat generated by the plant to heat a housing estate and to dry grain on the farm (necessary additional investments), and the production of substrates for biogas plants on farms limits the transport of raw materials for energy production and eliminates the negative impact of transport on the natural environment. Further research should focus on quantifying and valuing the positive externalities of such projects. This will allow a full assessment of the investment's efficiency, taking into account not only measurable economic effects, but also the value of public goods. A full cost–benefit calculation will be particularly useful to build out the development policy for this sector. The limitation of our research results from the adopted research method is related to the case study. We assessed the efficiency of only one technological solution. In further research, we plan to compare biogas plants operating with different technologies and of different sizes. This approach will provide answers to the question of what solutions should be promoted for farms interested in such investments.

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