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IDENTIFICATION OF AN EXAMPLARY BIOGAS PROJECT: SELECTED TECHNICAL AND ECONOMIC ISSUES

Keywords: biogas plant, poultry droppings, profitability of biogas investment

When making a decision in relation to an investment, the financial potential of an investor, the effects and risk of the undertaking are to be taken into account. This study deals with the initial assessment of an investment risk on an example of a biogas project to be implemented in Dolnośląskie Voivodeship in Bolków Commune. The experiences collected within the process of identification of the investment project shows the most important challenges of a technical nature, connected with the analyzed case and also their economic impact.

Background of the project

The direct use of unprocessed chicken droppings as a fertilizer in agriculture is the most common and the cheapest way of its utilization. For this purpose, an appropriate acreage is required because the annual dose of nitrogen cannot exceed 170 kg/ha. It is accepted that on arable lands, a safe annual dose of droppings is up to ca. 10-15 tons of dry matter per hectare. Instead, processing of chicken manure to a form which is less aggressive to the environment, prior to its agricultural use, is recommended and applied solution. This processing includes among others drying and composting combined with mixing with additives that are a source coal and other minerals. In some countries, the use of silage or pre-composted poultry droppings is allowed from livestock bedding as a fodder component. Dissolved in water poultry manure, similarly as sewage, is also used as a source of nitrogen in industrial installations for the production of algae (this sector is in the phase of a dynamic development owing to promising forecasts of the effectiveness of biodiesel production; in Poland there are no projects of this type at the moment). The use of chicken litters for the energy generation is an alternative for the above-described traditional ways of its utilization. Due to high contents of nitrogen and mineral substances, the use of this raw material is subject to numerous limitations. Droppings from bedding breeding may undergo thermal conversion in the processes of combustion, co-combustion, gasification or carbonization; for example, several steam power plants heated in 100% with droppings from poultry farms operate in the Great Britain. The smallest one of them recycles ca. 200 thousand tons of this type biomass annually and possesses the installed electric power of 30 MW [1].

A low-temperature biological conversion in the process of anaerobic digestion is the most preferred energy solution for the poultry manure from the environmental point of view. This solution combines benefits connected with the traditional utilization method of this valuable fertilizer in agriculture, which limits its noxiousness connected with smell and bacteriological threats in its raw state, with additional measurable ecological effects in the form of energy production from renewable resources, while not contributing to an increase of the emission of greenhouse gases (and it even reduces it as compared with an uncontrolled fermentation of raw droppings).

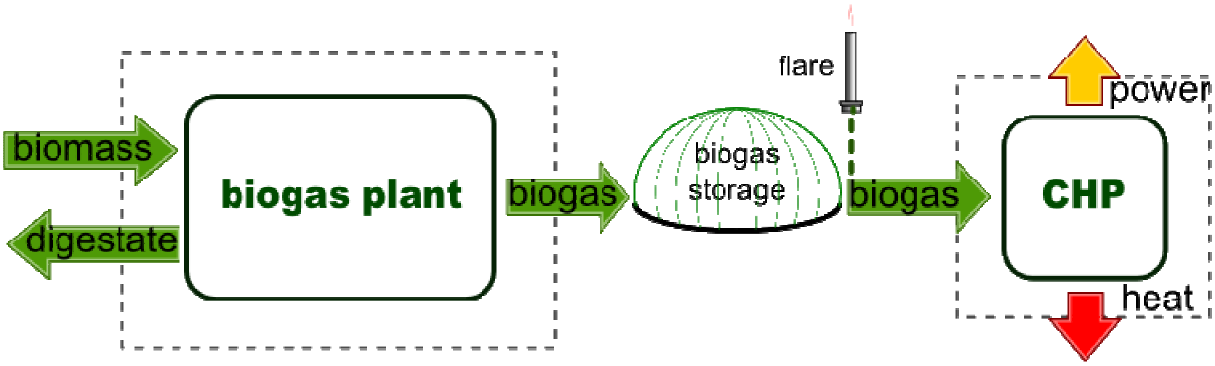


Fig. 1. Simplified diagram of biogas plant with heat and power generation

The promotion of the development of agricultural biogas plants is one of the priorities of the eco-energy policy both in Poland and in the European Community. In the light of strategic documents, properly designed and operated biogas plants appear to be systems that are not environmental risks but even protect the environment., However stereotypes of potential odour and biological risks accompanying biogas plants are still quite widespread. The support system implemented in Poland, as compared with solutions in other states, fails to effectively support the sector of biogas in the phase of the operation of installations (all renewable energy sources are identically "priced" through the "green certificate"). Nevertheless, special funds to support the investments in a competition form are periodically launched.

Technology

The anaerobic digestion is a commonly recognized direction of the organic waste utilization. It possesses a number of measurable benefits to the natural environment. For this reason, both the quantity of technical solutions and the scope of the applications of the process are constantly and dynamically increasing. Danish solutions, in the scope of the utilization of large quantities of liquid manure from pig farms, constituted historically an essential point in the development of agricultural biogas technologies. An intensification of animal breeding caused a real ecological threat and had a significant impact on the quality of life in the neighbourhood of such husbandries (therefore, in a considerable area of the country). To deal with this noxiousness, large biogas plants built by cooperative farmers were destined for the bioderadation of liquid substrate with low total solids content. They were based on cylindrical, vertical and closed tanks with continuous mixing (most often equipped in one big centrally placed agitator). Biogas produced in this process was used for the power and heat generation, while the farmers-shareholders of the undertaking collected the digestate (post-fermentation sediment) to fertilize fields. In this manner, they did not lose not only the value of the natural fertilizer delivered as a substrate to a biogas plant but they also collected a processed fertilizer with such properties that were better than of the one they got rid of. The further development of the Danish path concentrated above all on processes aimed at an improvement of the quality of the digestate (recycling of water in the process, treatment of water to the standards of potable water, concentration and separation of individual fertilizer ingredients, especially the compounds phosphorus etc.) [2-5]. A different situation was observed in Germany and other European states, where there was no such density of animal livestock in a relatively small area. Here, the impulse to develop biogas technologies was their energy aspect, i.e. their contribution to the limitation of the consumption of fossil fuels, which resources are limited and which use causes a negative environmental impact in local and regional levels (emissions of pollutants introduced into air by high emitters in large combustion power plants, a degradation of the environment in connection with the extraction of raw materials, transport of large quantities of fuels, frequently on large distances) and on the global level (emissions of greenhouse gases). The environmental policy of the European Union promoted the application of renewable energy sources, and some of the states like for example Germany, introduced measurable systems to support the development of alternative energy industry. The local conditions (e.g. intensity of animal production) caused on the one hand seeking for more energy efficient raw materials, others than natural fertilizers. On the other hand, they resulted in the need of a larger support to smaller scale systems, whose economic determinants are less favourable, yet there is at the same time a more sustainable environmental impact (transport of biomass and digestate). In this manner, co-fermentation of natural fertilizers became commonly used with silages from energy plants or with residues from the food processing industry. This forced the creation of multistage technologies, because the dynamics and the time required for the biodegradation of the individual substrates were considerably different. In case of some substrates, hydrolysis process is very slow, therefore, it needs to be separated from the fermentation process and intensified.

Nowadays, the so-called dry technologies become more popular. They enable the digestion of the not pumpable materials(due to dry matter content) required other transport methods instead of significant amount of process water used as a solvent [3-7]. With the progress in the control systems for stable substrate compositions, the process was conducted in more demanding environmental conditions, in the scope of temperatures that corresponded to the growth of thermophilic cultures of methanogenic bacteria. A shorter digestion time and a greater energy output from the volumetric unit of the bioreactor were obtained at the expense of a smaller stability and very narrow ranges of tolerances for the survival conditions of microorganism cultures [4, 5]. Currently in this innovative sector, an intensive progress is observed. It introduces improvements to the individual stages of the process or increases the usefulness of new substrates. The development another segment of biogas technologies is also under way with its applications for sewage treatment, where the charge material contains below 1% of dry matter.

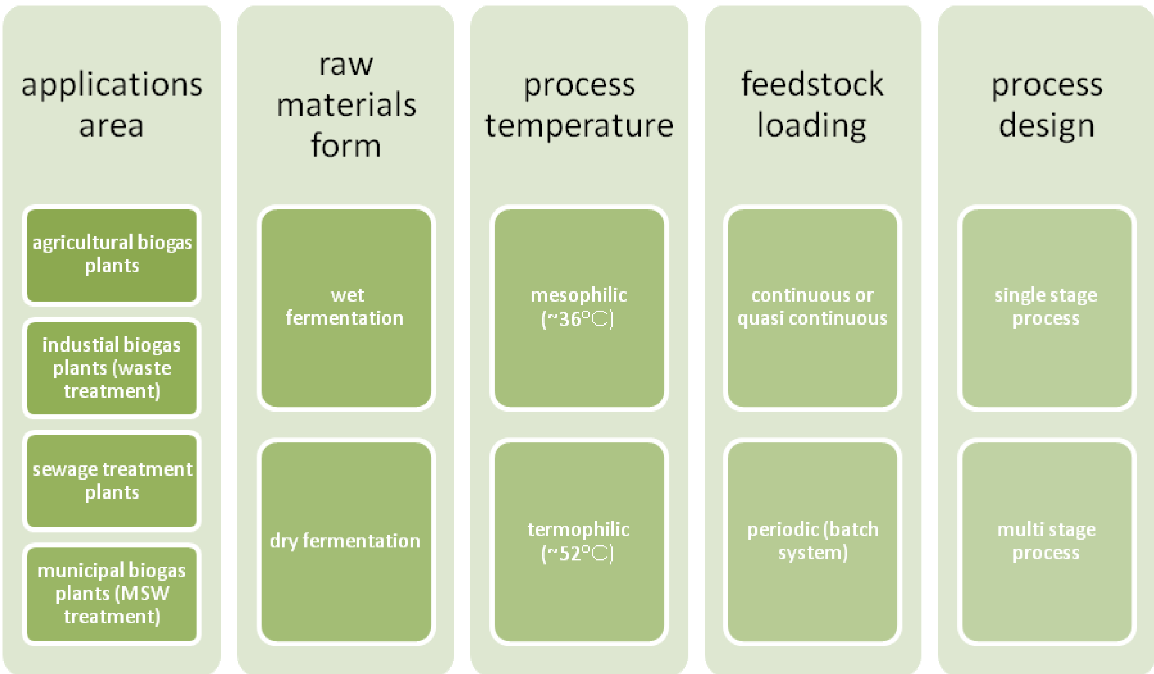


Fig. 2. Typical classifications of biogas technologies

Challenges

The use of large quantities of poultry droppings in a biogas plant may cause significant operational problems. Poultry manure has a tendency to disrupt methanogenesis due to too large acid reaction, a small value of the relation of biodegradable carbon to nitrogen (C/N) and ammonia form of nitrogen which is unfavourable to the process. It destabilizes the balance of the batch and the biogas production [4]. Additionally, too great water solubility eliminates the possibility to apply a technology based on the dry fermentation. It causes the necessity to introduce a structure forming material so that microorganisms should not undergo an excessive dispersion in connection with a well developed surface of the suspension.

Possible strategies concerning the minimization of the risk of disruption of the anaerobic fermentation process of such a difficult substrate as poultry droppings consist in balancing of the excess of nitrogen, through an introduction of the appropriate quantity of additional substrates rich in carbon (lipids and carbohydrates) or an introduction of special additives to the process in the form of chemical compounds which bind an excess of nitrogen (which do not participate in the process of fermentation) as early as on the stage of hydrolysis [4, 6]. The use of an ADA pressure reactor (patented by a Finnish company Preseco) is an example of the "treatment" of the process from an excess of ammonia nitrogen. Owing to it, NH_4^+ is partially bound in the form of ammonia carbohydrate (the balance of the reaction depends from the pressure). In the ADA reactor, there occurs a direct contact of biogas (mainly carbon dioxide) with ammonia ions which are present in the charge; this results in their partial neutralization to the form of $HNH_4CO_3^-$[8].

The technical variant considered within the framework of this study includes the classical mesophilic wet solution with a compensation of an excess of nitrogen through co-digestion with ensilaged pressed pulps from sugar factories, maize silage and seasonally with fresh grasses and other products of agricultural origin that are periodically available, in small quantities, which do not qualify for the use for food purposes. Optionally, when the digestion process is not stable enough or effective enough, a possibility is predicted to introduce both chemical compounds to bind the excess of ammonia nitrogen and additions of specially composed microelements to provide an optimal "diet" for those bacteria cultures that are involved in the process.

Table 1. Substrates available for biogas plant

type of substrate	total solids (TS) %	volatile solids (VS) % TS	total nitrogen (N) % TS	availability tons / year
poultry manure	40.0	75.0	3.8 – 5.4	30,000
beet pulp	22.0	95.0	no data available	10,000
maize silage	32.0	90.0	1.0 – 1.2	2,400
Total				42,400

Source*: author's estimation on the grounds of [4], [6], data from present disposer of poultry droppings and offers of the technology suppliers*

The biogas produced will be combusted in a gas cogeneration engine equipped with a synchronous self-excited generator in order to generate power and heat, which constitute the main sources of income for the foreseen installation. At the same time, the high fertilizing value of the fresh feedstock provides reasons to introduce a module of mechanical separation and drying or composting of the digestate.

Economic forecasts

The assumptions for the profitability forecasts of the project were accepted based on the authors' own estimations and information obtained from the initial offers from selected suppliers of biogas technologies.

Assumptions for calculations

The assumed substrates, which are presented in Table 1, should permit a production of 5,250 thousand Nm^3 of biogas per year with the methane content on the level of 60%. This gives a stream of the fuel chemical energy on the level of 3.5 MW, which allows an operation of the gas engine with the output of 1.4 – 1.6 MW, for example the GE JMS420 GS-B.L (1,415 kW) model or MWM TCG 2020 V16 (1,560 kW) model. The demand of water for the process is on the level of 55-60 thousand m^3. Assuming ca. 35% recycling of process water, the intake of fresh (surface or deep) water will be on the level of 100-105 m^3 per 24 hours. The annual volume of pre-fermented fertilizers will be ca. 6 thousand tons of dry matter with an approximate share of nitrogen on the level of 3.5-3.8%.

The total investment outlays for the discussed installation reach the level PLN 22 million ±10%. The investment will be financed in 25% from the investor's own funds and in 75% from an investment credit with an annual interest on the level of 8.0% (+1.0% commission) with quarterly repayment and annual grace period.

Parameters examined and the scope of their changes

The influence of the annual costs to obtain substrates (including water) on the profitability of the undertaking was analyzed. The unit cost for obtaining poultry manure was assumed to be on the level from PLN 15 to PLN 50 per Mg; for pulps from a sugar factory, on the level from PLN 40 to PLN 70 per Mg, and for maize silage on the level from PLN 100 to PLN 130 per Mg. The unit cost of the collection water was accepted in a very wide scope: from PLN 0.40 per m^3 (surface, rain waters and waters from a deep water intake included in the installation) to PLN 4.0 per m^3 (in the case of purchase from the water board). The scope of the changes of the annual costs to obtain substrates is from PLN 1.1 million to 2.6 million, whereas the expected value is on the level of PLN 1.6 million.

The amount of annual operating costs was the next parameter analyzed. It depends among others upon the costs concerning servicing of the cogeneration unit, the maintenance costs of the remaining technological devices in the biogas plant (spare parts, consumables), costs concerning an external biological service (monitoring of the installation work, laboratory analyses), consumption of energy for the own needs of the installation, remuneration, etc. If necessary, this item will be also burdened with the purchase of chemical additions to improve the stability of the process. Based on the information collected within the framework of the initial offers, the scope of the changes of the aggregate operating costs including fixed expenses (i.e. local taxes, overall costs, insurances etc.) was accepted in the range from PLN 800 thousand to PLN 1,350 thousand. The value of PLN 950 thousand was accepted for the base scenario.

On the side of incomes, those variants were analyzed which take into consideration the possibility or impossibility to sell heat and the possibility to sell of centrifuged fertilizers. It is assumed that the biogas plant meets the conditions of high efficient cogeneration and from 50 to 80 % of generated electricity is allowed to obtain an additional income regarding CHP certificate. The price for CHP certificate was assumed on the level PLN 60 per MWh.

Fig. 3 presents a forecast of the profitability of the project for the base scenario, which was expressed through the changes of the net present value and the internal rate of return in time. The discount rate accepted for the calculation of NPV corresponds to the capital cost on the level of 9.75%. The accumulated balance, which represents the time of the capital return without taking into consideration the discounting (5.5 years), is also presented in the chart. The NPV value is positive as early as in the eight year of the operation of the installation (before the total repayment of the loan). This can be considered as a good result with respect to comparable bioenergy projects. This is confirmed with the IRR value, which exceeds the value of 20% in the thirteenth year of operation. Taking into account a relatively high cost of raising the capital, no subsidies and carefully estimated investment budget, which are assumed in the analyzes, a potential of the project economic effectiveness which is worth of one's interest has to be recognized.

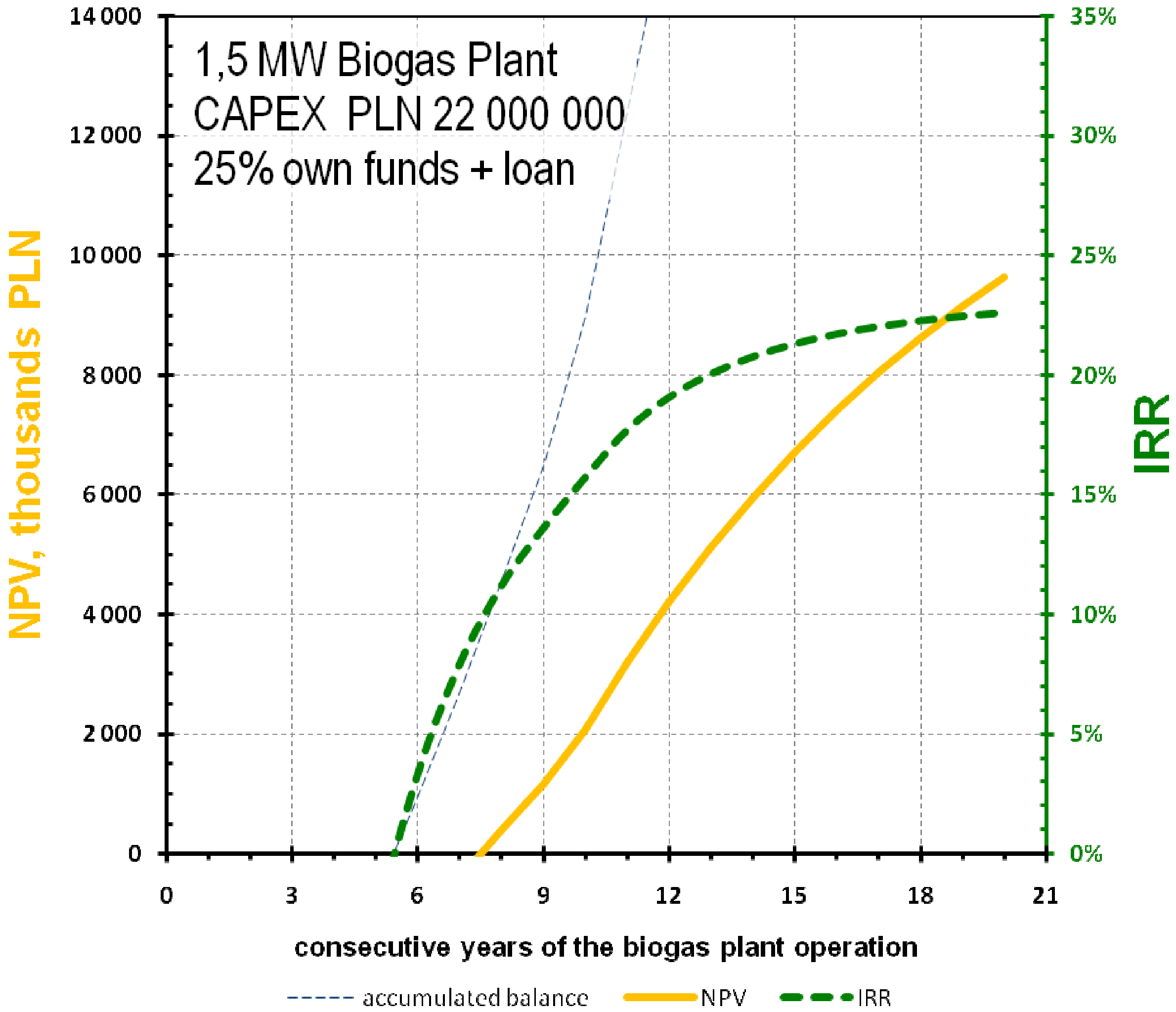
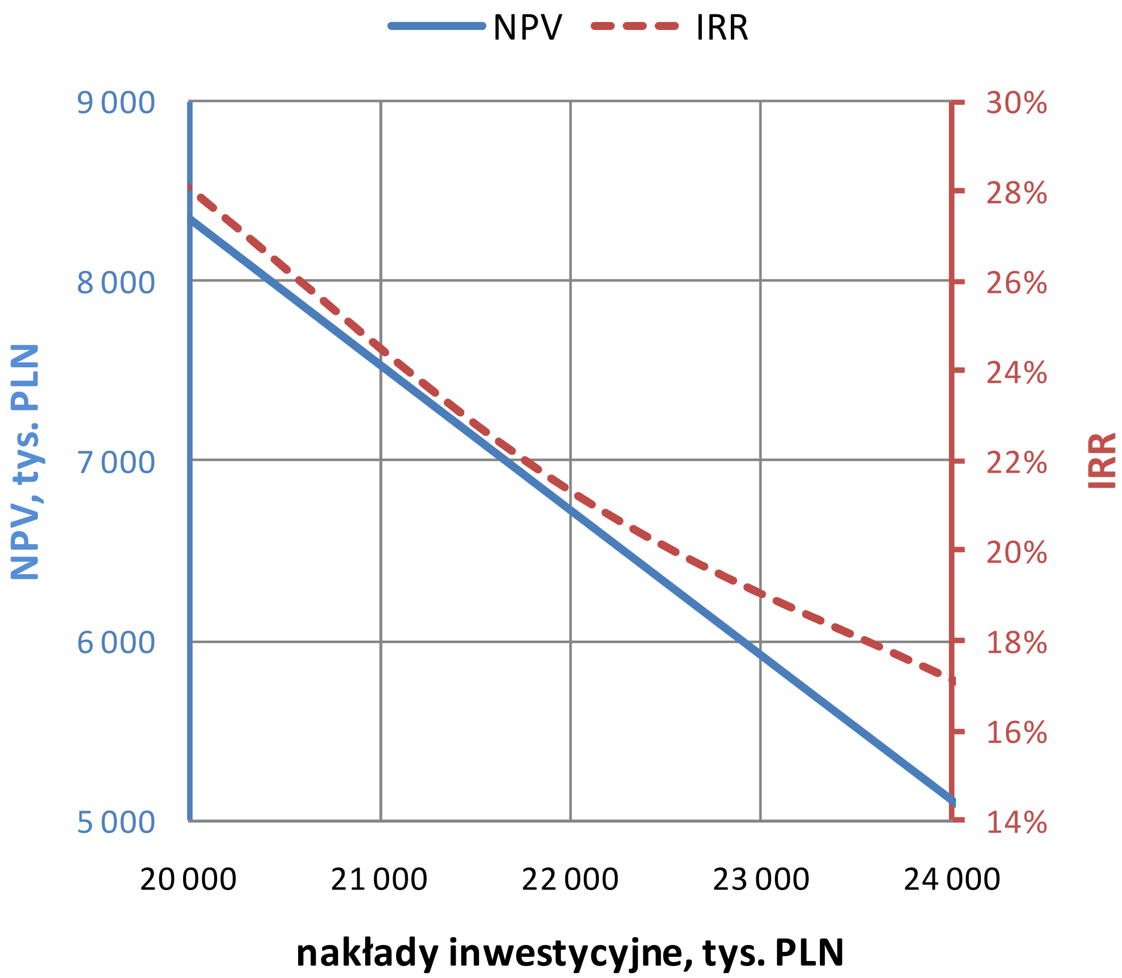


Fig. 3. Forecast of the profitability of the investment for the base scenario

Results of multi-variant analyses

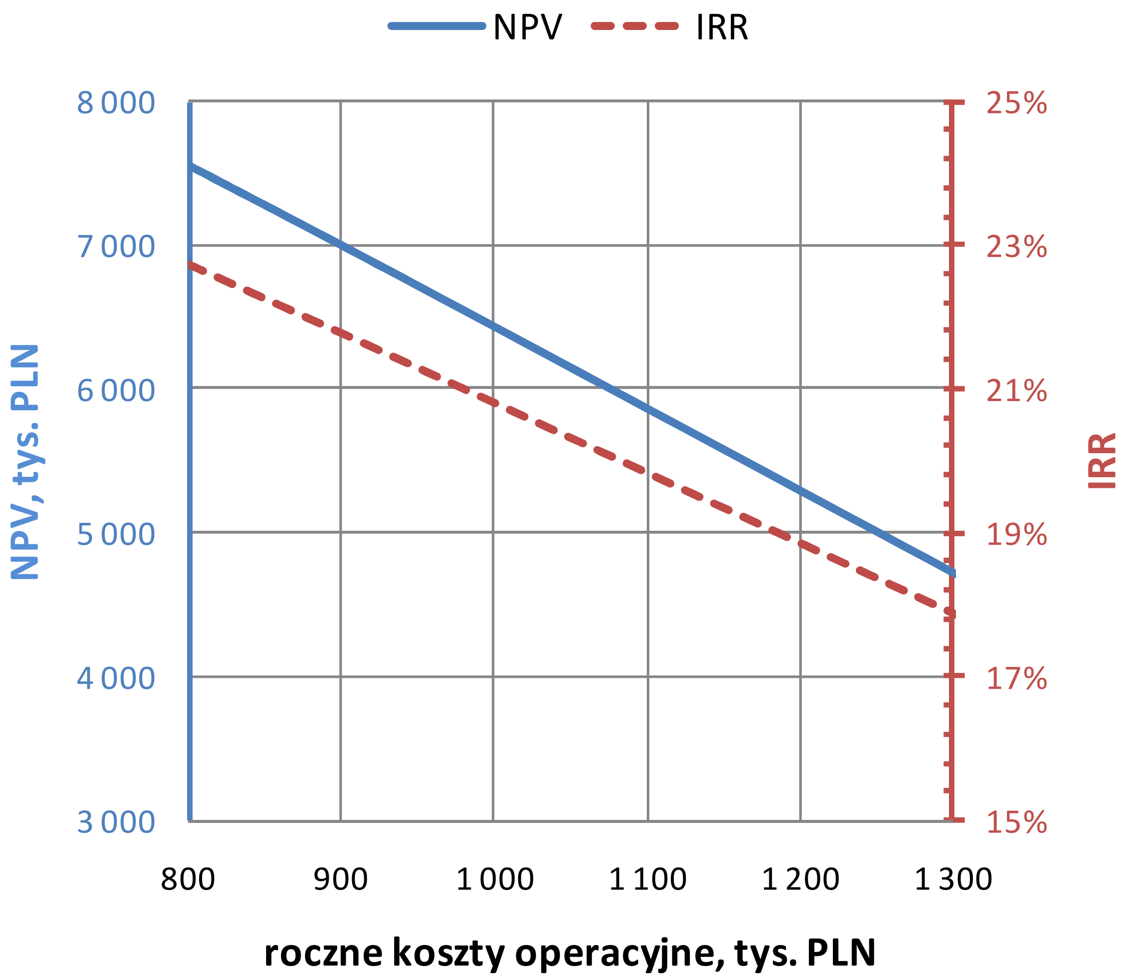
Based on the assumptions presented above, multi-variant economic calculations were carried out to examine the influence of the changes of the parameters examined on the profitability of the project. In further Figures 4-7, the changes of NPV and IRR were presented after 15 years of the operation of the project for the examined scope of the changes concerning the level of investment outlays, annual operating costs, the annual cost of obtaining of substrates and the level of annual operating incomes.



CAPEX, thousand PLN

Fig. 4. Profitability of the biogas plant in the function of the level of investment outlays

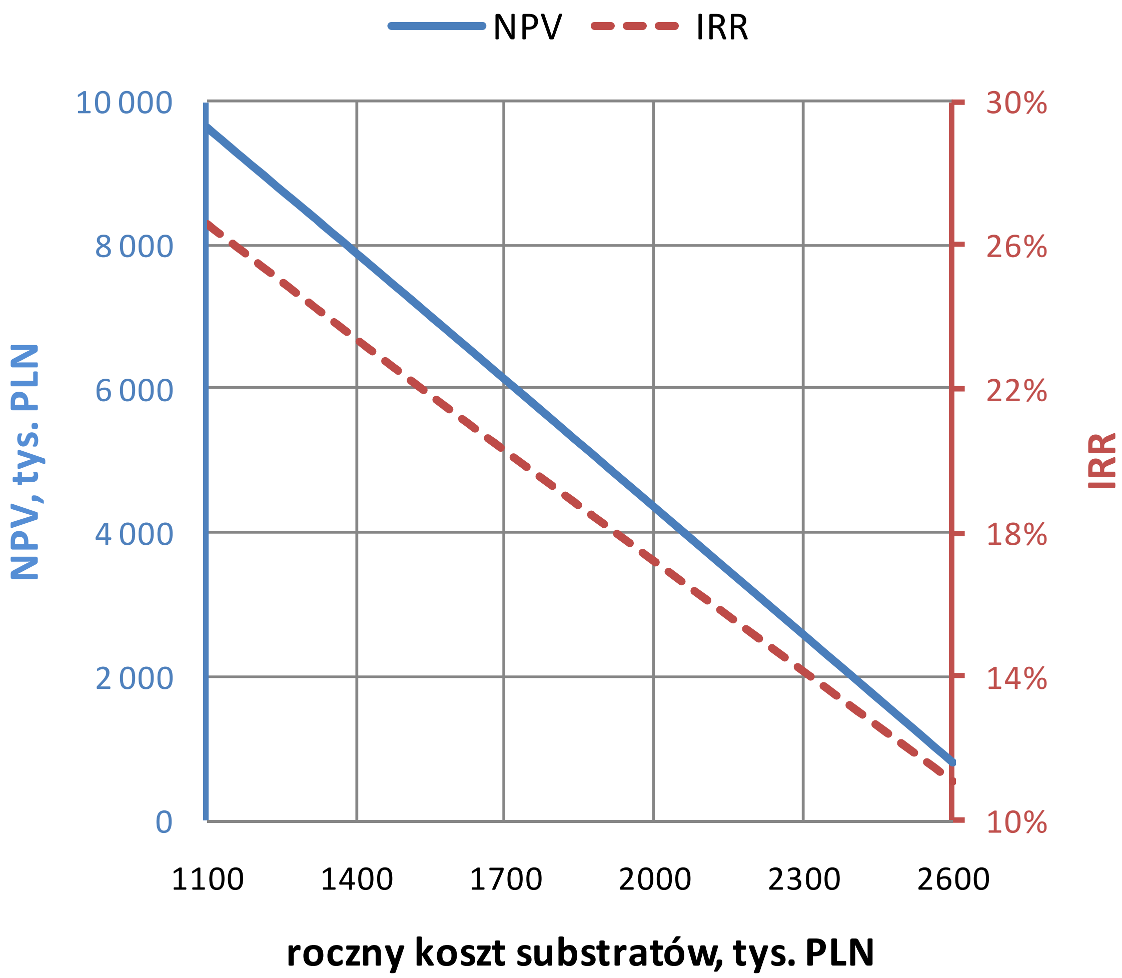
It is evident from the chart above, that the level of investment outlays as accepted for the calculations is in practice a limit value for the investor which they are able to accept. It should be noted that this amount concerns the total expenses and not only this part which is connected with the typical scope of the offer from a supplier of the technology. It can be expected, with a fairly high probability, that the expenses for the installation in question would be to the amount below PLN 20 million, which corresponds to considerably more attractive values of the dynamic indexes of profitability.



annual operating costs in thousand PLN

Fig. 5. Profitability of the biogas plant in the function of the level of annual operating costs

For the base scenario, the level of the annual operating costs (apart from the substrates), was defined on the level of PLN 950 thousand. The above chart depicts the sensibility of the profitability of the project on the assessment accuracy for this parameter. As it can be seen from the figure, this is not parameter which decides about the usefulness of the investment; however, an additional burden which results from the potential need to apply chemical additions to neutralize the excess of ammonia nitrogen in the reactor, has an impact on the investor's profit and should be treated as a final element of the risk management connected with the safe operation of the installation.

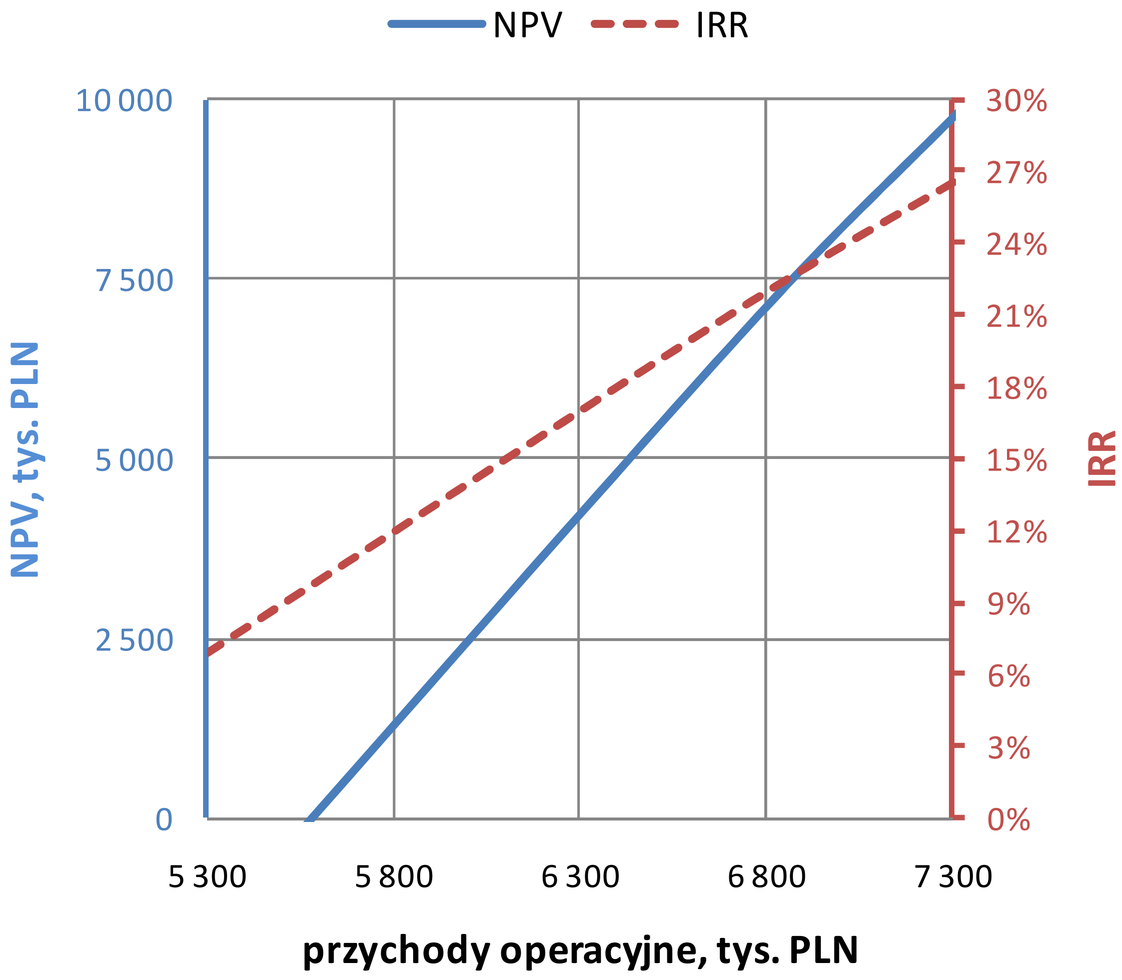


annual cost of substrates in PLN thousand

Fig. 6. Profitability of the biogas plant in the function of the level of costs of obtaining of substrates for fermentation

The supply of substrates is the key item in the statement of the expenses related to the agricultural biogas plant. Advantageous for the project is that the fundamental stream of biomass consists of wastes from animal husbandry, which are available at all the times and are characterized by a fairly low cost. Biomass and pulps that are cultivated for this purpose as well as substrates which are seasonally available constitute ca. 1/3 of the mass of the feedstock, owing to which no large storage capacities are required in transit silos for the biogas plant (lower investment outlays). The chart above indicates a strong dependence of the profitability of the project from the annual average costs of obtaining of biomass. The value of PLN 1.6 million as accepted in the base scenario is a real value which also takes into account derivative costs, i.e.

the logistics of the supply of materials. Any improvement of the conditions of the supplies of biomass significantly improves the account of the results of the investment.



operating incomes in thousand PLN

Fig. 7. Profitability of the biogas plant in the function of the level of annual operating incomes

The analyses on the side of receipts focused on the possibility of the sale of heat and digested fertilizers. The potential of the change of the profitability connected with a changed level of prices: either of the energy or the accompanying property rights, was not analyzed. The price of "black energy" was accepted on the level of 195 PLN/MWh, while the "Green Certificate" was priced 275 PLN/MWh. As there are possibilities for the installation to utilize heat, it is predicted that the requirement of the saving of 10% of the primary energy will be met. This entitles one to obtain Certificates connected with high efficient cogeneration. The value of this certificate was assumed on the lowest possible level: 60 PLN/MWh, while at the same time taking into consideration the fact that only a part (50 to 80%) of the energy generated will be considered as a high efficient cogeneration. The price for selling heat as assumed in the analyses was on a very low level (25 PLN/GJ), and its volume did not exceed 65% of the production.

The incomes from the sale of digested fertilizers were assumed to be on the same level as the cost of the purchase of raw poultry manure. They were defined based on the index of the unit cost per one kilogram of nitrogen on the level of PLN 3.30. It seems that in the reality the fertilizing value of post-fermentation sludges, which also contain potassium, phosphorus, calcium, magnesium and sulphur, and which are furthermore deprived of pathogens and aromatic noxiousness, is higher. This means that there is a further potential of an increase of receipts.

The risks connected with an impossibility to sell or use heat and post-fermentation fertilizers must be appropriately calculated and carefully taken into consideration before taking any investment decision, because these quantities have a very strong influence on the profitability of the project.

Summary and conclusions

Within the present study, selected technical and economic aspects based on the authors' own experiences were presented. They are in relation to a project of an agricultural biogas plant using a substrate, which was troublesome from the technological point of view. Typical strategies were presented of those technological solutions which are used in the case of an excess of ammonia nitrogen in the feedstock for anaerobic digestion. The economic determinants of the considered undertaking were in the focus. A forecast of the profitability for the most probable scenario was presented. The influence of aggregate cost and income items on the changes of the account of results in the time span of 15 years was examined. The obtained results permit one to state that the project is feasible from the technical point of view, and it is attractive from the economic point of view. Furthermore, it has to be added that there is a considerable potential of an improvement of the profitability in relation to the base scenario presented, which was defined on the basis of a rather cautious set of data. Above all it is connected with the amount of investment budget, obtaining of subsidies, potentially lower costs of the substrate and lower operating costs as well as an increase of incomes, e.g. through a higher price of the sale of heat, fertilizers or energy and property rights that accompany it. On the other hand, the technological risk connected with the substrate, which may extort a significant increase of the operating costs, which results in a reduction of the profitability of the project. Risks of a typical business nature connected with the possibility of the sale of heat and fertilizers for an attractive price may be also important.

The presented project seems to be interesting from the economic point of view, and it will be the subject of further detailed technical and economic analyses, e.g. within the framework of a feasibility study. Due to the fact of a fairly large scale of poultry farming in many Polish regions, the experience gained within the framework of the project may be of an assistance, and it can at least to a certain extent transposed in other locations with similar conditions in relation to substrates.

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