Theses of doctoral dissertation (PhD)

UTILISATION OF AGRICULTURAL WASTE IN BIOGAS PLANTS IN ORDER TO REDUCE ENVIRONMENTAL LOAD

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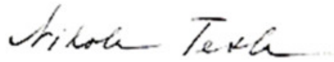
"There is no other fascinating area worth exploring than nature itself.
It is the main purpose of human sense to grasp this wondrous creation,
to explore the forces within and the laws controlling them." (Nikola Tesla)



INTRODUCTION

Greenhouse effect – global warming – climate change

Today, it is an undisputed fact that climate change caused by the greenhouse effect – triggered global warming is one of the greatest problems of mankind. The only problem is that only very few people take notice of this problem.

As a consequence of the greenhouse effect, the atmosphere of the Earth lets the short wavelength and high energy radiation of sunlight pass through, which warms up the surface of the Earth. The exiting long wavelength and low energy heat radiation is absorbed by the so-called greenhouse gases which can be found in the atmosphere. The increasing carbon dioxide concentration of the atmosphere contributes to global warming (*Kruijt*, 2008; *Nagy et al.,* 2015).

It has been proved that human activities altered the composition of the atmosphere and – partially as a result of this change – the climate of the Earth also changed (*IPCC*, 2007). I agree with this statement, but in my opinion it is the Earth's own life cycle which plays a role in the climate change of our planet.
According to *Hagymássy et al.* (2015), climate change has an impact on agricultural production.

Ecological footstep

Each organism on the Earth leaves a trace behind itself. As a matter of course, these courses are mostly never visible, but only their consequence can be observed. We live in the steps of our parents and grandparents while we also leave traces behind us. These traces are like traces left in the fresh snow. Once the weather starts getting warmer, the traces are becoming bigger until we might think a giant walked in our yard (*Figure 1*) The "footsteps" we leave on our earthly environment are called ecological footsteps (*Gilly*, 2001).

Figure 1. Six categories (land use types) of the ecological footstep

Source: *Megújuló energiapark* (2008)

Sustainable development and environmental consciousness

Sustainable development basically has the same concept as harmonious development described in the 1987 report of the World Commission of Environment and Development, only its name changed for today. There are numerous definition of this concept, the first of which is the most widely accepted.

As an ecologist, I find environmental protection, more specifically, ecological sustainability to be the most crucial, since it defines the quality of the society which has an impact on the economic subsystem. The topic of sustainability has to be examined in a complex way, since the joint examination of the three subsystems is indispensable for the interpretation of the whole system (*Figure 2*).

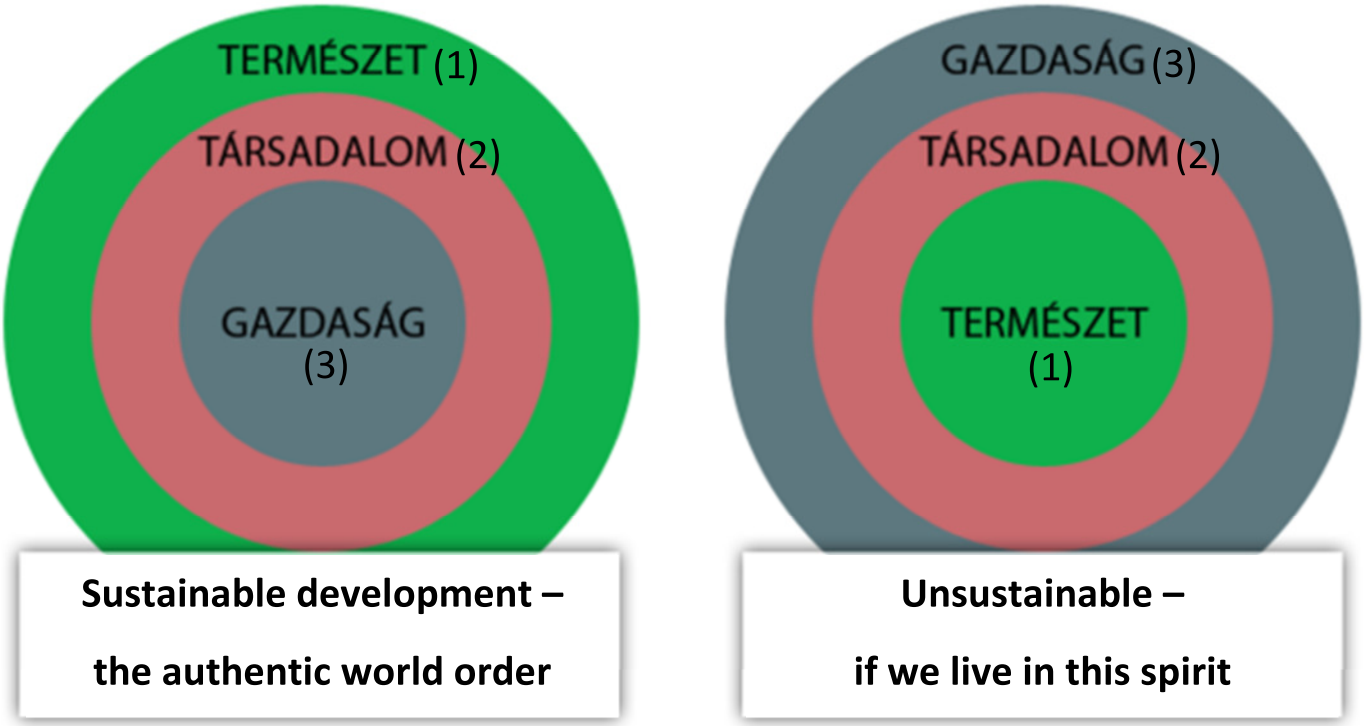


Figure 2. The sustainable and the unsustainable world order

Source: *Tóth* (2007)

Nature(1), Society(2), Economy(3),

Objectives

My fundamental objective is to analyse and evaluate the quantitative and qualitative production of biogas produced in bioreactors, with special regard to identifying the various influential factors, such as the diversity of fuel types and the opportunity of using them.

I examine how much biogas is needed to produce one unit of electricity, as well as the impact of the used feedstock on the quantity of produced biogas.

In my systematic approach, I set the aim to describe the correlations between the technological structure and operation of biogas plants, as well as the utilisation of biogas. More specifically, I intended to examine the structure of mesophilic and thermophilic bioreactors, as well as the method of their use, their operation and the various opportunities of operating combinations of bioreactors.

I also focused on how the composition of the input recipes used in biogas plants affect the staff needed for the operation of the plant and the production of biogas.

I was looking at whether there is any correlation between the number of employees and the quantity of feedstock used.

I examined the currently available and usable modern energy efficiency developments and surveyed the innovative solutions to be involved in the existing system of the examined plants, with special regard to increasing the efficiency of energy transformation.
Furthermore, I examine the potential extra cost (e.g. increasing transport expenses) of various extension and development plans in the case of capacity improvement.

I examined the effect of the operation of biogas plants on the environment, as well as the volume of environmental load and the expected changes in addition to using the environment.

MATERIAL AND METHODS

The regional situation of biogas plants in energy production

According to *Tamás* (2015), nowadays, the use of renewable energies and the improvement of energy efficiency play a significant role. It follows from this fact that the main objective should be the sustainable and environmental friendly utilisation of local energy sources. Biogas plants significantly contribute to the renewable energy production of Hungary.

As a result of the regional examination of biogas plants, it was concluded that biogas plants should be established where adequate amount of utilisable feedstock is available. This is an important logistics factor, because the transport costs of feedstock increase the general costs of the plant. Biogas production can be regarded as decentralised energy production, energy is produced locally in these plants.

Since the overwhelming majority of plants are located in the countryside, decentralised energy production has an especially high impact on job creation and maintaining employment.

The sortiment of feedstock used for biogas production determines how much utilisable waste material, byproducts, produced industrial crops and municipal sludge can be processed and utilised in the plant from the given region. The higher amount of these materials is used, the more the given region is exempted from harmful, untreated materials and their treatment also becomes cheaper in an environmentally friendly way.

Introducing the production system of the Nyírbátor Regional Biogas Plant

The examined and evaluated plants were marked T1, T2, T3, T4, T5 and T6. Plant T5 is the Nyírbátor Regional Biogas Plant, but the other examined biogas plants did not give their consent to disclosing of their names.

The Nyírbátor Regional Biogas Plant (*Pictures 1 and 2*) started to operate in 2003 (*Juhász et al.,* 2014). The plant is located on two sites, one of which is the pre-treatment (heat treatment) of animal waste and the other is the biogas production and utilisation plant.

Pictures 1–2. The Nyírbátor Regional Biogas Plant

Source: own photo

Biogas production process

The originally planned technology of operation was greatly modified with regard to the used feedstock; therefore, the recipes have been in constant change in order to reach the highest biogas output. Based on the available feedstock sortiment, the bioreactors are fed with 4.2–4.5 kg m^{-3} per day (active volume) organic dry matter. The amount of materials constituting the daily recipe is calculated on the basis of the average values of laboratory analyses or with the consideration of the digestible organic matter content calculated based on direct examination and the typical C/N ratio. Diluting water is pumped into the mixing tank which is then used either in the form of cattle liquid manure or raw poultry abattoir wastewater. If these are missing, the fermented digestate from the post reservoirs represents the watery phase, thereby providing 1.5–2.5% hydrolysed organic matter into the fermentation process.

Hall 1 serves the purpose of temporarily storing solid phase feedstocks. From here, the necessary organic feedstock amount is moved into the mixing tank with a front-end loader. During feeding, a submersible motor-equipped mixer constantly homogenises the mixture, thereby contributing hydrolysis. The odour load originating in the hall and the mixing tanks is transported by an air extractor system to the deodorant biofilter with a capacity of 15 000 m^3 per hour. The used solid feedstock are constantly available (except for manure-based constituents): vegetable chaffs stored in accordance with the given season, such as the green ear chaff produced as energy crop from early summer, energy grass, Sudan grass, sweet sorghum and weedy meadow grass constitute the buffer mass. This feedstock is supplemented by the vegetable waste, sweet maize, green pea, common beans, broccoli and tomato from canneries. In the winter period, vegetable feedstock is provided by silo of various composition. The usual components of this mixture are silo maize, sweet maize, husks, grain, ear-end chips, weedy meadow hay, chaffed straw, dryer waste and sunflower chaff. If higher organic dry matter content is necessary in the winter period, forage maize, triticale, maize and sunflower groat is added.

Whey is regularly used as the by-product of the dairy industry as a substrate constituent as it is an active organic component which regulates acidity and stabilises the enzyme balance.
There is a possibility to add liquid cattle manure to the substrate on a daily basis which greatly contributes to the safe maintenance of the bacterial flora developed in the bioreactors, thereby making symbiotic processes more balanced. Due to easier handling and more active biological inclusion, the restructuring of the backwashing liquid manure system of cattle housing technology increases the daily quantity of liquid cattle manure which results in the proportional decrease of using farmyard manure.

In the mixing tank, any activity which would accelerate biochemical processes and result in significant gas production has to be avoided. For this reason, no co-fermentate is mixed to the components in the mixing tanks and the homogenised substrate with the set organic dry matter content is stored in the mixing tank for

a short period of time (below 25 °C for not more than 24 hours). Feedstock put together in a mixing tank provides feed for fermentation for 18–20 hours. The empty tank is being filled up and mixed immediately. If the diluting material for the substrate is the fermentate from either post reservoir (whose usual temperature is between 33–36 °C), increased supervision is necessary in the surrounding of the mixing tanks especially in the case of permanent summer heat. Also, the amount of removed fermentate should conform to the requirement of not increasing the substrate to the critical temperature.
The substrate is pumped from the mixing tanks into the mesophilic bioreactors with a vertical pump every four hours through a PVC and stainless steel pipe system of 160 mm diameter. The path of the fluid is controlled using pneumatic valves. The valves and the fluid quantity are adjusted by a biogas machinist using a central computer.
The substrate is sent from the mixing tanks to the mesophilic bioreactors. The organic dry matter content of the substrate is between 6.2–7.0%. The pump system is able to transport the substrate without any difficulties if the grain size of the vegetable components is not larger than 2–5 cm.

The organic dry matter still missing from the load of the bioreactor is transported from the 2nd preparation hall into the anaerobic zone. The sterilised meat juice is transported from the animal waste pre-treatment plant (*Decree of the Ministry of Environmental Protection*, 2001) to the preparation hall with a tanker and it is pumped into to insulated 30 m^3 tanks which are equipped with extra heating and homogeneity is provided with mixers. Following the four-hour-long cycle period, the meat juice is pumped into the mesophilic bioreactors.

Due to the hydraulic flow (communicating vessels) between the mesophilic and thermophilic bioreactors, fermentate of a volume equal to the quantity of the "raw" substrate flows from the mesophilic stage into the paired thermophilic bioreactor. The same amount of rotted fermentate flows into the post reservoir.

Since the C/N ratio of meat juice is 13–15, i.e., its carbon content is inadequate for the satisfactory course of methanisation processes, the missing quantity of carbon is replenished with industrial fat (e.g. leftovers from vegetable oil industry use). The surplus sludge of the biological wastewater purification plant is stored in the reservoirs placed in the 2nd preparation hall. Since the hall was built later than the primary plant, it is not automated and the ongoing processes are performed manually. The liquid from the buffer reservoirs are transported into the proper bioreactors through a pipeline using a rotary pump.

The timing of material transport is selected in a way to make sure that feeding takes place in the resting period of the bioreactor (mixing breaks); therefore the liquid exiting by means of hydraulic flow at the bottom contains a lower concentration of organic matter than at the upper levels of the bioreactor. As a result, organic matters from the post bioreactors leached into the post reservoirs to a lesser extent. Post reservoirs are open, but covering them reduces the odour load of the environment.

It is important to keep the efficiency of fermentation at the highest level, because the non-decomposed protein content of the resulting organic manure significantly increases its unpleasant odour.

Preparation of feedstock of animal origin

Animal fats and proteins are an important group of feedstock to be used for biogas production. The utilisation of animal byproducts and waste originating from abattoirs and animal farms for biogas production can only be performed if strict animal health rules are conformed to. The primary rule is that only feedstock of animal origin belonging to category 2–3 can be used following prior sterilisation or pasteurisation. This rule made it necessary to establish a heat treatment plant.

Contaminated and clean zones were established in the plant in which materials can be relocated without the risk of re-contamination or infection. Critical points were identified in the course of technology which are under constant control and their parameters are logged by a computer in a closed system. The byproducts or waste transported into the plant on trucks are loaded into pits using a special feeder which then forwards them to a grinder.

It is the first condition of heat treatment that the grain size of the feedstock shall not exceed 5.0 cm. The ground feedstock is transported into a tank using a feeder and a rotary pump, where a digital scale measures and logs the quantity to be performed heat treatment on. The ground mass is forwarded to disinfectors on a pressure of 3–5 bar, where it is sterilised for at least 20 minutes at a minimum pressure of 3 bar and at a minimum temperature of 133 °C. From here, the hot material is "shot out" into a tank by its own pressure, where – having lost its pressure – it is temporarily stored. The released putrid steam passes through a condenser, where it loses its water content and the air is deodorised using a biofilter. The sterilised meat juice exiting the tank is filtered for parts bigger than 6mm (mainly bones) and the juice is pumped into the tanks of final products where smaller solid parts settle onto the bottom of the tank.

A tanker transports the sterilised meat juice for biogas production at the plant using a closed unloading system. The separated solid parts are transported to a composting plant for further treatment. The timely heat treatment of materials is provided using two grinders and three disinfectors. The entire process is logged by a computer in order to conform to the tracking rules. The vehicles performing transport and the transport containers are washed and disinfected in the preparation halls, after which they pass through a disinfector framework towards the clean zone parking lots. On average, the plant performs the heat treatment of 20000–25000 tons of material per year.

Following transport, the submersible motor-equipped mixers homogenise the substrate which is an important condition of fermentation efficiency. Regular mixing is controlled by a software which is capable of changing the operational period of mixers. The bioreactor temperature can be maintained using a part of the hot water in the block heating units (*Picture 3*).

Picture 3. Automatic heating control of bioreactors

(Nyírbátor Regional Biogas Plant, 2016)

Source: own photo

The heating control system automatically maintains 38 °C in mesophilic bioreactors and 55 °C in thermophilic bioreactors. The fermentation space in the mesophilic bioreactor is heated with floor and wall heating, while that of thermophilic bioreactors is heated with wall heating.

The organic dry matter content of the fermentate (organic manure) exiting the thermophilic bioreactors is 1.3–2.8% which was supplemented by 0.5–1.3% inorganic dry matter in the previous years. Probes were installed into the bioreactors to constantly monitor temperature and acidity which can be checked online using the central computer.

The gas analyser equipment makes it possible to monitor the advantageous or disadvantageous course of the anaerobic fermentation by taking a sample from each bioreactor and displaying the measured data.

Furthermore, this equipment measures the volumetric percentage of methane, carbon dioxide and oxygen, as well as the concentration of sulphur hydrogen and ammonia in the produced biogas.

Gas phase and desulphurisation

The biogas produced as a result of the biochemical processes is located in the upper 0.8 m tall space which is protected from gas diffusion. The biogas produced in the biogas plant is unique both in respect of the favourable and unfavourable parameters as defined in view of the indexes to be described in general. The f63luctuation of methane content is small, between 60–63 vol%, i.e., the heating value can be planned with a great reliability, similarly to the amount of electric and thermal energy to be produced.

In addition to the numerous positive factors, the utilisation and use of animal waste has an unfavourable impact on the quality of gas, because the sulphur content of proteins in the gas results in a high sulphur hydrogen level. The desulphurisation of the gas is performed by sulphur bacteria activated by blowing in a proper amount of air in accordance with the concentration of sulphur hydrogen fed into the bioreactors as measured by gas analysers. During the activity of these bacteria, elemental sulphur is precipitated in the gas space of the bioreactor.

It is the disadvantage of the system that only an amount of oxygen not exceeding the lower level of the limit value of explosion can be fed into the bioreactor and that anaerobic conditions have to be provided in the bioreactor in order for fermentation to start. In the biogas plant, the desulphurisation problem is caused by the system adjusted to the previously calculated biogas output which cannot always provide the proper level of desulphurisation (which is significantly higher than the planned level) of the currently produced biogas quantity. It is an additional problem due to the air-based desulphurisation that the process does not only go on in the bioreactors, but also in the outlet pipeline system, where a significant amount of sulphur is precipitated on the pipe walls. The removal of this sulphur is extremely complicated. The biogas is transported to the final point of use, i.e., the block heating unit with gas condensers, which guarantee that at least 60 mbar pressure is provided at the gas engines after the gas distributor.

The path of organic manure

The rotted fermentate transported into the post reservoirs passes through pulley-equipped separators and solid particles larger than 0.6 mm are filtered out.

The significant proportion of this material consists of leftover fibres from cellulose scaffolds and the adhering non-fermented protein residue and dead bacteria. The larger fractions of the inorganic materials in the process are also transported into the separated feedstock. This solid material is a sterile medium with a dry matter content between 25–35%. It can be used for further fermentation in the biogas plant as base or as litter, for making compost or as fertiliser to be applied directly on the field.

According to various observations and the several-year-long irrigation crop production experiments, this material has an outstanding conversion rate, it is a significant nitrogen base and contains proportional amounts of potassium and phosphorus. As a result of its enzymatic effect, it can be taken up easily by crops even as foliar fertiliser.

Utilisation of biogas

The produced biogas is currently utilised in four block heating plants. One part of the electricity produced by the synchronised generators operated with biogas engines in these units is directly used for the operation of the biogas plant (to the extent necessitated by the actual demand). The rest of the produced electricity is forwarded to the transformer room and fed into the external high voltage grid through the switching system. One generator serves the transformer of the poultry abattoir from where electricity is forwarded to the surrounding plants (*Figure 3*).

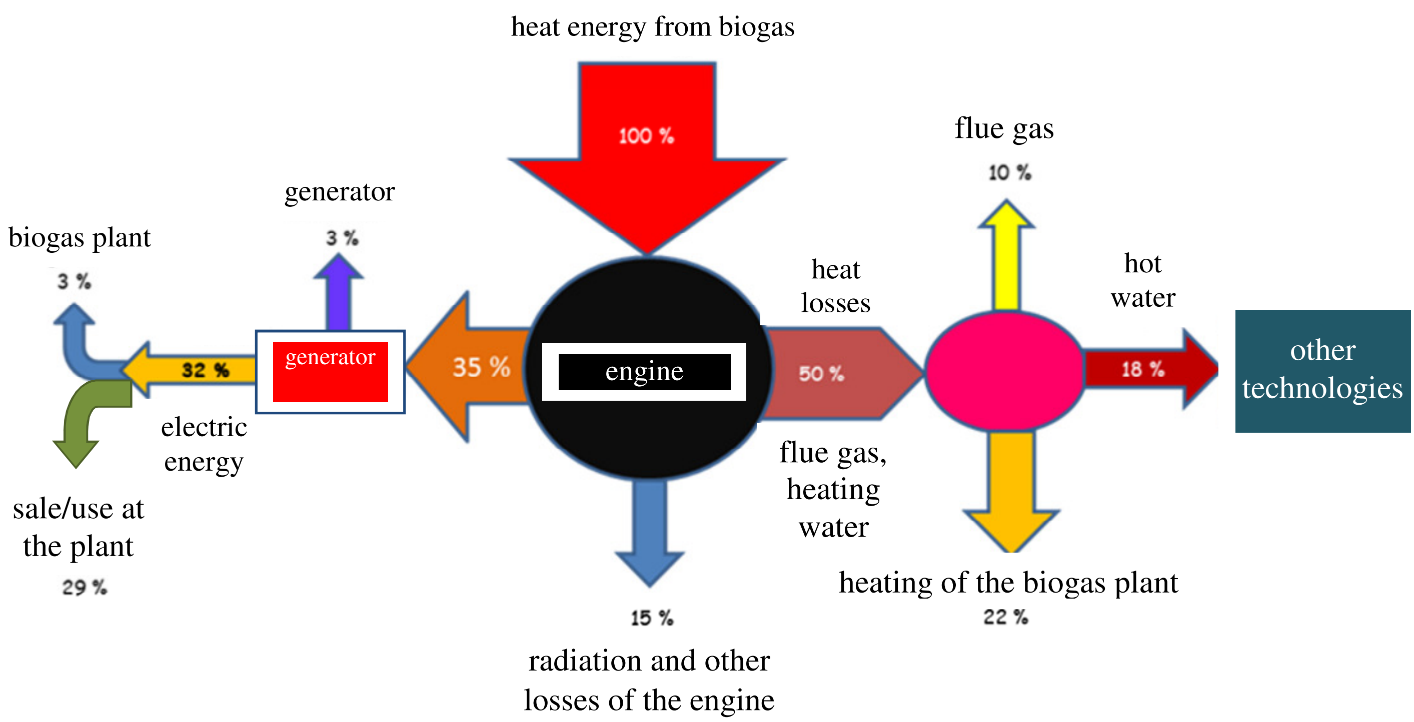


Figure 3. The total energy cycle balance (Nyírbátor Regional Biogas Plant, 2016)
Source: own construction based on *Petis* (2007)

The large quantity of 92–110 °C water produced during the cooling of the gas engines has been used to a small extent so far. The heat quantity used for the heating of the bioreactors and transported to the poultry processing plant does not exceed 30% of the total produced heat energy in a year. It is difficult to find the technological harmony between the constantly operated power plant which continuously produces hot water and the heat utilisation points which call for sectioned, cyclic heat use. Without proper use of the produced heat, the gas engines automatically stop.

Examination and statistical methods

The statistical analyses and the preparation of interaction graphs were performed with R 3.2.4. (*R Core Team*, 2016), RStudio (*RStudio Team*, 2016) and "agricolae" (*de Mendiburu*, 2016).

Statistical method: due to the numerous biological, environmental and human factors occurring during biogas production, the alpha error was chosen to be 10% (alpha=0.1). Averaged over the three examined years, biogas outputs and electricity production were examined using ANOVA with the following R codes:

- *model=aov(formula = output ~ time factor, data = database)*
- *summary(model)*
- *anova(model)*

The effect of biogas on electricity production was examined with a general linear model (glm) based on *Huzsvai* (2012) with the following R code:

- *model<-with(database, lm(biogas~electricity))*
- *summary(model)*
- *anova(model)*

The effect of the quantity of the used feedstock on the personnel was used with general linear model (glm) based on *Huzsvai* (2012) with the following R code:

- *model<-with(database, lm(personnel~number))*
- *summary(model)*
- *anova(model)*

As a part of my research, I conducted six in-depth interviews with biogas plant managers. In-depth interviews can be used for qualitative data collection. During the personal inquiry, the interviewer can gather in-depth information which can help them understand the systems and correlations of the given topic (*Wyss*, 1991). Interview duration was around one hour. At the beginning of my research, I made a list of the biogas plants operating in Hungary. As a next step, at the recommendation of my supervisor, I contacted the managers of all biogas plants in Hungary. Six of these plants responded to my request. Following the establishment of connection with these managers, I performed personal local survey at the given plants.

It is an important feature of the SWOT analysis that the first two areas, i.e., strengths and weaknesses point out the internal characteristics of the company, while the other two, i.e., opportunities and threats examine the environment surrounding the company, according to *Chikán* (1997). In this thesis, I describe the characteristics of the examined biogas plants using a SWOT analysis.

RESULTS

Results of the data collected in biogas plants

The examined biogas plants are of different size and they are all located in the North Great Plain region. The monthly and yearly electricity and biogas production of the examined plants are shown in *Table 1* and *Figure 4*.

Table 1. Monthly energy and biogas production of the examined plants

	T1	T2	T3	T4	T5	T6	Average
Monthly electricity production (kWh)	192000	645000	167000	181000	1466773	375000	490550
Monthly biogas production (nm^3)	97000	234000	101000	85000	705719	208300	242300

Source: own construction

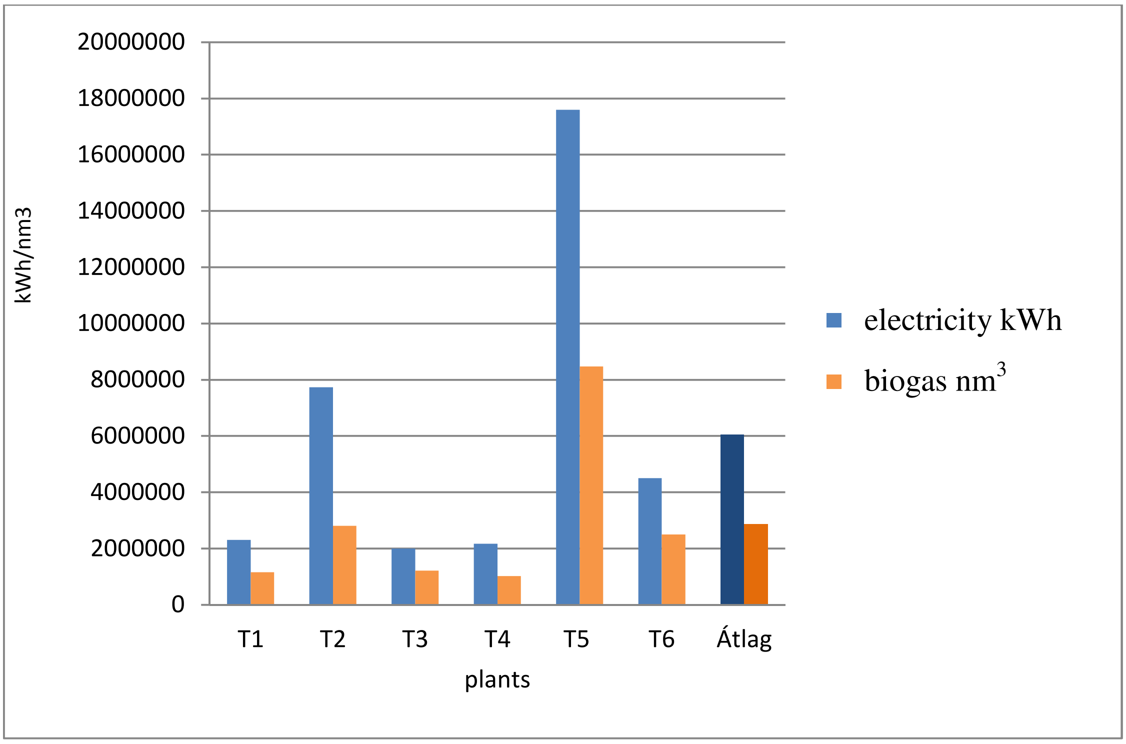


Figure 4. Yearly electricity and biogas production of the examined plants (kWh, nm^3)

Source: own construction

Figure 5 shows the proportion of the used feedstock at the examined plants. It can be seen that feedstocks of animal origin are more represented (nearly two thirds) in comparison with feedstocks of vegetable origin (32%) and other feedstock types (9%).

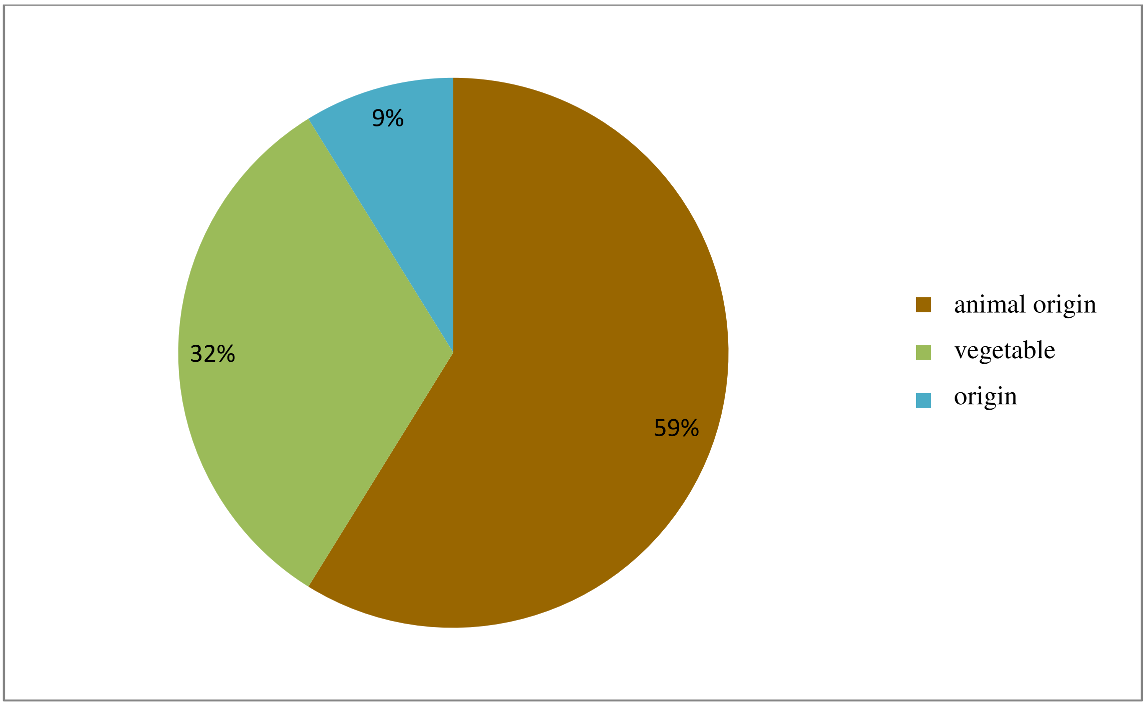


Figure 5. Proportion of feedstock used at the examined plants

Source: own construction

Table 2 and *Figure 6* show the data obtained from the examined plants in relation to the composition of biogas.

I examined the effect of using the different types of feedstock on personnel. Using the obtained data, I changed the order of plants and described the proportionality between personnel and the number of used feedstock. (*Figure 7*).

Table 2. General characteristics of the biogas produced by the examined plants

Biogas composition (%)	T1	T2	T3	T4	T5	T6	Average
CH_4	56,2	61	64	57	63	61	60,36667
CO_2	31,2	33,7	23,5	23	25	29,9	27,71667
H_2S (ppm)	110	123	97	111	107	118	111

Source: own construction

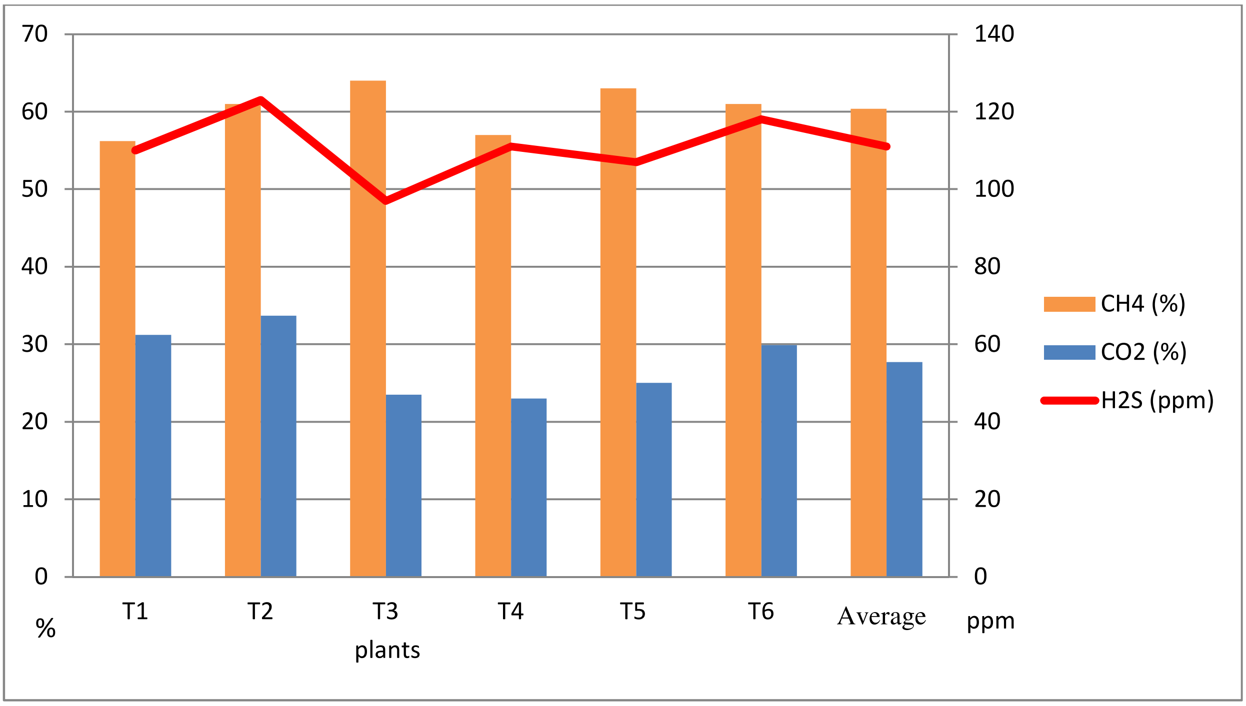


Figure 6. Composition of biogas produced at the examined plants (CH_4%, CO_2%, H_2S ppm)

Source: own construction

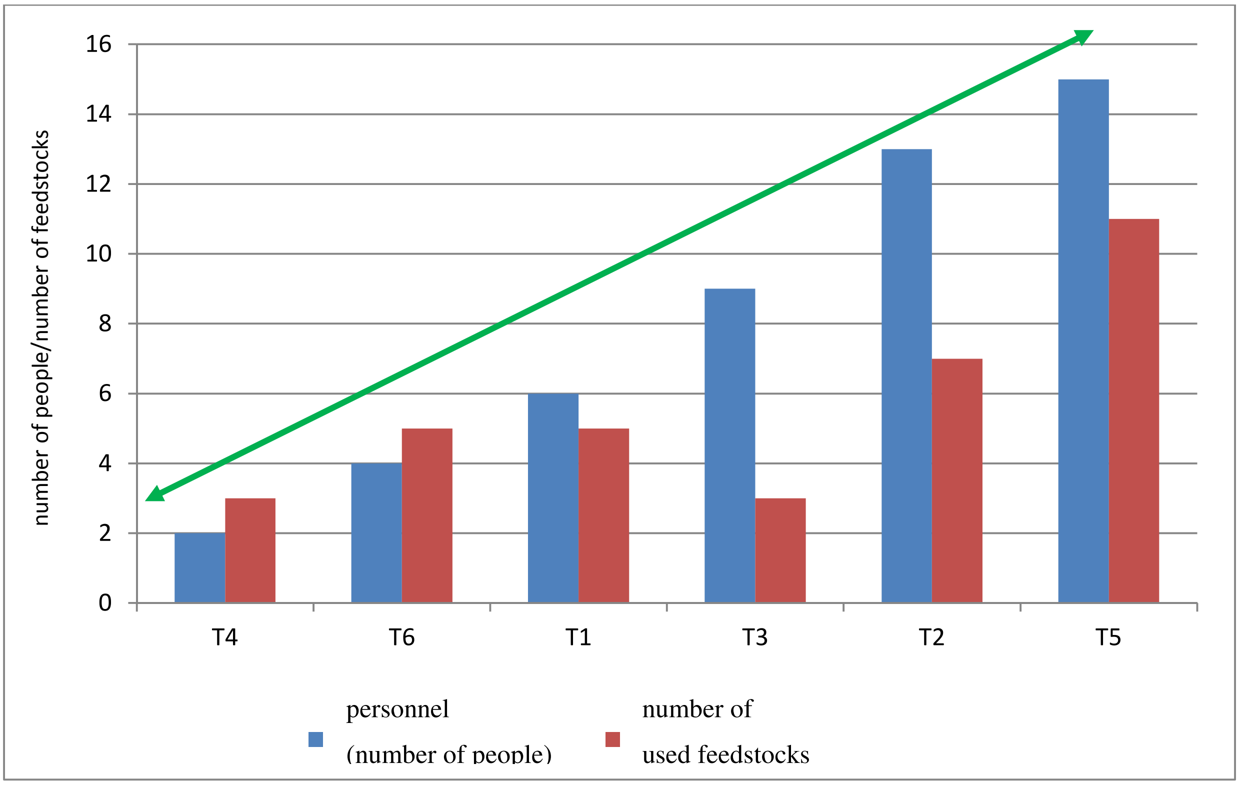


Figure 7. Correlations between personnel and the number of used feedstock of the examined plants
Source: own construction

Based on the obtained data, the number of used feedstocks affects staff size. According to the performed regression analysis, there is a correlation between the number of used feedstock and staff size (r=0.74). The type of used feedstock affected staff size to a 54.28% extent (P<0.1).

Evaluation of the data measured at the Nyírbátor Regional Biogas Plant

Table 3 shows the biogas and electricity production of the Nyírbátor Regional Biogas Plant in 2016. In the current system of operation, the biogas plant is capable of producing 8.46 million nm^3 biogas and 17 601 MWh electricity per year.

Figure 8 shows the biogas and electricity production of the Nyírbátor Regional Biogas Plant in the examined years. There is a clearly visible close correlation between the amount of produced biogas and the related electricity production.

Averaged over the examined years, there was no difference in biogas production on a monthly level; therefore, biogas output was constant as shown by ANOVA (*Table 4*). There was no significant difference between the examined years and each month.

Table 3. Biogas and electricity production of the plant

(Nyírbátor Regional Biogas Plant, 2016)

Months	Produced biogas (m^3)	Produced electricity (MWh)
January	761704	1564,513
February	740712	1557,747
March	702008	1418,366
April	747418	1536,567
May	710494	1474,567
June	748938	1555,352
July	694237	1461,208
August	754634	1546,290
September	691167	1445,367
October	675046	1439,682
November	607120	1251,038
December	635156	1350,576
Total	8468634	17601,273

Source: own construction

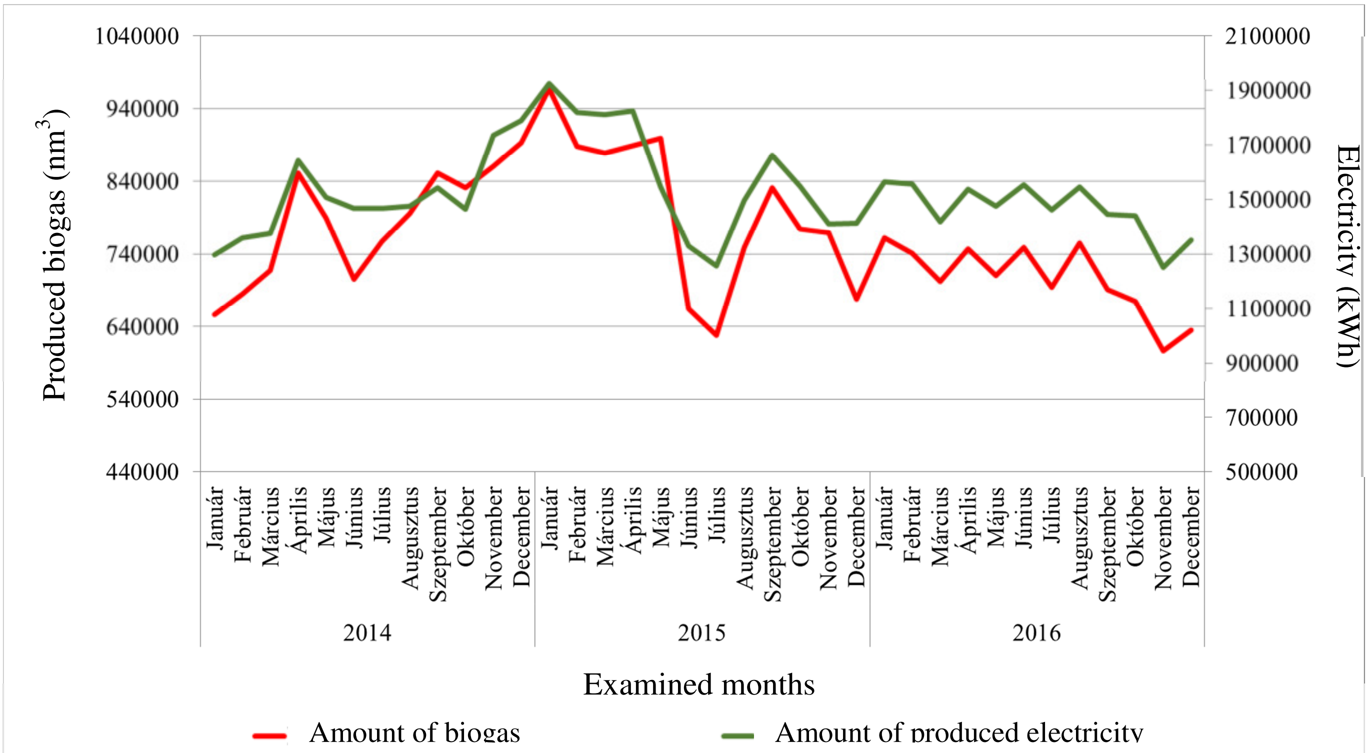


Figure 8. Correlation between the produced biogas and electricity

Source: own construction

Table 4. Seasonal effect on gas production averaged over the examined years

	df	Error sum of squares	Variance	F	Significance (>)
Month	11	$5.064*10^{10}$	$4.604*10^{9}$	0.475	0.9^{ns}
Residue	24	$2.324*10^{11}$	$9.683*10^{9}$		
Significance: 0 '***' 0,001 '**' 0,01 '*' 0,05 '.' 0,1 Not significant 'ns'					

Source: own construction

Averaged over the examined years, there was no difference in electricity production on a monthly level, i.e., electricity production was also constant (*Table 5*).

The examined years had a significant effect on gas production (*Table 6*).

Table 5. Seasonal effect on electricity production, averaged over the examined years

	df	Error sum of squares	Variance	F	Significance (>)
Month	11	$1.721*10^{11}$	$1.565*10^{10}$	0.476	0.9^{ns}
Residue	24	$7.896*10^{11}$	$3.290*10^{10}$		
Significance: 0 '***' 0,001 '**' 0,01 '*' 0,05 '.' 0,1 Not significant 'ns'					

Source: own construction

Table 6. Yearly effect of gas production

	df	Error sum of squares	Variance	F	Significance (>)
Year	2	$6,198*10^{10}$	$3,099*10^{10}$	4,626	0,0169*
Residue	33	$2,211*10^{11}$	$6,699*10^{9}$		
Significance: 0 '***' 0,001 '**' 0,01 '*' 0,05 '.' 0,1 Not significant 'ns'					

Source: own construction

Based on the graph, it can be concluded that biogas production had an impact on electricity production (*Figure 9*).

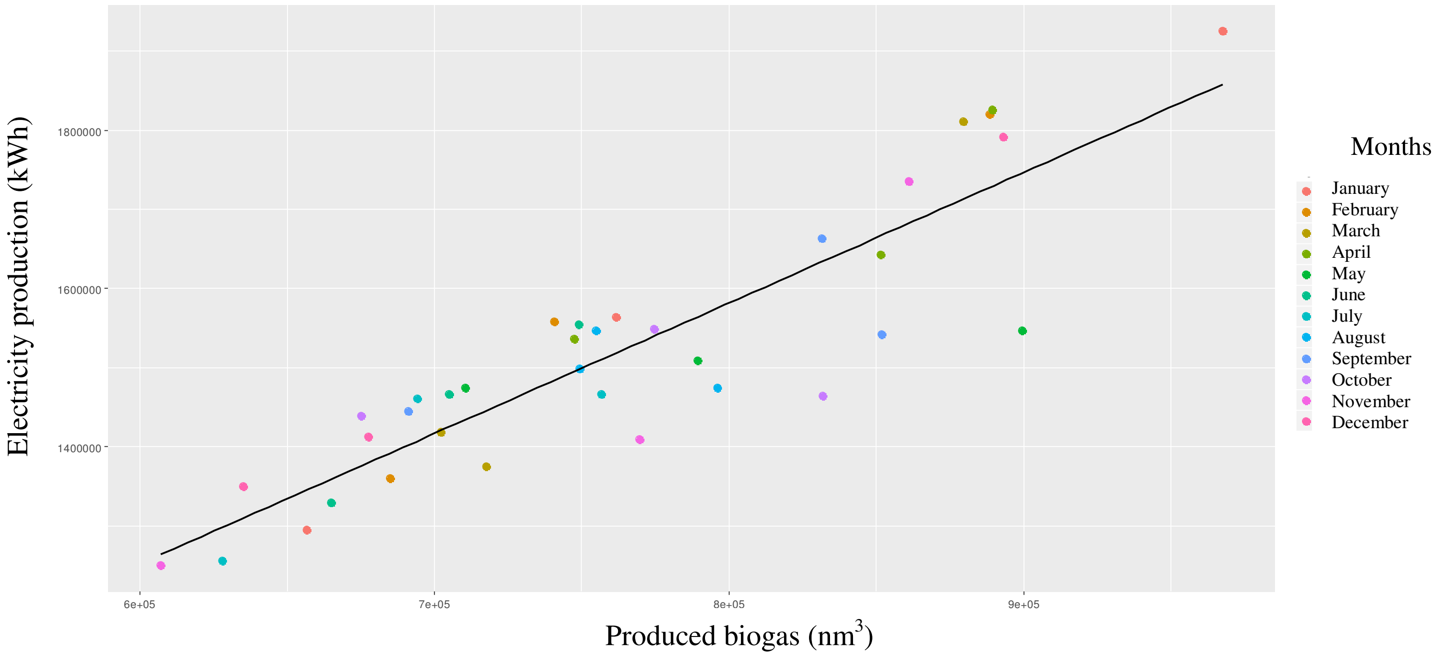


Figure 9. Correlation of biogas output and electricity production, averaged over the examined years

Source: own construction

CONCLUSIONS

In my opinion, biogas production can be competitive with fossil fuels only if the whole production process is considered to be a system.

I examined the advantages of this system and concluded that the processed feedstocks, byproducts and waste in the biogas plants have a positive effect on the environment surrounding us.

The proper disposal of the waste coming from various industrial sectors during the biogas production process is important not only from the environmental protection aspect, but it also represents a significant income for the operator from the economic aspect.

There are promising signs showing that the use of renewable energies and their integration into the energy supply systems is a constantly accelerating process.

According to various researchers and experts, approximately 200 biogas plants can potentially be established in Hungary until 2020.

I concluded that the biogas and electricity production of the Nyírbátor Regional Biogas Plant was constant in the examined years, independently of the fact that is operates with a varied sortiment.
In 2016, the plant stopped using glycerine as feedstock.
I concluded that the examined years had a significant ($P<0.05$) impact on gas production.
I examined the gas output in each year, based on which the lowest significant difference was 67979.56.
I used regression analysis to examine the effect of biogas production on the amount of electricity production. Averaged over the three examined years, there was a close ($r=0.89$) correlation between the amount of biogas and electricity production ($P<0.001$). Based on the obtained results, it can be concluded that the amount of biogas production affected electricity production to a 79.29% extent.

NEW AND NOVEL SCIENTIFIC FINDINGS

1. I concluded that the operation of agricultural biogas plants is fundamentally affected by the physical structure of the used feedstock, especially dry matter content and organic matter content.

2. I concluded that heat production is a regular concomitant of biogas production. A system adjusted to the quantity and quality of heat production is necessary both from technical, technological and economic aspects.

3. I concluded that, from the aspect of the operation of bioreactors, environmental protection, as well as the use of input materials originating from crop production and the fermentate are indispensable tasks.

4. I concluded that – during the examined years – the biogas and electricity production of the Nyírbátor Regional Biogas Plant is reliable due to the wide range of used feedstock.

5. The lowest significant difference in gas production between each year was 67979.56 ($P<0.05$). There was no significant difference between 2014 and 2015, but I found significant differences between 2015 and 2016, as well as between 2014 and 2016. The reason for this finding was described using the quantitative and qualitative indexes of the different feedstock types. Accordingly, I concluded that the results of 2016 mainly roots in the lack of glycerine.

6. I used regression analysis to examine the effect of biogas production on electricity production. Averaged over the three examined years, there was a close correlation ($r=0.89$) between the amount of biogas production and electricity production ($P<0.001$). Based on the obtained findings, it was concluded that the amount of produced biogas affected electricity production to a 79.29% extent.

FINDINGS TO BE USED IN PRACTICE

1. The unused heat produced during electricity production in biogas plants has to be used in an innovative way in order to gain efficiency. Accordingly, I recommend the use of an adsorption cooling equipment which makes it possible to operate a cold storage plant in the period from April to November where it is not necessary to provide temperature below +5 °C. This process is suitable for storing vegetables and fruits at the proper temperature. In the above mentioned period, the utilisation of waste heat could be efficiently performed by establishing a crop drying plant which is suitable for both roughage and grains.

2. Based on my experience obtained in research, I recommend that the fermentate leaving the bioreactors needs to be treated by means of phase separation, during which the solid and liquid phase is separated from each other. Due to the 15-20% organic matter content of the solid phase, it has to be used and fed back to the initial phase of the production process as diluting fluid which will decrease feedstock costs. The liquid phase has to be pumped through a decanting equipment which, following further dilution, is able to be used in greenhouses as microsprinkler nutrient solution treatment, due to its 1-2% organic matter content. This method will result in two new products from one.

3. I recommend the utilisation of the fermentate by feeding it back into the bioreactors for the purpose of utilising it in crop production. In order to do so, the mutual systematic correlations of direct and indirect (using a separator) utilisation have to be used.

4. Based on my examinations, I recommend the establishment of a post storage space for organic manure, equipped with floor heating, where the dry matter content of organic matter (30-40%) can be increased to 75-80% in 2-3 days; therefore, it can also be used for fertilisation purposes.

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