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Environmental impacts associated with production and utilization of agricultural biogas

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Abstract

This article includes the theoretical information about biogas, the production process, general information about renewable energy and regulations considering the digestion of manure and other fermentation by-products. The paper however is focused on environmental impacts of agricultural biogas production and utilization. It includes information about possible emissions that can be avoided and their environmental impact. More detailed calculations of the possible annual energy production in Poland are presented in the last part of the article.

Keywords: biogas, renewable energy, emissions

Streszczenie

Czynniki środowiskowe związane z wykorzystaniem biogazu rolniczego

W artykule zawarto informacje dotyczące biogazu rolniczego, jego produkcji, ogólne informacje o odnawialnych źródłach energii oraz informacje dotyczące aspektów prawnych fermentacji metanowej gnojowicy oraz późniejszego wykorzystania powstałych w tym procesie produktów. Skupiono się na czynnikach środowiskowych związanych w produkcją i wykorzystaniem biogazu rolniczego. Zawarto informacje dotyczące możliwych do uniknięcia emisji oraz sposobu, w jaki wpływają one na środowisko i człowieka. Zaprezentowano również nieco bardziej szczegółowe obliczenia potencjału energetycznego gnojowicy pochodzącej z hodowli bydła i owiec.

Słowa kluczowe: biogaz, odnawialne źródła energii, emisje

1. Introduction

As our world is continuously developing, the demand for the energy increases. The depletion of conventional energy sources, such as fossil fuels (coal, crude oil, natural gas), and environmental issues caused by use of such fuels have finally led us to a conclusion: we should use the energy from renewable sources.

Renewable energy sources are a great alternative for the conventional, nonrenewable energy sources. What makes them special, is that they constantly renew themselves in natural processes, so they can be treated as infinite. Also, the extraction of renewable energy sources is less harmful to the environment, than it is in case of fossil fuels: the hazardous emissions of substances such as green house gases can be limited [1].

2. Biogas

Biogas is a gas produced from anaerobic digestion of organic matter, i.e. sewage, animal manure or municipal solid waste. Organic matter is a source of food for bacteria that produce methane. Manure is the main organic matter required to produce agricultural biogas, however it doesn't have to be the only source- some other types of waste (such as sewage sludge, industrial waste, animal by-products and municipal solid waste) can be also added as a secondary organic source [2]. The other ingredient required to produce agricultural biogas is bacteria, which is necessary to transform fats, proteins and carbohydrates located in manure and possibly other organic matter into simple acids (such as acetic or propionic acid). Simultaneously, another type of bacteria is introduced to convert those acids to methane and carbon dioxide. Such bacteria are commonly present in manure [2].

The calorific value of biogas depends on the percentage of methane- the more methane, the higher the calorific value of biogas. Methane content depends of the composition of the feedstock. We usually assume that the calorific value of biogas containing 65% of methane is equal to 23 MJ/m^3 [3].

Calorific values of biogas and other fuels are presented in Table 2.1.

Table 2.1. Comparison of calorific value of biogas and other energy sources [4].

Fuel type	Calorific value [MJ/m^3]	Conversion factor*
Biogas	20-26	1
Natural gas	33.5	0.77
Diesel	41.9	0.62
Hard coal	23.4	1.1
Rape biofuel	36.5	0.70
Ethanol	29.6	0.85
Firewood**	13.3**	2
*Compared to 1m^3 of biogas, calorific value equal to 26 MJ/m^3		
**Calorific value of firewood varies with its moisture content (8-18 MJ)		

Hydrogen sulfide, the decomposition product of proteins, is present only in small amounts, however it may cause the corrosion of pipelines and other metal elements. Water vapor is also troublesome since it may condense in the pipelines.

Agricultural biogas is most commonly produced from animal manure. Organic industrial waste and agricultural waste can be also used as substrates. There are three groups of starting materials:

a) Agricultural
- Animal manure
- Energy crops
- Plant production waste

b) Municipal
- The organic fraction of municipal waste (biodegradable)
- Sludge
- Grass clippings and organic waste
- Food leftovers

c) Industrial:
- Food industry waste
- Dairy waste
- Sugar industry waste
- Pharmaceutical waste
- Beauty industry waste
- Biochemical waste
- Paper industry waste
- Meat processing waste.

The main substrate for biogas production is slurry. Slurry is a mixture of faeces, urine and water. The concentration of each constituent varies with the feeding regimes and the amount of water. Biogas production potential increases as the slurry dilution decreases. Urine and dung are less important in the production process- because of its high moisture content, urine can be only used as additive in the fermentation process, and dung requires special feeding method.

Table 2.2 shows the typical manure production for cattle, flock and poultry, and their characteristic biogas production potential.

Table 2.2. Empirical data on biogas production from animal manure [4].

Parameter	Unit	Cattle		Flock		Poultry
		Dung	Slurry	Dung	Slurry	Droppings
Dry mass content (dmc)	t dmc/t waste	0.23	0.1	0.2	0.07	0.15
Organic dry mass content in relation to dry mass (odm)	t odm/t dmc	0.80	0.8	0.9	0.82	0.76
Organic dry mass content in relation to dry mass per unit (odm/unit)	kg odm/unit·day	3.0-5.4, average: 4.2		2.5-4.0, average: 3.3		5.5-10, average:7.78
Biogas production	m^3/t odm	175-520, average: 347		220-637, average: 428		327-722, average: 524
Biogas production	m^3/unit day	1.5-2.9, average: 2.2	0.56-1.5, average: 1.03	0.6-1.25, average: 0.93		3.5-4.0, average: 3.75

It is estimated, that each year the following amounts of manure are produced (manure left of the pasture is excluded):

- Horse: 0,8 Mg
- Cow (feeding in the barn and on the pasture): 5,5 Mg
- Cow (feeding only in the barn): 12,0 Mg
- Calf (feeding in the barn and on the pasture): 4,0 Mg
- Calf (feeding only in the barn): 8,0 Mg
- Sheep: 0,5 Mg
- Swine: 1,51 Mg
- Hen: 0,55 Mg
- Goose: 11,0 kg [5].

A cow, fed both in the barn and on the pasture, leaves about 5.5 Mg of manure, however the amount of manure left on the pasture should also be considered in the calculations. This manure contains only 23% of dry mass, and 80% of that dry mass is organic matter.

The quantity and quality of used bedding also influences the amount of produced manure.

Biogas can be used in most applications designed for natural gas- we can use it to produce electricity, in CHP plants of which the electrical efficiency can score up to 41%. If we remove water vapor and sulfide we can use biogas in the same engine as natural gas, and it becomes more and more common in the Europe. Also, it can be used in fuel cell technology- also for bi- and tri-generation, where the efficiency of heat and electricity production can be even higher than 60% [6]. Biogas can be also used in natural gas grid, however it has to be upgraded to increase the content of methane to 97%.

Agricultural biogas can be used in many ways, depending on the location of the biogas plant, the distance from the industrial network and the electricity and heat requirements of the location. Due to well developed agricultural sector in Poland, there is a great opportunity to use biogas made from manure. According to data provided by Ministerstwo Rolnictwa i Rozwoju Wsi, in Poland there is a possibility to produce 5 000 000 000 m^3 of biogas, primarily from agricultural by-products, manure and agri-food industry by-products. The real potential for biogas production from agricultural and agri-food industry by-products is estimated to be 1 700 000 000 m^3 of biogas annually. Each year, 14 000 000 000 m^3 of natural gas is used in Poland, and 500 000 000 m^3 of that biogas is used by individual customers in rural areas. The estimated amount of biogas after the treatment would cover about 10% of domestic gas demand or completely fulfill the demand in rural areas and additionally provide 125 000 MWhe (electricity) and 200 000 MWhc (heat) [7].

In Poland, biogas from agriculture and food industry has still a small share in country's energy balance. According to the database prepared by Instytut Energetyki Odnawialnej, there are 11 agricultural biogas installations localized in Pawłówkowo, Płaszczyca, Kujanki, Koczała, Liszkowo, Niedoradz, Studzionka, Nacław, Świelono, Kalsk and Kostkowice, and their declared, total power is equal to 9.014 MWel and 8.549 MWt. The country's potential for agricultural biogas production is calculated based on the area of tillage and the amount of agricultural waste. The primary energy produced in this sector in 2008 was several hundred times less than in Germany, however the potential for producing energy from biogas is similar in both countries. The total primary energy produced from biogas in Poland in 2009 was 188 TJ. Electricity production from biogas was equal to 21.7 GWh in 2009, and the heat production was 80 TJ [8].

In 2008, only 0.05% of the final energy use was produced from agricultural biogas, and 2.3% of the final energy was produced from all kinds of biogas, including sewage and landfill biogas [9].

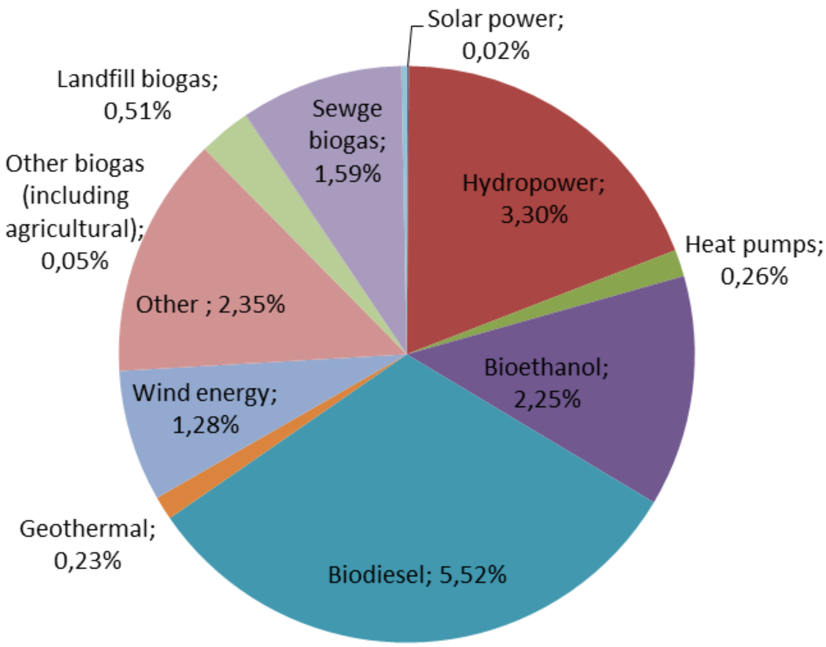

Figure 2.1. Different renewable energy sources as a percentage in final energy consumption in 2008 [8].

3. Environmental impacts

The biogas produced from animal manure in anaerobic digestion plays more and more important role in pollution prevention, fulfilling the assumptions of Kyoto Protocol and in many other issues related to human and environmental health. More sustainable solutions for handling of manure and other organic waste are necessary to maintain human and animal health, and food safety. The manure and slurries produced in agriculture sector need to be managed optimally to prevent pollutions, greenhouse gases emissions and other environmental issues.

The largest source of agricultural biogas is animal manure from cattle or swine farms. Over 1500 mln Mg of animal manure are produced in European Union countries each year. Other important source are energy crops, that also are suitable for anaerobic digestion.

The estimated amounts of animal manure in Poland are:

- Cattle:
  - heads: 5 483 000;
  - livestock units: 3 502 000;
  - tons: 77 000 000.
- Flock:
  - heads: 18 112 000;

- livestock units: 1 512 000;
- tons: 33 000 000.

- Total manure: 110 000 000 tons [9].

Manure can become a source of air and water pollution it it's poorly managed. The major threats are leaches of nutrients (such as nitrogen or phosphorus), ammonia evaporation or pathogen contamination. 18% of the overall GHG emissions (expressed as carbon dioxide equivalent) and 37% of anthropogenic methane is produced by the animal production sector. The global warming potential of methane is 21 times higher than the global warming potential of carbon dioxide. Also, this sector is responsible for 65% of anthropogenic nitrous oxide and 64% of anthropogenic ammonia [9].

If the manure is well managed, it can be a great renewable energy source. Also, the by-products of anaerobic digestion can be further used in agriculture as fertilizers. However, the digestate as a fertilizer must be handled properly- either way, it can contribute to excessive ammonia emissions, leaches of nitrate or phosphorus overloads. There are regulations that limit the amount of nitrate used on farmlands. Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC) is an example of such regulations.

There are some principles that need to be fulfilled to achieve environmental benefits from using digestate as a fertilizer [10]. To avoid ammonia volatilization, the crusting surface in the digested manure storage tank must be well established. To prevent from stirring, the digestate must be pumped in at the bottom of the storage tank. The sediments must be evenly distributed in the entire volume of digestate before applying it to crops. Also, the digestate has to be protected against evaporation and climate conditions.

3.1. Methane emission reduction

Methane is a hazardous green house gas. Its global warming potential is 21 times bigger than the global warming potential of carbon dioxide (its potential is assumed to be equal to 1), and it is responsible for about 18% of green house effect. Agricultural sector is responsible for about one third of total methane emissions, and about 20% of total methane emission is caused by ruminants and manure. The methane emission from enteric fermentation is equal to 25-37 dm^3 of CH_4 per kg of consumed dry matter [4].

Animal manure stored in livestock buildings and storage tanks is the second source of methane emissions. The world's methane emission caused by domestic animals increases by about 0.7% annually. The emission of methane occurs when the organic matter is decomposed without presence of oxygen. The reason of methane emission is the use of untreated slurry and dung as fertilizers. In Poland, agriculture is responsible for over 20% of total methane emissions. In 2000, the amount of emitted methane was 469.4 thousand tones [13]. Anaerobic digestion of animal manure and burning of biogas is a great way to deal with methane emissions. Also, methane emissions during slurry storage can be avoided by transporting slurry directly to the digester, which is then, after fermentation, used as a fertilizer which causes no methane emissions. It is estimated that using biogas technology may contribute to about 50% reduction in world's methane emissions from animal manure [11].

3.2. Nitrous oxide emission reduction

Nitrous oxide is a green house gas that absorbs infrared radiation. It is responsible for 6% of global warming effect. Its global warming potential is 310 times higher than the global warming potential of carbon dioxide. Manure fermentation allows reducing the nitrous oxide emission by increasing the amount of ammonium nitrogen, which is more easily absorbed by plants.

The world's nitrous oxide emission from agriculture is equal to 6.3 mln tones of $N\text{-}N_2O$, and 2.1 mln Mg are emitted from animal manure [15]. In Poland, agriculture is responsible for 69% of total N_2O emissions. Nitrous oxide emission from agriculture was 53.3 thousands of tones in 2000, and 18.6 thousands of tones was emitted from animal manure [13].

3.3. Reduction of greenhouse effect

Slurry fermentation reduces the green house effect by reducing the amount of green house gases (such as methane and nitrous oxide) and by producing biogas, which can successfu$_2$lly substitute some nonrenewable energy sources, that cause green house gases emission. Agricultural biogas is a renewable energy source. Burning of biogas emits less carbon dioxide than burning of conventional energy sources.

Also, using biogas as an energy source allows us to conserve some nonrenewable energy sources, such as coal, petroleum or natural gas.

3.4. Reduction of SO_2 and NO_x emissions

Biogas is a great substitute for conventional energy sources, because it allows us to avoid emissions of toxic gases, such as sulfur dioxide and nitrogen oxides. Energy production is responsible for 95% total SO_2 emissions and 56% of nitrogen oxides emissions in Poland [16]. Both those gases are responsible for acid rains. Using agricultural biogas for energy production causes that the emission of sulfur dioxide is hundred times lower, and emission of nitrogen oxides is three times lower in comparison to coal burning [11].

3.5. Water pollution reduction

If untreated slurry is used as a fertilizer it may cause ground and surface water pollution. Pollution occurs when the fertilization is poorly planned, fertilizer doses are too big and when the atmospheric conditions are unfavorable.

- When the dose of fertilizer is too big, the plants are not able to absorb all of the nitrogen, so it leaches in nitrate forms to groundwater. That leaches reduce the quality of potable water. Water in about 60% of household wells has reduced quality [12].
- Nitrates are converted to nitrites, which are toxic for humans. They cause hemoglobin oxidation and are precursors of carcinogenic nitrosamines.
- Nitrogen and phosphorus compounds cause eutrophication of aquatic environment.
- Also, the untreated slurry can contaminate the soil with pathogens, such as viruses, bacteria and parasite eggs.

To avoid such negative impacts it is recommended to use to proper time and doses of fertilizers. Only fermented slurry should be used as a fertilizer, hence the most of the nitrogen is present in the form that can be easily absorbed by the plants. All of the nitrogen is absorbed so there is no possibility of nitrates formation and therefore the leakage into the groundwater is almost impossible.

3.6. Odor emission reduction

Slurry is a source of odors. The most dangerous gases are released during its homogenization. The composition of such gases is:

- 60% methane
- 35% carbon dioxide
- 2-8% hydrogen sulfide, and
- Trace amounts of hydrogen and ammonia.

Hydrogen sulfide is the most toxic of the above substances. The emission o toxic gases may contribute to health issues. People and animals who live close to improperly designed slurry storage tanks may suffer from headaches, muscle tension and irritation of mucous membranes of eyes and respiratory tract.

During fermentation, the organic compounds are decomposed to volatile organic compounds, and then to the less harmful end products such as methane and carbon dioxide. The most of the odors are eliminated during the fermentation process.

3.7. Slurry as a fertilizer

The properties of slurry change during fermentation process. The concentration of ammonium nitrogen increases. Ammonium nitrogen is easily absorbed by plants. Also, during fermentation, the carbon compounds decompose and therefore the amount of organic substances can be decreased by 30%-50%, and it improves its fertilizing quality. Also, some hazardous elements, such as pathogenic organisms and weed seeds, are eliminated.

3.8. Organic waste

Adding organic waste from agri-food industry to manure before fermentation is a great opportunity both for biogas production and for the environment. It enhances the biogas properties and deals with troublesome organic waste, which is usually disposed to landfills and emits methane.

3.9. Alternative energy source

Agricultural biogas plants give the local populations a clean, alternative source of energy. Using a local energy source improves the stability of energy supply to the customers and decreases the dependence between local communities and other sources of energy [4].

3.10. Negative impacts of biogas production

- Risk of increased ammonia emissions. About 25% of nitrogen present in farm animal manure is in form of ammonium. About 10% of urine is present in form of urea, that can easily hydrolyze to form ammonia (in a process called ammonification). It is estimated, that the ammonia emission coefficient for swine is equal to 5.1 kg NH_3 / units per year. Other portions of ammonia may be emitted from lagoons used to store slurry. The biggest emission is caused by spraying the slurry on the fields- during fermentation process, the amount of ammonium nitrogen in slurry and its pH increases- the risk of emission of ammonia to the atmosphere also increases. Then, the ammonia falls on the soil surface, oxidizes, and contributes to soil acidification.
- Risk of environmental contamination with toxic substances. In some cases, fermentation of animal manure and organic waste may be dangerous for the environment. This risk is caused by organic waste containing toxic substances, which remain in the biomass after being fermented. Such substances are sewage sludge that may contain some quantities of heavy metals. If they are mixed with slurry and used as a fertilizer, they may cause soil and plants contamination.

3.11. Economic issues

The investment expenditures required to build one agricultural biogas plant with a treatment facility are equal to 10-15 mln PLN. The power of such plant is assumed to be MW_{el}=1MW and it produces 3.5-3.8 mln m^3 of biogas annually. The methane content is estimated to be 52%-60%. The parameters of that biogas are the same as the parameters of methane rich natural gas (methane content is equal to 98%). Investment costs for biogas plants producing 1 000 000 000 m^3 of biogas annually are estimated to be 4-6 billion PLN [7].

4. Emissions

Agricultural activities contribute to green house gases emissions. It is responsible for relatively small emissions of carbon dioxide, which is the most common green house gas, because farmlands (almost half of the EU surface) actually reduce CO_2 emissions. However, agricultural sector is a source of two important gases:

- Nitrous oxide- released to the atmosphere during reactions of nitrogenous fertilizers in the soil. N_2O is responsible for almost half of all the emissions in agricultural sector.
- Methane- a product of digestion processes of ruminants, such as cows and sheep.

Both methane and nitrous oxide emissions are caused by storage and distribution of manure. In 2007, the agricultural sector was responsible for 9.2% of all the green house gas emissions in EU-27, which can be expressed as 462 Mt CO_2 equivalent. In EU, agriculture is responsible for 4.2% of methane emissions and 5% of nitrous oxide emissions. In 1990-2007, the amount of green house gases emitted in agriculture sector in EU-27 decreased by 20% (117 Mt CO_2 equivalent).

The emissions in agriculture can be decreased by increasing the efficiency of livestock. For example, a milker that produced 8,000 l of milk per year will generate less green house gases (17.4 g of methane per 1 kg of milk) than two milkers that produce 4,000 l of milk per year (30.8 g of methane per 1 kg of milk). Also, the change of feeding procedures would influence the amount of emissions. [13]. Table 4.1 represents the average emissions and energy inputs for selected types of materials per 1 MJ.

Table 4.1. Energy inputs and emissions from selected types of biogas plants (per tonne of material) [14].

	Electricity [MJ]	Heat [MJ]	CO_2 [kg]	CO [g]	NO_x [g]	SO_2 [g]	HCl [g]	CH_4 [g]	Particles [g]
Farm scale liquid manure	26	190	3.1	3.6	15	0.8	1.4	1.1	0.6
Large scale liquid manure	53	85	3.6	2.7	11	0.4	0.8	1.0	4
Large scale food industry waste	53	85	3.6	2.7	11	0.4	0.8	1.0	4
Large scale municipal organic waste	230	320	15	11	46	1.7	3.0	4.0	1.5

Figure 4.1 represents the main sources of emissions in agriculture.

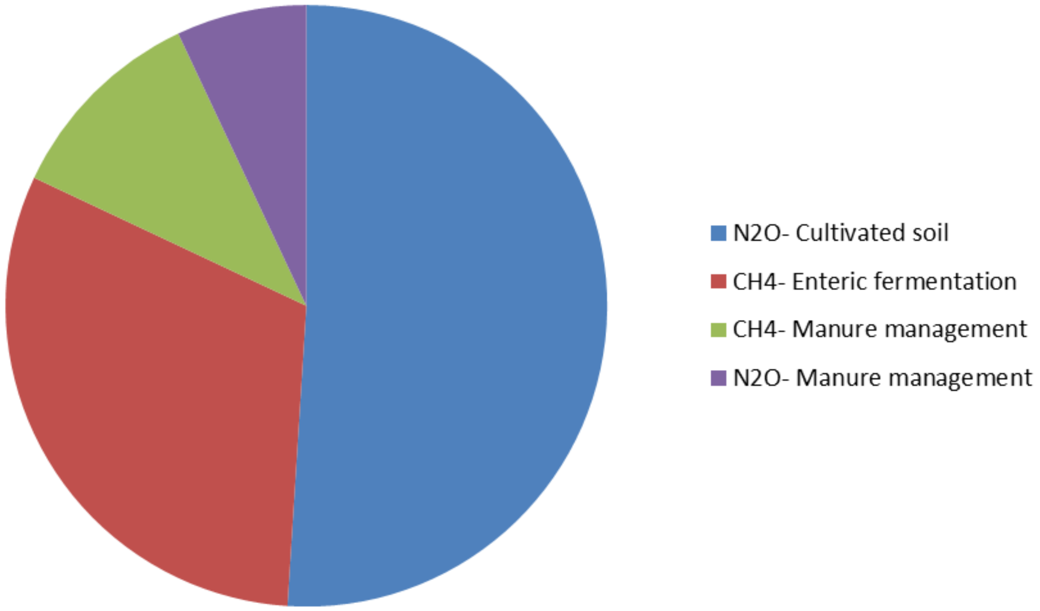

Figure 4.1. Main emission sources in agriculture [15]

Different biogas systems influence the environment in different ways. It is caused by the differences in digested material, energy efficiency of biogas production, methane losses and the selected end use technology, therefore it is impossible to obtain the standard emissions that can be used in multiple calculations. The emissions should be calculated or measured individually for each biogas plant to obtain appropriate accuracy.

5. Calculations

As it was presented earlier in Table 2.2, the average biogas production potential for cattle, flock and poultry is:

- Cattle: 2.2 m^3/unit·day
- Flock: 0.93 m^3/unit·day
- Poultry: 3.75 m^3/unit·day.

In Poland, it is estimated that there are 3 502 000 cattle and 1 512 000 flock units. The daily biogas production for cattle is:

$$E_{bio,d,c} = I_c \cdot BPC_c \tag{5.1}$$

Where:

I_c – number of cattle units in Poland [units]

BPC_c – biogas production coefficient for cattle unit [m^3_n/day·unit]

Assuming that BPC_c equals 2,2 [4] and estimated number of cattle units in Poland is 3 502 000 the estimated daily biogas production could be as high as 7 704 400 m^3. This means that annually the total biogas production from cattle farms could be 28 236 626 000 m^3_{bio}/year.

The daily biogas production for flock is:

$$E_{bio,d,f} = I_f \cdot BPC_f \tag{5.2}$$

Where:

I_f – number of flock units in Poland [units]

BPC_f – biogas production coefficient for flock unit [m^3_n/day·unit]

The amount of biogas that could be produced from all flock farms in Poland, assuming that there are 1 512 000 flock units and the biogas production coefficient for flock is 0,93, is 1 406 160 m^3_{bio}/day, and the annual biogas production from flock farms is 513,248,400 m^3_{bio}/year.

The total daily biogas production for both cattle and flock farms could be as high as 28749874400 m^3_{bio}/day, and the annual biogas production would be 3 325 354 400 m^3_{bio}/year.

Net calorific value for average biogas (containing about 65% of methane, and NCV of Methane is 39,7 MJ/m^3_n) is 23 MJ/m [3].

The daily energy production from both cattle and flock farms is:

$$EP_{bio,d} = E_{bio,d} \cdot NCV_{bio} \tag{5.3}$$

Where:

$E_{bio,d}$ – daily energy production from biogas from both cattle and flock farms [$m^3_{n,bio}$/day]

NCV_{bio} – net calorific value of biogas [MJ/m^3_n]

The daily energy production from biogas is 209 542 880 MJ/day.

The annual energy production from both cattle and flock farms is:

$$EP_{bio,a} = E_{bio,a} \cdot NCV_{bio} \tag{5.4}$$

Where:

$E_{bio,a}$ – annual energy production from biogas from both cattle and flock farms [$m^3_{n,bio}$/year]

NCV_{bio} – net calorific value of biogas [MJ/m^3_n]

The annual energy production is equal to $7{,}6 \cdot 10^{10}$ MJ/year.

The efficiency of electricity production for a gas engine varies between 35%-45% (48% in case of modern engines) [16]. For the purposes of this project it can be assumed, that the efficiency is equal to 40%.

The daily electricity production is:

$$E_{el,d} = EP_{bio,d} \cdot \eta_{ge} \tag{5.5}$$

Where

$EP_{bio,d}$- daily energy production for both cattle and flock farms [MJ/day]

η_{ge}- efficiency of a gas engine [-]

The daily electricity production from both cattle and flock biogas is equal to 83 817 152 MJe/day (23282,5 MWh).

The annual electricity production is:

$$E_{el,a} = EP_{bio,a} \cdot \eta_{ge} \tag{5.6}$$

Where

$EP_{bio,a}$- annual energy production for both cattle and flock farms [MJ/year]

η_{ge}- efficiency of a gas engine [-]

The annual electricity production from biogas could be $3{,}05 \cdot 10^{10}$ MJe/year (8498127.911 MWh).

The calculation results are presented in Table 5.1.

Table 5.1. Calculation results.

daily biogas production		
cattle	7704400	m3/day
flock	1406160	m3/day
both	9110560	m3/day
daily energy production		
both	209542880	MJ/day
daily electricity production		
both	83817152	MJ/day
both	23282,54222	MWh/day
annual biogas production		
cattle	28236626000	m3/year
flock	513248400	m3/year
both	28749874400	m3/year
annual energy production		
both	76483151200	MJ/year
annual electricity production		
both	30593260480	MJ/year
both	8498127,911	MWh/day

6. Environmental effects

According to Annual Danish Emission Inventory Report, coal combustion is responsible for the following emissions:

- SO_2: 33 g/GJ
- NO_x: 125 g/GJ
- PM10: 2,2 g/GJ [17].

The emissions from biogas combustion are:

- SO_2: 11g/GJ
- NO_x: 31 g/GJ
- PM10: 1,5 g/GJ [18]

Combustion of agricultural biogas would allow us to avoid the following of emissions:

$$E_a = E_{coal} - E_{own} \tag{6.1}$$

Where:
E_a- avoided emissions [g/GJ]
E_{coal}- emissions from coal combustion [g/GJ]

E_{own}- own emissions from biogas combustion [g/GJ]

If a part of energy produced during coal combustion would be replaced with agricultural biogas combustion, we could avoid:

- SO_2: 22 g/GJ
- NO_x: 94 g/GJ
- PM10: 0,7 g/GJ

Table 6.1 represents the emissions that could be avoided if we would replace a certain amount of coal with agricultural biogas.

Table 6.1. Selected emissions for coal and biogas combustion, and the emissions that could be avoided.

	SO2	NOx	PM10
	g/GJ		
Coal	33	125	2,2
Agricultural biogas	11	31	1,5
Avoided	22	94	0,7

In 2009, 81640 GWh were generated from hard coal combustion, and 50353 GWh were generated from lignite combustion in Poland [19]. Agriculture can influence the energy sector. If the manure produced by all the cattle and flock livestock units would be digested to produce biogas, and then this biogas would be combusted, we could replace almost 8500 GWh of energy produced by coal combustion (or other fossil fuels) with this environmentally friendly gas.

The calculations presented above assume that the whole agricultural biogas potential can be used. Unfortunately, it is impossible- only a part of that energy can be used.

7. Conclusions

Agricultural biogas is a great source of energy, but it is also underestimated. It is renewable and relatively cheap energy source. The bigger demand for agricultural biogas from manure and agri-food industry would influence the development in rural areas by increasing the farmer's income and could have a positive impact on the environmental quality in Poland.

All polish cattle and flock farms are capable of producing more than 9000000 m^3 of biogas each day. Such amount of biogas can be used to produce 8.5 TWh annually; in 2010 156.3 TWh were produced in Poland, mainly from coal [20]. In such case, about 5% of the energy in the whole country could be derived from agricultural biogas, and as a result, Poland could avoid emitting 22 grams of sulfur dioxide, 94g of nitrogen oxides and 0.7 grams of PM10 per each produced GJ.

During biogas production the animal manure is used, while otherwise it would be difficult to utilize. Using slurry and urine for biogas production reduces the amount of organic waste. Also, the fermentation residues can be used as environmentally friendly organic fertilizers.

As much as 850 ktoe of energy produced from various types of biogas in gross final energy will contribute to prevent 3 400 000 tons of CO_2 emissions from fossil fuels annually [21].

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