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Supporting Sustainable Agriculture: the Potential to Reduce GHG Emissions – the Case of Agricultural Biogas Production in Poland

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1. Introduction[1]

Since the publication of the Brundtland report (WCED 1987) Sustainable Development became one of the key concepts in economic development. Agriculture belongs to the most important sectors of the economy from the sustainability perspective, due to its twofold impacts as a "user" of the natural environment – depleting natural resources and causing threats to the environment, but also as a "protector" of nature due to its environmental services and mitigation potential. In numerous attempts to define "Sustainable Agriculture" (e.g. Tilman et al. 2002, Pretty 2008), definitions are derived from various dimensions of "sustainability", as Majewski (2008) points out, focusing on environmental, technological or socio-ethical aspects (e.g. emphasis on satisfying the needs of the present generation without undermining the prosperity of future generations).

Renewable energy production in agricultural sector corresponds with all those aspects allowing for reduced consumption of fossil fuels and improvement of the balance of greenhouse gases (GHG) emissions, identified as important challenges that agriculture faces (Pedroli & Langeveld 2011, Olesen et al. 2011, Pawłowski & Pawłowski 2016) in

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fulfilling its sustainability responsibilities and helping to solve some food, energy and environment related problems (Iotti and Bonazzi 2016). Production of renewable energy that reduces the use of fossil fuels may be considered the most essential move toward the Sustainable Development paradigm. It is also a response to the EU climate and energy policy which for the year 2020 sets three main targets for the European Union: 20% reduction in GHG emissions from the 1990 level, 20% of the EU energy produced from renewable energy sources (RES) and 20% improvement in energy efficiency (European Parliament 2009). Established in 2014 the climate and energy policy framework of the EU imposes further reduction of greenhouse gas emissions in 2030 by 40% compared to 1990 and an increase in the share of renewable energy to at least 27% of total consumption (European Commission 2014). Given the rather slow pace of the GHG emissions reduction the European Commission has prepared a Proposal for a Regulation (European Commission 2016), which establishes additional targets for GHG emissions from the non-ETS sector[2] in the perspective of the year 2030. An average 30% reduction of GHG emissions from the 2005 level is expected in the EU (7% in the case of Poland). Taking into account that non-ETS includes agriculture we can expect that the issue of emissions from agriculture will become increasingly important in the coming years.

One of the ways to increase the role of agriculture in reducing GHG emissions may be the production of biogas from manure and agricultural wastes.

The assessment of the potential to reduce GHG emissions in Poland by manure-based biogas production in the farming sector is the main aim of this paper.

2. GHG Emissions from agriculture

Agricultural production is responsible for about 15% of the total Worldwide GHG emissions (WRI 2017) and about 10.3% in the EU (17.5% if only non-ETS sector is taken into account). In the case of the

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[2] These targets concern emissions from most sectors not included in the EU Emissions Trading System (EU ETS), such as transport, buildings, agriculture and waste [https://ec.europa.eu/clima/policies/effort_en].

EU about half of the GHG emissions from agriculture comes from crop production, and another half from livestock sector (Eurostat 2015).

The main greenhouse gases emitted by agriculture are methane (CH_4) and nitrous oxide (N_2O), which have respectively 45% and 46% share in global GHG emissions from agriculture in CO_2 equivalent, while the share of CO_2 is estimated at only 9% of global agricultural emissions (EAT 2015). For comparison, the share of CO_2 in the total global structure of GHG (measured in kg of CO_2e) is estimated at 82.4% (European Environment Agency 2013). The animal production sector is the main source contributing to agricultural emissions of methane in the EU (mainly enteric fermentation and manure storage), while application of manure and mineral nitrogen fertilizers is responsible rather for N_2O emissions (IPCC 2014). The importance of methane and nitrous oxide in the total emissions results from the fact that the impact of these compounds on the greenhouse effect is approximately 23 (CH_4), and almost 300 (N_2O) times stronger than the impact of carbon dioxide (IPCC 2007, Thomson et al. 2012). Recently, particularly great attention has been paid to the issue of methane emissions because of the rapid increase in the concentration of this gas in the atmosphere in the last few years (Dlugokencky 2016). At the same time a lower growth rate in CO_2 emissions and rather stability in the case of N_2O are observed (Thomson et al. 2012).

The largest emitters of methane from agriculture in the EU are France, Germany, the United Kingdom and Poland (Table 1).

Table 1. Methane and nitrous oxide emissions in selected EU countries
Tabela 1. Emisja metanu i podtlenku azotu w wybranych krajach europejskich

Country	Total greenhouse gas emissions[1]	Emissions from agriculture[2]			
		Methane (CH_4)	Nitrous oxide (N_2O)	Methane and nitrous oxide	Share of countries in EU emissions from agriculture [%]
	[million tonnes of CO_2 equivalent]				
EU-28	4 548.4	198.8	271.9	470.6	100.0
France	490.3	38.4	50.8	89.3	19.0
Germany	939.1	25.8	43.7	69.5	14.8

Table 2. cont.
Tabela 1. cd

Country	Total greenhouse gas emissions[1]	Emissions from agriculture[2]			
		Methane (CH_4)	Nitrous oxide (N_2O)	Methane and nitrous oxide	Share of countries in EU emissions from agriculture [%]
	[million tonnes of CO_2 equivalent]				
United Kingdom	582.9	22.1	29.7	51.8	11.0
Poland	399.3	11.5	25.2	36.7	7,8
Italy	461.2	15.3	20.1	35.4	7.5
Spain	340.8	17.9	19.8	37.7	8.0
Romania	118.8	8.7	9.5	18.2	3.9
Ireland	58.5	11.0	6.9	18.0	3.8
Netherlands	191.7	9.2	6.7	15.9	3.4
Denmark	51.6	4.2	5.4	9.6	2.0
Rest	1023.3	40.4	59	88.5	18.8

[1]*Excluding Land Use, Land Use Change and Forestry (LULUCF) net removals.*
[2] *Emissions from agricultural transport and energy use are excluded, as these sectors are not defined as part of the agriculture sector by the current IPCC (The Intergovernmental Panel on Climate Change) reporting guidelines.*
Source: Eurostat 2015, Eurostat 2016

3. Biogas production – a way to reduce GHG emissions from agriculture

Production of agricultural biogas from manure and other wastes from agricultural production may be considered the most sustainable way of producing clean energy. Much more controversial is biogas production from crops normally used for food, because as substrates they compete for agricultural land with food crops (Paterson et al. 2016, Pawłowski 2015). Production of agricultural biogas from manure not only contributes to the reduction of methane emissions which would take place during traditional manure storage but also replaces energy from fossil fuels with renewable energy (Shih et al. 2012, Bentley et al. 2010, IPCC 2006, Oenema et al. 2007).

Agricultural biogas has an advantage over other forms of renewable energy because its production is independent of natural conditions such as availability of wind, running water or sunlight. Some authors (e.g. Pöschl et al. 2010, Persson et al. 2014, Jacobson 2009) indicate a higher stability of supply of energy from biogas in comparison to other renewable energy sources [RES].

It is worth mentioning that the digestate, a by-product of the anaerobic fermentation of manure has a high fertilizing value. Using digestate as a natural fertilizer has also some disadvantages from the sustainability perspective such as worsening of the balance of soil organic matter. Although the amount of nutrients in the digestate and manure used in the process are comparable, the carbon content in digestate is lower (Möller and Stinner 2009).

From the economic point of view there is a problem of the relatively high costs of energy generated from biogas. Numerous analyses carried out in many countries indicated a rather low profitability of agricultural biogas production, particularly in small farms (van Foreest 2012, Kost et al. 2013, Delzeit and Britz 2012, Sulewski et al. 2016). One of the disadvantages of small biogas plants is the lack of economies of scale that can be achieved in larger businesses (Bruins and Sanders 2012, Jacobsen et al. 2014). However, small biogas plants have some advantages which are particularly important from the point of view of sustainability such as independence from fluctuations of biomass prices, simpler and less costly administrative procedures and securing the energy self-sufficiency of farms (Dobbelaere et al. 2015, Paterson et al. 2016). On the other hand logistics of big biogas plants usually requires transportation of substrates and products over long distances which limits the positive impact of biogas on reduction of GHG emissions (Szabó et al. 2014). Despite the existing controversies, the development of agricultural biogas production based on anaerobic fermentation of manure seems to be the most effective way to reduce methane emissions from agriculture, which is particularly important for countries with a high number of livestock, such as Poland.

4. Method

The evaluation of the potential of GHG reduction by manure anaerobic fermentation is based on the prior estimations of potential production of agricultural biogas in Poland (Majewski et al. 2016). The basis for the estimations was the number of animals of main groups of livestock converted to Livestock Units (LU)[3] and normative amounts of natural fertilizers (solid and liquid manure, slurry) per 1 LU.

The potential for biogas production was estimated for the sample of farms represented in the Polish FADN (Farm Accountancy Data Network) database. The average production of solid manure, liquid manure and slurry per 1 LU in specified regions was multiplied by the number of animals in the FADN population[4] and aggregated to the country level.

Parameters published by KTBL[5] (average values for indicated ranges) that characterize specific types of manure were used for estimation (Table 2).

Table 3. Yields of biogas from selected substrates [m^3/t of organic dry matter]
Tabela 2. Produkcja biogazu z wybranych substratów [m3/t suchej masy]

Source of substrate	Cattle	Pigs	Poultry	Horses
Solid manure	255	360	521	315
Liquid manure	350	450	–	–
Slurry	370	370	–	–

Source: KTBL (2005) – modified

[3] Livestock Unit - is a reference unit which facilitates the aggregation of livestock from various species and age as per convention, via the use of specific coefficients. The reference unit used for the calculation of livestock units (= 1 LSU) is the grazing equivalent of one adult dairy cow producing 3 000 kg of milk annually, without additional concentrated foodstuffs [EUROSTAT]
[4] The farm population represented in FADN consist of about 731 thousand entities which generate nearly 90% of all agricultural production in Poland using 88% of agricultural land and keeping 99,7 % of farm animals (in terms of LU) (Floriańczyk et al. 2016).
[5] Kuratorium für Technik und Bauwesen in der Landwirtschaft

The potential for biogas production from manure was estimated in three scenarios, namely:

- hypothetical scenario – assuming the total amount of manure from all animals represented by farms in the FADN population is processed to biogas,
- theoretically workable scenario – taking into account only farms with animal herds greater than 30 LU that may provide substrates for installation with electrical capacity of 10 kWe,
- realistic scenario – assuming that only a half of farms with animal herds greater than 30 LU would undertake biogas production.

Estimated values of the potential for biogas production based on manure from specified groups of animals are presented in Table 3.

A total hypothetical potential was estimated at the level of approximately 2 762 million m^3 of biogas, while the theoretically workable and realistic potentials were less than 30% and about 15% of the hypothetical value respectively (appr. 797 and 399 million m^3) (Majewski et al. 2016). These amounts differ significantly. However, the dispersed structure of livestock production and the fact that the majority of the animals are kept in relatively small herds can be considered the key factors limiting real opportunities for biogas production from animal wastes in Poland.

Table 4. Potential of agricultural biogas production from different types of manure in Poland*
Tabela 3 Potencjał produkcji biogazu z nawozów naturalnych w Polsce*

Livestock	Hypothetical scenario		Theoretically workable scenario		Realistic scenario	
	mln. m^3	% of total	mln. m^3	% of total	mln. m^3	% of total
Cattle	1379.6	50.0	417.6	52.4	208.8	52.4
Pigs	1193.1	43.2	352.2	44.1	176.1	44.1
Other	189.8	6.8	27.6	3.4	13.8	3.4
Total	2762.4	100.0	797.4	100	398.7	100.0

* based on 2013 livestock numbers
Source: own calculations

Based on the estimated potential of biogas production the possible reduction of methane emissions from the livestock sector in Poland has been calculated. Because production of agricultural biogas does not eliminate emissions from enteric fermentation the analysis was limited to the storage of manure only, considering:

- direct reduction of GHG emissions due to processing manure into biogas in the process of anaerobic fermentation,
- indirect reduction of GHG emissions in a form of emissions avoided due to less electricity produced from conventional energy sources balanced by electricity from biogas converted in CHP installations.

In order to assess the potential to reduce emissions resulting from manure storage the methane conversion factors (MCF)[6] developed by the IPCC (2006) for specified types of manure were applied. Methane conversion factors indicate the share of methane, which is emitted to the atmosphere during storage of specific types of manure (maximum methane capacity). A possible reduction of methane emission from Polish agriculture due to eliminating storage of natural fertilizers used directly in biogas production was estimated with the use of the following formula:

$$E_r = \sum_m Q_m \times MCF_m \quad (1)$$

where:

E_r – emission reduction in CO_2e,

Q_m – country level total methane-producing capacity of the specified natural fertilizer type (m) expressed in CO_2 equivalent,

MCF_m [%] – Methane Conversion Factor for the specified natural fertilizer type (m) is the percentage of natural fertilizer's maximum methane-producing capacity that is actually achieved during storage in annual average temperature.

[6] MCFs – (methane conversion factors) are determined for a specific manure management system and represent the degree to which the maximum methane-producing capacity of the manure is achieved. The maximum methane-producing capacity of the manure varies by species and diet [IPPC 2006].

In other words MCF is a part of organic matter actually converted into methane – for the assessment the default level of 2% for solid manure and 17% for slurry and liquid manure has been applied after IPCC (2006).

In order to estimate the emissions avoided, the amount of CO_2 emitted at the existing level of conventional electricity production has been reduced proportionally, as if the demand for conventional energy was lower due to introducing the substitute in a form of electricity from biogas plants.

For the estimation of the emission avoided the following formula has been used:

$$E_a = E_{el\ RES} \times U_e \qquad (2)$$

where:
E_a –emission avoided in tonnes CO_2 equivalent,
$E_{el\ RES}$ – amount of electricity from Renewable Energy Sources (RES) [MWh],
U_e – emission of CO_2e in electricity generation in CO_2e/ MWh.

The CO_2 emission factors recommended by The National Centre for Emissions Management (KOBIZE) have been applied in the analysis. The unit emission of CO_2 in the case of electricity generation in Poland according to KOBiZE is equal to 0.812 Mg CO_2e/MWh (KOBiZE 2014).

5. Results

The total value of GHG emissions from Polish agriculture was estimated at 30244,6 thousand tonnes of CO_2 equivalent in the year 2010 (Eurostat 2012). Animal husbandry (mainly enteric fermentation and manure storage) was responsible for about 50% of the total agricultural emissions.

Eliminating storage of manure and producing biogas converted further into electricity and heat in CHP installations (instead of spreading manure on the fields) would result with a noticeable reduction of methane emissions (Table 4).

Table 5. Reduction of GHG emissions due to elimination of manure storage and emission avoided after transforming manure into energy in farm biogas installations
Tabela 4. Redukcja emisji gazów cieplarnianych w efekcie zaniechania przechowywania nawozów naturalnych i zastąpienia energii ze źródeł konwencjonalnych energią z biomasy

Scenario	Potential reduction of GHG emissions [thousand tonnes CO_2e] due to:		Reduction of GHG emissions due to processing manure into energy in relation to:	
	Elimination of manure storage	replacing fossil fuels (emissions avoided)	Reference point	[%]
Hypothetical	1032.1 (24.3%)	4239.5 (75.7%)	Total GHG emissions at country level	1.54
			Total GHG emissions from agriculture	17.4
			Emissions from livestock production	43.0
Theoretically workable	303.1 (24.8%)	1223.7 (75.2%)	Total GHG emission at country level	0.45
			Total GHG emission from agriculture	5.0
			Emissions from livestock production	12.5
Realistic	151.6 (24.8%)	611.9 (75.2%)	Total GHG emission at country level	0.22
			Total GHG emission from agriculture	2.5
			Emissions from livestock production	6.22

Source: own research and Eurostat data (2012, 2016).

Eliminating manure storage would reduce GHG emissions from Polish agriculture by about 1032.1 thousand tonnes of CO_2 equivalent in the hypothetical scenario and about 303.1 or 151.6 thousand tonnes respectively in the theoretically workable and realistic scenarios.

Saving fossil fuels due to converting biogas into electricity would result with much greater reduction of GHG emissions in a form of emissions avoided – 4239.5; 1223.7 and 611.9 thousand tonnes of CO_2 equivalent in respective scenarios.

In order to illustrate the importance of reductions, estimated values of potential GHG emission reductions were referred to total emissions at different scales: of the country level, agricultural sector and livestock production as recorded in official statistics (Eurostat 2012, 2016). At the country level reduction of GHG emissions in relation to the total emissions is relatively small (1.54%, 0.45% and 0.22% in respective scenarios).

Relative reductions of GHG emissions due to converting natural fertilizers into renewable energy are much more significant if the agricultural sector or livestock production are considered as a reference levels. The total reduction of GHG emissions in Poland due to elimination of the storage of natural fertilizers and partial replacement of electricity generated from fossil would result in a reduction of emissions equal to 17.4% of GHG emission from the agricultural sector in the case of the hypothetical and approximately by 5.0% and 2.5% in the case of the theoretically workable and realistic scenarios respectively.

6. Conclusions

A number of analyses confirm that production of biogas can effectively reduce GHG emissions as well as the carbon footprint of livestock production, and provide a number of other environmental and social benefits (Massé et al. 2011). The scale of emission reduction is determined by the method of biogas utilization. Uusitalo et al. (2014) compared three ways of producing biogas (biowaste, waste water treatment plant sludge and agricultural biomass) and various ways of its utilization. They found that the reductions of GHG emission would achieve the highest values if the biogas is used as a fuel in transportation (reduction at the level of 65-72% compared to the use of fossil fuels which is generally coherent with results noted by Tuomisto and Helenius 2008). Detailed analyses that confirm that agricultural biogas production could be one of the most environmentally effective ways of generating energy was also carried out by Szabó et al (2014), who studied the case of the biogas plant in Tiszaszentimre (Hungary).

The examples cited as well as many other studies (Kimming et al. 2011, Jury et al. 2010; Rehl and Müller 2013) suggests that the effectiveness of minimizing GHG emissions through biogas production depends on many factors, including such of greater importance as the source of substrates and the way biogas is utilized.

Considering sources of substrates the highest reduction of GHG emissions occurs when biogas is produced from waste materials. This is the case of our estimation of the GHG emissions' reduction assuming natural fertilizers, instead of being stored before application on fields, are processed into biogas, next into electricity and heat in small scale on-farm biogas plants. An additional gain from producing and consuming this energy on farm is elimination of GHG emissions related to the transportation of energy and substrates, typical for large scale operations.

According to the estimates presented in the paper, the use of natural fertilizers for energy production would reduce greenhouse gas emissions by 5271.6 thousand tonnes of CO_{2e} (17.4% of GHG emissions from agriculture and 1.28% of the total country emission) in the hypothetical scenario. Respective values in the theoretically workable scenario are 1526.8 thousand tonnes of CO_{2e} emission reduced (5% and 1.54% respectively of total emissions from agriculture and from various sources nationwide). In the realistic scenario it would be half as much. It can be concluded, that producing agricultural biogas from natural fertilizers, further converted to electricity and heat, improves sustainability of the agricultural system, particularly in the environmental dimension.

The present potential of GHG emissions' reduction based on biogas production estimated at the country level in Poland is limited, despite the fairly large size of the livestock sector. This is mainly because the fragmented farm structure in Poland is an important constraining factor - many farms are too small to run efficiently even the smallest micro scale biogas plants. However, taking into account the on-going concentration processes in Polish agriculture, the number of larger livestock farms with the potential to be profitable in renewable energy production from biogas will increase in a long-term perspective.

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Wspomaganie zrównoważonego rolnictwa: potencjał redukcji emisji gazów cieplarnianych – przypadek produkcji biogazu rolniczego w Polsce

Streszczenie

Sektor rolnictwa może stać się znaczącym producentem energii odnawialnej ze źródeł rolniczych, takich jak odpady z produkcji zwierzęcej (nawozy naturalne). Wzmocniłoby to możliwy wkład energii odnawialnej w łagodzenie negatywnych efektów zewnętrznych generowanych przez sektor rolny. Należy do nich emisja gazów cieplarnianych, w której znaczny udział ma rolnictwo, głównie sektor produkcji zwierzęcej. W Unii Europejskiej rolnictwo polskie jest czwartym co do wielkości emitentem metanu i tlenku azotu z produkcji rolniczej, z udziałem 7,8%.

W artykule dokonano oceny potencjalnej redukcji emisji gazów cieplarnianych w Polsce dzięki produkcji biogazu na bazie fermentacji beztlenowej nawozów naturalnych (obornik, gnojówka, gnojowica), przetworzonego następnie na energię elektryczną. Możliwość produkcji biogazu została oszacowana dla populacji 731 tys. gospodarstw ze zwierzętami z wykorzystaniem danych z próby FADN, co stanowi około 97% sektora produkcji zwierzęcej w Polsce. Potencjalne zmniejszenie emisji metanu zostało obliczone jako ekwiwalent CO_2.

Szacunek produkcji biogazu rolniczego sporządzono dla trzech scenariuszy:

- hipotetycznego, zakładając wykorzystanie nawozów naturalnych od wszystkich zwierząt gospodarskich w Polsce,
- teoretycznie wykonalnego – zakładającego, że minimalna skala produkcji zwierzęcej dla inwestycji w produkcję biogazu w gospodarstwie rolniczym przekracza 30 dużych sztuk przeliczeniowych zwierząt,
- realistycznego – zakładającego, że jedynie połowa gospodarstw posiadających co najmniej 30 dużych sztuk przeliczeniowych podejmie produkcję biogazu.

Według sporządzonych szacunków wykorzystanie nawozów naturalnych do produkcji energii zmniejszyłoby emisję gazów cieplarnianych z rolnictwa o 17,4% w przypadku scenariusza hipotetycznego, o 5% w scenariuszu teoretycznie wykonalnym oraz o około 2,5% w scenariuszu realistycznym (odpowiednio o 1,54%, 0,45; oraz 0,22 całkowitej emisji z różnych źródeł w skali kraju). Zmniejszenie emisji GHG nastąpiłoby z tytułu redukcji emisji metanu poprzez wyeliminowanie składowania nawozów naturalnych, a także ze względu na zwiększony udział "czystej energii" w całkowitym zużyciu energii. Pozwoliłby to zatem na niższe zużycie paliw kopalnych (np. węgla) w konwencjonalnych elektrowniach. W obecnej sytuacji rynkowej w Polsce, głównie wobec relatywnie niskich cen energii elektrycznej, produkcja energii elektrycznej z biogazowni rolniczych nie jest opłacalna ekonomicznie bez subsydiów. Niewystarczające wsparcie dla produkcji biogazu wskazuje, że korzyści z produkcji energii z nawozów naturalnych są niedoszacowane co dotyczy zwłaszcza redukcji emisji gazów cieplarnianych. Produkcja biogazu rolniczego ułatwiałby osiągnięcie celów strategii energetycznej UE i uczyniłaby sektor rolny bardziej zrównoważonym.

Abstract

Agricultural sector can become a major producer of renewable energy from different sources, including such as animal wastes (natural fertilizers). It is important due to its potential role in mitigating negative externalities generated by agricultural sector, among other greenhouse gas emissions, mainly from the livestock sector. Within the European Union the Polish agriculture is the fourth largest producer of methane and nitrogen oxide from agricultural production, with a share of 7.8%. This paper aims to assess the potential reduction of GHG emissions in Poland due to biogas production based on manure anaerobic fermentation. Possible biogas production was estimated for a population of 731 thousand Polish livestock farms with the use of data from the FADN sample, which represents about 97% of the animal production sector in Poland. The potential reduction of methane emissions was calculated as CO_2 equivalent for three scenarios:

- hypothetical, assuming the use of natural fertilizers from all livestock in Poland,
- theoretically workable, assuming that the minimum scale of animal production for viable investment in biogas production in the farm exceeds 30 Livestock Units,
- realistic scenario – assuming that only a half of farms with animal herds greater than 30 LU would undertake biogas production.

Reduction of GHG emissions can be achieved through elimination of manure storage and processing natural fertilizers into biogas, next converted into electricity and heat, as well as due to emissions avoided as a result of the increased share of "clean energy" in the total energy consumption and a lower use of fossil fuels (e.g. coal) in conventional power plants.

According to the estimates, the use of natural fertilizers for energy production would reduce greenhouse gas emissions from agriculture by 17.4% in the hypothetical scenario, 5.0% in the theoretically workable and about 2.5% in realistic scenario (1.54%, 0.45% and about 0.22% respectively of total emissions from various sources nationwide).

In the current market situation mainly due to relatively low energy prices production of electricity from small scale agricultural biogas plants in Poland is not profitable without subsidies. Growth of the agricultural biogas industry would facilitate meeting the EU Energy Strategy targets making the agricultural sector more sustainable.

Słowa kluczowe:
biogaz, gazy cieplarniane, emisja, rolnictwo zrównoważone

Keywords:
biogas, greenhouse gasses, emission, sustainable agriculture