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ORIGINAL PAPER

LOGISTIC ASPECTS OF THE ECOLOGICAL IMPACT INDICATORS OF AN AGRICULTURAL BIOGAS PLANT

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ABSTRACT. **Background**: Poland must fulfill its obligations regarding increasing the share in the production of energy from renewable sources. By 2020, this share for Poland is to amount to a minimum of 15% of green energy consumption in final gross energy consumption. Poland has significant biomass potential that can be used for biogas production. Biogas can be produced in biogas installations installed in landfills, sewage treatment plants or agricultural biogas plants. Literature sources state that in studies of environmental effects concerning the operation of agricultural biogas plants, it is the logistics of the feedstock load that causes the greatest environmental burdens as well as that the distance to which the feedstock is transported significantly affects the growth of global warming potential. In this publication for the first time for Polish conditions will be presented the results of the analysis of logistics aspects and their impact on the ecological impact indicators of four agricultural biogas plants differing in the way the feedstock is provided.

Methods: The assessment of ecological impact indicators was carried out using the Life Cycle Assessment (LCA) methodology based on ISO 14040-44 and using the LCIA Impact 2002+ method. In this method 15 impact categories are distinguished to which damage categories: Human health, Ecosystem quality, Climate change and Resources are assigned. Primary data obtained in the tested biogas plants and selected secondary data obtained from the Ecoinvent database v. 3.4 were processed using the SimaPro Ph.D. v. 8.3.0 calculation program. All results are analyzed relative to the functional unit defined as producing 1000 MWh of electricity. The analyzed four agricultural biogas plants are representative examples for particular types of agricultural biogas plants.

Results: The results of the calculations show that the greatest environmental effects are related to the stage of providing the raw material in biogas installations, mainly due to the long-distance transport of substrates with the use of heavy transportation equipment. The results of the variant analysis show that transporting slurry with a pipeline would allow for 10-fold reduction of environmental damage in relation to BAU, i.e. transport by means of a farm tractor with a barrel.

Conclusions: The logistics aspects of the operation of selected agricultural biogas plants differing in the way the feedstock is provided are one of the main factors affecting their ecological efficiency. The transport of raw materials, both as to the length of the transport route and the means of transport used, impact on the ecological impact indicators of agricultural biogas plants.

The obtained positive environmental effects from the production of electricity from biogas are often significantly reduced by inadequate transport of raw materials or their transport over long distances.

Further work is required to convince the biogas plants operators on the need of proper logistics solutions. Preferably if based on the results of the presented analyzes, they should consider submitting a logistics management system for the flow of raw materials in a biogas plant, to the certification for example in the ISCC system and REDcert.

Key words: life cycle assessment, agricultural biogas plant, renewable energy, ecological performance /effectiveness, ecological impact indicators.

INTRODUCTION

One of the most important problems of the modern world is the changing climate. There are facts examined that the impact of carbon dioxide emissions of anthropogenic origin on climate change is unquestionable [Gore 1992]. Human activity in the sphere of industrial and agricultural development significantly increased greenhouse gas emissions to the atmosphere. The considerable population

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development and economic growth since the industrial era caused, inter alia, an increased demand for energy and expansive exploitation of fossil fuel deposits, and as a result an increase in the concentration of carbon dioxide, methane and nitrogen oxides in the atmosphere. Coal resources are shrinking, and its extraction is becoming less and less profitable. The Polish energy sector is based in more than 90% on burning fossil fuels. According to the 2016 data from the International Energy Agency (IEA), many Polish power plants are old and damage the environment in a significant way. Over 62% of coal-fired power plants have been operating for over 30 years. In 2016, the import of liquid fuels to Poland was at the level of 11,5 million m3, of which about 45% was the fuel delivery from Russia [POIandTO 2018]. It is necessary to diversify energy sources by developing a local, domestic market, so as to be as independent as possible from the import of conventional fuels in an uncertain economic and political situation in the world. One of the diversification paths is the use of energy from renewable sources: wind, solar, biogas.

Having been a member of the European Community since 2004 and ratifying the Kyoto Protocol, Poland must fulfill its obligations regarding increasing the share in the production of energy from renewable sources. By 2020, this share for Poland is to amount to a minimum of 15% of green energy consumption in final gross energy consumption. This includes the gross consumption of renewable electricity in the electricity sector (25%), in transport (21%) and in heating and cooling (54%) [Minister of Economy 2010]. The average annual growth rate of final gross energy consumption from renewable sources in the period from Poland's accession to the European Union to 2015 was 4.9% [CSO 2017]. The individual components contributed: biomass in 70.74%, wind in 11.96%, photovoltaics in 0.58%, biogas in 2.88%, in the total energy obtained from RES in 2016 [CSO 2017].

Despite the fact that the share of solid biofuels (biomass) in the domestic acquisition and use of renewable energy every year is subject to certain fluctuations, related to the percentage share of other RES, it is still the dominant source of green energy and reached 70.74% in 2015. For comparison, the share of wind energy in the same year was only 11.96% and biogas 2.88% in the total energy obtained from RES. The smallest share was recorded for geothermal energy (0.24%) [CSO 2017].

Poland has significant biomass potential [Muradin and Foltynowicz 2014] that can be used for biogas production. Biogas can be produced in biogas installations installed in landfills, sewage treatment plants or agricultural biogas plants. The assumptions of the energy policy until 2030 indicated the creation of a minimum of one agricultural biogas plant in each municipality, that is, a total of about 2000 installations [Ministry of Economy 2009]. The plan will not be fully implemented, as by 2018 only 96 installations with a total capacity of 100.6 MW were commissioned. Unlike other renewable energy installations, the operation of agricultural biogas plants entails significant problems regarding the logistics aspects related to supplying the raw material to the biogas production process.

Literature sources state that in studies of environmental effects concerning the operation of agricultural biogas plants, it is the logistics of the feedstock load that causes the greatest environmental burdens [Bacenetti et al. 2015]. Huopana et al. [2013], in turn, claims that the distance to which the feedstock is transported significantly affects the growth of global warming potential. In Polish conditions, attention is also paid above all to the logistics aspects of the supply of raw materials to biogas plants, as well as their storage at the plant [Kowalczyk-Juśko et al. 2014]. However, these are often only descriptions of processes without providing specific data. The work "Logistic aspects of biogas plant operation" of AGH authors presents the functioning of one agricultural biogas plant from the point of view of logistic processes. The processes in which knowledge and tools used in logistics are applied were determined. The biogas plant has been located in the supply chain, with underlining the dependence between its stable functioning and the adequately structured information and material flow chain. The following processes have been distinguished in the biogas plant operations:

- obtaining the substrate in the form of forage and slurry,
- production of silage and then ferment, which will be transformed into biogas,
- generating electricity and heat,
- resale of part of the generated energy,
- energy consumption for own needs,
- waste management (sediment) in the form of high quality fertilizer.

The authors inform that the stored substrates were transported by a sealed pipeline (liquid manure) and by belt and screw relays (dry substrate). The method of preparation and storage of the silage and its related transport are not provided.

Tucki et al. [2016] discussing the problems of agricultural biogas plant exploitation in Poland among the factors affecting its effectiveness mention, among others:

- minimizing the distance of transport of feedstock to the biogas plant,
- adequate infrastructure (as short as possible to main power point),
- possibility of managing post-fermentation pulp on own fields or guarantee of receipt by other entities.

However, he did not specify the sizes of the smallest distances should be.

Stejskal [2008], presenting the practical experience of running a biogas plant in the Czech Republic, draws attention to a few basic criteria that should be met by providing raw material for a biogas plant:

- the region intended for obtaining the raw material should not be too large,
- effective transport logistics,
- the obtained raw material should be suitable for the production of biogas, so as not to transport raw material with a low content of organic dry matter, important due to the production of biogas,
- individual raw materials obtained should come from a single place in sufficient quantity to secure effective transport through large-capacity vehicles.

A number of works by the team of Maj, Piekarski, and Kowalczyk-Juśko are devoted to logistics issues in the operation of biogas plants. The paper "Supply logistics for agricultural biogas plant" presents the logistics of raw material supply to an agricultural biogas plant [Maj et al. 2014]. The types of substrates used for biogas production with the indication of main problems in the transport of particular biomass types are indicated. The selection of means of road transport for transporting biomass was also presented depending on the place of loading, the quantity and type of assortment of the transported cargo.

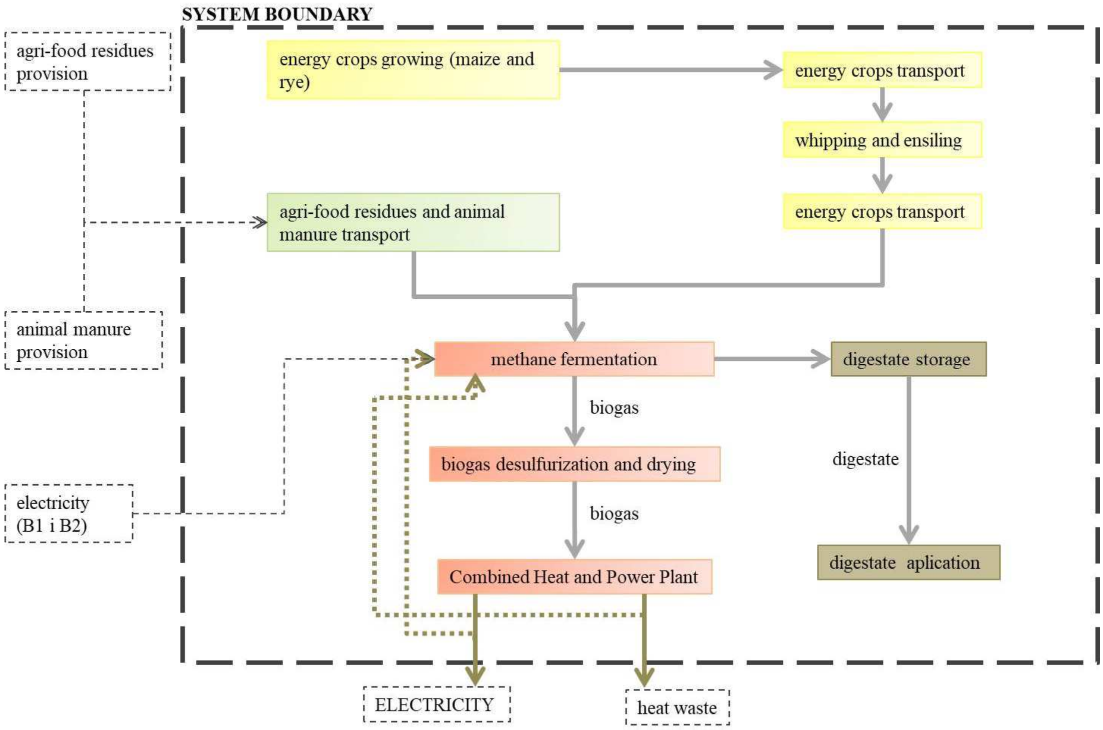
As shown in the presented works, the authors are aware of the importance of logistics processes in the operation of agricultural biogas plants, however, they have not presented examples based on specific data from biogas plants.

In this publication for the first time for Polish conditions will be presented the results of the analysis of logistics aspects and their impact on the ecological efficiency of four agricultural biogas plants differing in the way the feedstock is provided. The analyzed biogas plants are representative examples for particular types of agricultural biogas plants.

MATERIALS AND METHODS

The assessment of ecological impact indicators was carried out using the Life Cycle Assessment (LCA) methodology based on ISO 14040-44 and using the LCIA Impact 2002+ method [Jolliet et al. 2003]. In this method 15 impact categories are distinguished to which damage categories are assigned. Damage categories are a much broader environmental aspect than impact categories. There are four categories of damage: Human health, Ecosystem quality, Climate change and Resources. Primary data obtained in the tested biogas plants and selected secondary data obtained from the Ecoinvent database v. 3.4 were processed using the SimaPro Ph.D. v. 8.3.0 calculation program. All results are analyzed relative to the reference unit, which is named as the functional unit. The most cumulative result of the eco-indicator, the indicator used to quantify the impact of a given product on the environment, is obtained at the weighing level. The higher is the eco-indicator value, the higher the negative environmental impact. On the other hand the negative value means a beneficial effect on the environment. The value of the eco-indicator can also be presented in damage categories and impact categories, expressing the value of impact at environmental ecopoints (marked with the Pt symbol).

A functional unit was defined as producing 1000 MWh of electricity with standard parameters. Input data were collected for separate unit processes implemented under the modern mesophilic fermentation technology.



Source: Muradin, 2018, PhD thesis, available in the Main Library of PUEB

Fig. 1. System boundary of electricity production in the biogas plant

Table 1. The most important parameters of the tested agricultural biogas plants

Indicator	B1	B2	B3	B4
Voivodeship	Wielkopolskie	Wielkopolskie	Śląskie	Pomorskie
Installed power	1.000 MW	0.526 MW	0.526 MW	1.000 MW
Work time [h/year]	8100	8200	8000	8100
The amount of biogas [m^3/year]	4 169 760	1 725 155	2 195 639	4 204 800
The amount of electricity produced [MWh/ year]	7861	3007	4193	7951
The amount of heat produced [MWh/ year]	7769	3193	5132	8150
The amount of heat used [MWh/ year]	1470	2221	4393	8120
Total efficiency [%]	51	69	88	86
The amount of digestate [year]	35515	19744	26025	26083
The digestate management	not separated, fertilization of arable fields	not separated, fertilization of arable fields	mechanical separation, fertilization of fields and bedding for cows (dry fraction)	not separated, fertilization of arable fields

Source: own work

The boundaries of the system, presented in Fig. 1, included cultivation of energy plants along with transport to a biogas plant, provision of feedstock, energy production, storage and application of digestate. The construction and demolition of the biogas plant as well as the production of waste substrates were excluded from the scope of the study. Four biogas plants located in three western Polish voivodships: Wielkopolskie, Śląskie, and Pomorskie were selected as research objects, which for the purposes of this analysis were designated as B1, B2, B3 and B4 biogas plants. The research of individual agricultural biogas plants was conducted on the basis of a direct interview with the owners or operators of the installation. The most important parameters of the tested agricultural biogas plants are collected in Tab. 1.

LOGISTICS OF THE FEEDSTOCK DELIVERY

Waste from agro-food production as well as energy crops harvested from the field was transported to a biogas plant using heavy wheeled transport. Liquid animal manure was transported by a farm tractor with a barrel with a capacity of 20 to 25 m^3 by a gravity pipeline. The remaining raw materials were transported with a trailer or with different types of lorries mentioned in Table 2.

Table 2. Feedstock transport in biogas plants in relation to annual operation

Biogas plant	Type of feedstock	The amount of feedstock [Mg/year]	Type of transport	Disposable tonnage [Mg]	Distance [tkm/year]
B1	pig manure	14824.0	tanker farm tractor	25	1889234500
	maize	21693.0	farm tractor with a trailer	20	27780860
B2	maize	2025.0	farm tractor with a trailer	20	287494
	silage maize	11489.7	lorry 16-32t, EURO4	24	20504340
	pig manure	1595.9	tanker farm tractor	20	174050
	distillery residues	5919.6	rurociąg	-	-
	carrot plup	402.6	lorry 16-32t, EURO4	7	10915546
	potato pulp	590.0	lorry 16-32t, EURO4	25	38400000
		12837.0	lorry 16-32t, EURO4	18	12282241
	protein sediments	936.0	lorry 16-32t, EURO4	30	2485701
B3	maize	2190.0	farm tractor with a trailer	20	26409
	rye	10835.0	farm tractor with a trailer	20	59211
	distillery residues	1107.0	gravity pipeline	-	-
	cattle manure	1535.9	gravity pipeline	-	-
B4	chicen manure	10770.4	tanker farm tractor	20	23590
	potato pulp	273.1	farm tractor with a trailer	20	37292
	distillery residues	3917.0	tanker farm tractor	20	30685778
	post-flotation sludge	1240.9	lorry 16-32t, EURO4	20	15398328,1
	post-slaughter waste cat.3	105.9	lorry 16-32t, EURO4	10	179437
	catering waste	854.0	lorry 3,5-7,5t, EURO5	10	14586320
	fat waste	1101.7	tanker lorry 16-32t, EURO4	20	6068736
	pig manure	5652.0	tanker farm tractor	20	31945104
	maize	14824.0	farm tractor with a trailer	20	12425268

Source: own work

In the case of B1 and B4 biogas plants, green maize was delivered directly after harvest from the field to the biogas plant and ensiled in the silo. Loading into the digester biogas tank was carried out with a JCB telescopic loader. In the case of B2, the corn after the harvest was transported by lorry to the place of storage. The ensiling was performed in foil sleeves, and then a silage successively delivered via a feeder to the digester biogas tank. Only a potato pulp was collected on the area of the biogas plant, which was next dosed by a telescopic loader and screw feeder directly into the fermenter at appropriate daily doses. The distillery residues were transported by a gravity pipeline.

In the case of B3 biogas plant, maize and rye from the field were transported using a tractor for storage silos. Then the silage was transported to the feeder with a telescopic loader. Bovine manure was transported directly from the barns. The liquid feedstock (the distillery residues, and animal manure) were transported by a gravity pipeline.

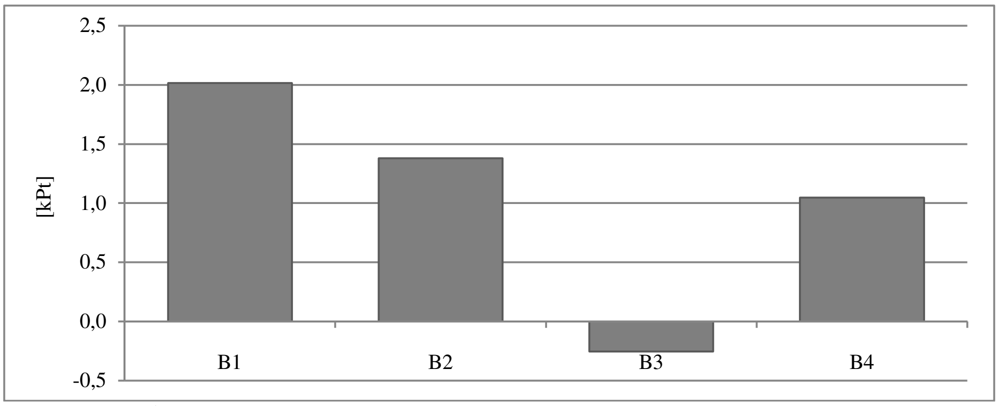
The biogas plant B4 was supplied with slaughterhouse waste (cat. 3), post-flotation sludge from animal feed production, post-production water from sweets production, catering waste, fats and pig manure. The types of transport used are listed in Table 2. These substances were first delivered to the hygienizator, where they were pasteurized. From there, they were sent via a pipeline to the digester biogas tank.

Data regarding the production of lorries and their operating conditions and emissions from diesel fuel combustion were taken from the Ecoinvent database [2017]. The obtained data from this database was converted into a model tractor with an average weight of 7.200 kg with a capacity of 110 HP (81 kW), burning diesel oil (Stage IIIB) in accordance with the directive [Directive EC 26 2004].

In the case of transport of residues from agro-food processing, the maximum distance to which the feedstock was transported was counted from the place of production to the area of the biogas plant. Substrate delivery, as well as the return path, was taken into account, i.e. the so-called empty course. In the case of a manure, one-way transport can sometimes be considered. It is assumed then that the return path is carried out with a load of digestate distributed to the field, which significantly affects the reduction of environmental loads associated with the transport of the load by limiting the distance travelled with an empty course [Lijó et al. 2017]. Unfortunately, in the case of biogas plants, the transport of manure did not include this type of loadings activities. The distances covered by various vehicles are collected in Table 2. In order to determine the maximum transport distance of energy crops from the field after harvest to the ensilage site, the method described by Hartmann [2006] was applied. Assuming that the area necessary for silage maize cultivation is circular and has a silo in its center, the radius of this circle determines the maximum one-way distance that the farm tractor with trailer must overcome.

RESULTS

The analysis of the research results showed that the largest negative cumulative environmental impact in relation to the functional unit (FU; which is 1000 MWh of electricity produced) is characterized by the B1 biogas plant, where the value of the eco-indicator is 2.02 kPt. The most beneficial effect on the environment is shown by the biogas plant B3 with a value of the eco-indicator at the level of minus 0.24 Pt as shown on Fig. 2. The minus values of the eco-indicator mean a beneficial effect on the environment.



Source: own work

Fig. 2. Results of the cumulative eco-indicator for the tested biogas plants

The total impact on the environment expressed in eco-points [Pt] has been assigned to particular stages of operation of each of the tested biogas plants. The results of the calculations indicate that the greatest environmental effects are related to the stage of feedstock assurance in B1, B2, and B4 biogas plants as well as the stage of corn cultivation for the needs of the same biogas plants as shown in Table 3. In turn the most beneficial effect (negative values of the eco-indicator), shows the stage of energy production from the combustion of biogas produced during the methane fermentation process. This is related to the avoidance of environmental burdens from the production of electricity from non-renewable conventional sources (Table 3).

In the case of B3 biogas plant, the impact of individual stages of the plant's operation has a very small share in the value of the cumulative eco-indicator in comparison to analogous stages in other biogas installations. This is particularly caused by the significant reduction in the transport of substrates and their acquisition practically at the place of processing for biogas.

Table 3. Cumulative eco-indicator values for individual stages of operation of the tested biogas plants

biogas plant operation stages	biogas plant no.			
	B1	B2	B3	B4
	eco-indicator value Pt/1000 MWh]			
maize cultivation	404.12	504.13	2.67	207.20
rye cultivation	-	-	8.82	-
feedstock provision	1905.79	1193.59	2.58	1164.56
energy production	-276.21	-294.164	-311.15	-315.82
digestate storage	0.01	0.02	59.66	0.01
digestate application	-18.66	-23.85	-16.40	8.52

Source: own work

In the case of B3 biogas plant, an increase in the negative environmental impact of the digestate storage stage (Table 3) was observed compared to other biogas plants tested. This is related to the fact that only this installation has an open tank, so-called a lagoon, which is a post-fermentation liquid storage. Environmental influences are therefore associated with the uncontrolled emission of methane, ammonia and nitrogen oxides into the atmosphere.

In each biogas plant, a different annual amount of maize silage is used in the methane fermentation process. Therefore, the cumulative eco-indicator for the maize cultivation phase per 1 Mg of maize silage was recalculated. It allows to assess the unitary impact of the above stage on the environment (Table 4).

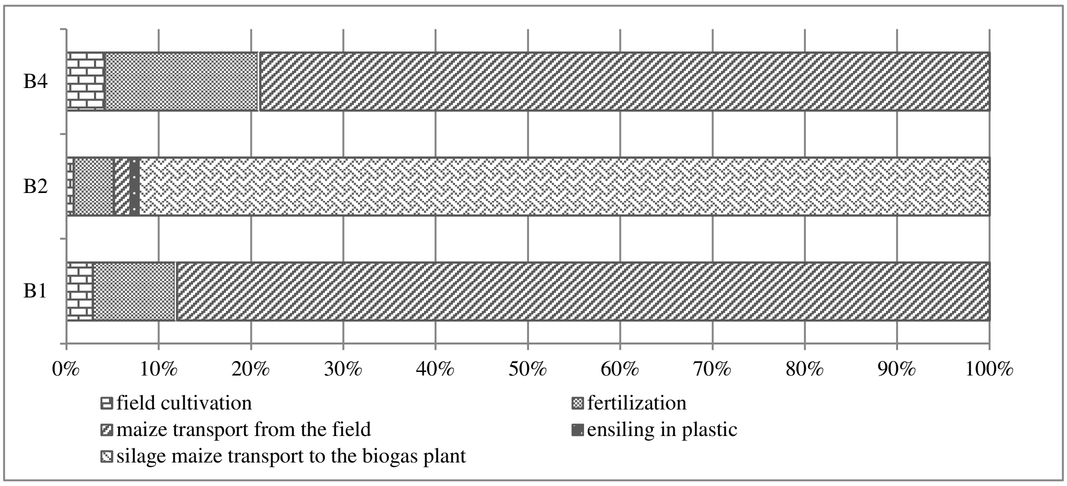
Table 4. Cumulative eco-indicator values for the maize cultivation phase per 1 Mg of maize silage of the tested biogas plants

Indicator	biogas plant no.			
	B1	B2	B3	B4
The cumulative eco-indicator value [kPt/1000 MWh]	404.12	504.13	2.67	207.20
The amount of silage maize [Mg/1000 MWh]	1885.65	673.54	223.23	1351.21
Cumulative eco-indicator values per 1 Mg of maize silage [Pt]	0.21	0.75	0.01	0.15

Source: own work

The value of the cumulative eco-indicator (0.75 Pt) for the maize cultivation stage calculated per 1 Mg of maize silage produced in the B2 biogas plant significantly exceeds the values for other biogas plants (Table 4). The production of silage maize covers various unit processes. The research results show that the key unit process of the maize cultivation stage is its transport from the place of production to the biogas plant in order to silage it (Figure 3).

In the case of B1 and B4 biogas plants, this transport concerns fresh maize chaff from the field to the silo located in the biogas plant. However, in the case of a B2 biogas plant, it is a process of transporting silage maize to the installation area, successively throughout the year, because the biogas plant does not have the capacity to store the load.



Source: own work

Fig. 3. The share of unit processes of the production of silage maize in environmental impact

The environmental assessment shows that the most unfavorable impact in the B1 biogas plant at the stage of feedstock provision is the process of transporting pig manure from the place of production (swine farm) to the biogas plant along with its loading into the digester biogas tank (1903.10 Pt) as shown in Table 5a.

Table 5. Cumulative eco-indicator values [Pt] for the feedstock preparation stage with division into individual unit processes for B1, B2, B3 biogas plants

5a

B1			
ME	MSL	T_{PIG}	TV
1.00	1.69	1903.10	1905.79

5b

B2						
T_{PIG}	$T_{SEDIMENT}$	T_{CARROT}	T_{POTATO}	T_{DR}	MSL	TV
6.08	46.43	201.55	935.92	0.00	3.62	1193.59

5c

B4										
T_M	$T_{CHICKEN}$	T_{WASTE}	T_{C3}	T_{PF}	T_{POTATO}	T_{FAT}	T_{DR}	ME	MSL	TV
319.37	0.72	273.15	1.29	107.45	0.52	21.38	306.73	133.80	0.14	1164.56

T_{PIG} – pig manure transport, $T_{SEDIMENT}$ – protein sediments transport, T_{CARROT} – carrot pulp transport, T_{POTATO} – potato pulp transport, T_D – distillery residues transport, MSL – maize silage loading, $T_{CHICKEN}$ – chicken manure transport, T_{WASTE}– catering waste transport, T_{C3} – post-slaughter waste transport, T_{PF} – post-flotation sludge transport T_{FAT} – fat waste transport, ME – maize ensiling, TV – total value.

Source: own work

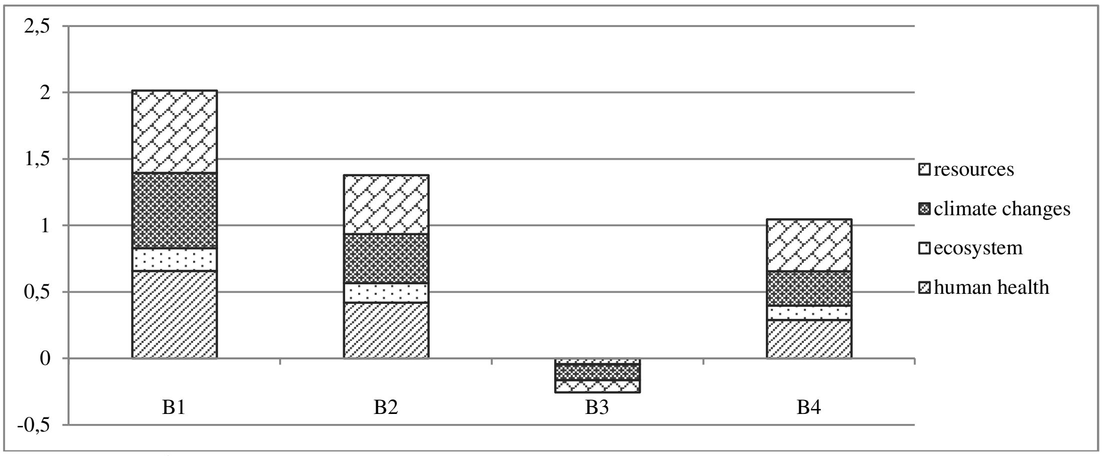
In the case of the B2 biogas plant, the stage of providing the feed is primarily related to the supply of waste from agro-food processing from the place of production, i.e. from the processing plant to the biogas plant area and loading of the feed into the digester biogas tank. This is done with a working lorry engine or a barrel-trailer tractor (pig manure) directly to the pre-tanks. The values of eco-indicators for carrot and potato pulp transport processes account for a total of 95.3% of the value of the cumulative eco-indicator of the total biogas plant impact (Table 5b) on the environment.

Biogas plant B4, similarly to the B2 biogas plant, is characterized by a large variety of inputs. It is obtained primarily from agro-food processing plants from external suppliers. The stage of providing the batch is therefore divided into a number of subprocesses related to the transport of waste and their direct loading to the initial tanks.

In the case of this biogas plant, the stage of providing the feedstock also includes the process of maize ensiling and its subsequent storage (Table 5c). The pig manure transport processes (319.37 Pt) and the stillage (306.73 Pt) are characterized by the highest values of the cumulative eco-indicator (Table 5c). This is mainly due to the type of transport, which in this case is a tractor with a 20 m^3 barrel. High impact on the environment is also demonstrated by processes related to the transport of catering waste, post-flotation sludge and the process of silage ensiling in concrete silos on the site.

Due to the low value of the eco-indicator for the feedstock provision stage in biogas plant B3 (2.58 Pt in Table 3) there was no need to divide this stage into individual unit processes.

In the case of the biogas plants tested, due to transport processes, among all four damage categories three of them are therefore most heavily burdened: 'resources', 'human health' and 'climate changes' (Figure 4). It corresponds to the most negative impact in three impact categories: ''breathing disorders related to exposure to inorganic compounds', 'impact on global warming' and 'use of non-renewable energy'. This is closely related to emissions of airborne chemical substances from the combustion of diesel in motor vehicles used for transport.



Source: own work

Fig. 4. Eco-indicator values in damage categories for biogas plants tested

SENSITIVITY ANALYSIS

The analysis of the sensitivity of results to changes in the distance of transporting substrates from the place of production to the biogas plant was based on the "business as usual" (BAU) variant. The scope of changes in the range of ± 25% (in relation to BAU) of the transport distance of substrates from the place of production to the biogas plant was applied. Changes in a distance in internal transport in the biogas plant were not taken into account (transport by telescopic loader and pipelines), therefore, a variant analysis was carried out for three of the tested biogas plants (B1, B2, B4). The biogas plant B3 was excluded from the variant analysis because the transport of raw materials took place only in the internal area of the plant.

Changes in the impact of biogas plants on the environment in relation to changes in the length of the transport route show that reducing the length of the road reduces the cumulative eco-indicator value by 24% for the B1 biogas plant, 32% for the B2 biogas plant and 25% for the B3 biogas plant. On the other hand, the increase in the length of the road by 25% causes an increase in the total negative environmental impact by 19% for the B1 biogas plant, 18% for the B2 and 20% biogas plants.

Another logistical aspect beyond the length of the transport route is the means of transport used. As has been shown, the largest environmental loads associated with the transport of liquid substrates (pig slurry) concerned the B1 biogas plant. The functioning of this biogas plant is based on two substrates such as maize silage and pig slurry. Maize is grown in the vicinity of a biogas plant, then transported to the biogas plant and ensiled in a silo. Whereas the slurry is transported by an agricultural tractor with a barrel from a distance of up to approximately 5 km from a biogas plant. To assess the environmental impact of the slurry transport process, a sensitivity analysis based on simulation conditions was carried out. A hypothetical option was assumed where slurry transport would be carried out using a pipeline. The results of the variant analysis show that transporting slurry with a pipeline would allow for 10-fold reduction of environmental damage in relation to BAU, i.e. transport by means of a farm tractor with a barrel.

CONCLUSIONS

Analyzing the ecological determinants of the operation of selected agricultural biogas plants in terms of their effects of environmental impact attention has been paid to the logistics aspects and their impact on the ecological impact indicators of four agricultural biogas plants differing in the way the feedstock is provided. The results of analyzes on the examples of functioning biogas plants confirmed previous literature reports that one of the main factors affecting the efficiency of agricultural biogas plant operations is the transport of raw materials, both as to the length of the transport route and the means of transport used.

The biggest negative environmental effects were obtained for a biogas plant, to which the transport of liquid raw material, i.e. pig manure or distillery residues, was carried out with the help of a tanker farm tractor.

The sensitivity analysis of the results showed that substitution of pig manure transport by road with a pipeline transport would significantly reduce environmental damage.

The obtained positive environmental effects from the production of electricity from biogas are often significantly reduced by inadequate transport of raw materials or their transport over long distances.

The biogas plants operators should be convinced of the need for proper logistics solutions. Preferably if based on the results of the presented analyzes, they will consider submitting a logistics management system of the flow of raw materials in a biogas plant to the certification for example in the ISCC system and REDcert [Stoma 2014].

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LOGISTYCZNE ASPEKTY EKOLOGICZNYCH WSKAŹNIKÓW ODDZIAŁYWANIA BIOGAZOWNI ROLNICZEJ

STRESZCZENIE. **Wstęp:** Polska musi wypełnić swoje zobowiązania dotyczące zwiększenia udziału energii ze źródeł odnawialnych w produkcji energii elektrycznej. Do roku 2020 ten udział dla Polski ma wynosić co najmniej 15% całkowitego zużycia energii w końcowym zużyciu energii brutto. Polska ma znaczny potencjał biomasy, który można wykorzystać do produkcji biogazu. Biogaz można produkować w instalacjach biogazowych instalowanych na składowiskach odpadów, oczyszczalniach ścieków lub biogazowniach rolniczych. Źródła literaturowe stwierdzają, że w badaniach skutków środowiskowych dotyczących eksploatacji biogazowni rolniczych, logistyka wsadu surowca powoduje największe obciążenia środowiska. Odległość, na której transportowany jest surowiec, znacząco wpływa na wzrost potencjału globalnego ocieplenia. W niniejszej publikacji po raz pierwszy dla polskich warunków zostaną przedstawione wyniki analizy aspektów logistycznych i ich wpływu na wskaźniki oddziaływania środowiskowego czterech biogazowni rolniczych różniących się sposobem podawania surowca.

Metody: Ocena wskaźników oddziaływania ekologicznego została przeprowadzona przy użyciu metodologii Analizy cyklu Życia [Life Cycle Assessment (LCA)] opartej na normie ISO 14040-44 z zastosowaniem metody LCIA Impact 2002+. W tej metodzie wyodrębnia się 15 kategorii oddziaływania, do których zaliczane są takie kategorie szkód jak wpływ na zdrowie ludzi, wpływ na jakość ekosystemu, wpływ na zmiany klimatu i zasoby naturalne. Dane pierwotne uzyskane w badanych instalacjach biogazowych i wybrane dane wtórne uzyskane z bazy danych Ecoinvent v. 3.4 zostały przetworzone przy użyciu programu obliczeniowego SimaPro Ph.D. v. 8.3.0. Wszystkie wyniki były analizowane w odniesieniu do jednostki funkcjonalnej zdefiniowanej jako wytworzenie 1000 MWh energii elektrycznej w biogazowni rolniczej. Analizowane cztery biogazownie rolnicze są reprezentatywnymi przykładami dla poszczególnych rodzajów biogazowni rolniczych.

Wyniki: Wyniki analiz wskazują, że największe negatywne efekty środowiskowe związane są z etapem dostarczania surowca do instalacji biogazowych, głównie ze względu na transport wsadu na duże odległości przy użyciu ciężkiego sprzętu transportowego. Wyniki analizy wariantowej pokazują, że transport gnojowicy za pomocą rurociągu pozwoliłby na 10-krotne zmniejszenie szkód środowiskowych w stosunku do BAU, tj. transportu za pomocą ciągnika rolniczego z beczką.

Wnioski: Aspekty logistyczne działania wybranych biogazowni rolniczych różniących się sposobem podawania surowca są jednym z głównych czynników wpływających na jego efektywność ekologiczną. Transport surowców, zarówno pod względem długości trasy transportu, jak i wykorzystywanych środków transportu, wpływa na wskaźniki oddziaływania ekologicznego biogazowni rolniczych.

Uzyskany pozytywny wpływ na środowisko wynikający z produkcji energii elektrycznej z biogazu jest często znacznie ograniczany przez niedostateczny transport surowców lub ich transport na duże odległości.

Konieczne są dalsze prace, aby przekonać operatorów biogazowni o potrzebie odpowiednich rozwiązań logistycznych.

Najlepiej, gdyby w oparciu o wyniki przedstawionych analiz rozważyli poddanie systemu zarządzania logistyką przepływu surowców w biogazowni certyfikacji np. w systemie ISCC oraz REDcert.

Słowa kluczowe: analiza cyklu życia, biogazownia rolnicza, energia odnawialna, efektywność ekologiczna, wskaźniki wpływu ekologicznego.

LOGISTISCHE ASPEKTE ÖKOLOGISCHER KENNZIFFERN DER UMWELT-BEANSPRUCHUNG SEITENS EINER LANDWIRT-SCHAFTLICHEN BIOGASANLAGE

ZUSAMMENFASSUNG. Einleitung: Polen muss seine Verpflichtungen bezüglich der Vergrößerung des Ausmaßes der erneuerbaren Energie bei Erzeugung der elektrischen Energie erfüllen. Bis 2020 soll diese energetische Beteiligung für Polen mindestens 15% des Gesamtenergieverbrauchs im Rahmen des endgültigen Brutto-Energieverbrauchs betragen. Polen verfügt über ein bedeutendes Potenzial an Biomasse, das man zur Erzeugung des Biogases in Anspruch nehmen kann. Das Biogas kann in den in Abfalldeponien installierten Biogasanlagen, Kläranlagen und in landwirtschaftlichen Biogasanlagen erzeugt werden. Die Literaturquellen besagen, dass in den die Umweltschutz-Gefährdung anbetreffenden Forschungen, die hinsichtlich des Betreibens von Biogasanlagen geführt werden, die Logistik der Rohstoff-Komponente die meiste Beanspruchung der Umwelt verursacht. Selbst die Entfernung, auf die der Rohstoff befördert wird, beeinflusst wesentlich den Anstieg von Potenzial der globalen Erwärmung. Im Rahmen der vorliegenden Abhandlung werden zum ersten Mal für die polnischen Gegebenheiten Ergebnisse der Analyse logistischer Aspekte und deren Einflusses auf die

Kennziffern der Umwelt-Beanspruchung seitens vier landwirtschaftlicher Biogasanlagen, die sich durch die Methode des Darreichens von Rohstoffen voneinander unterscheiden, dargestellt.

Methoden: Die Auswertung der Kennziffern der ökologischen Beanspruchung wurde unter Anwendung der Methodologie der Analyse des Lebenszyklus [Life Cycle Assessment (LCA)], die auf die ISO-Norm 14040-44 mit der Inanspruchnahme des Verfahrens LCIA Impact 2002+ gestützt ist, vorgenommen. Innerhalb dieser Methode werden 15 Beanspruchungskategorien, zu den man solche negativen Einflussfaktoren wie: Einfluss auf die Gesundheit der Bevölkerung, Einfluss auf die Qualität des Ökosystems sowie Einfluss auf die Klimaveränderungen und natürliche Ressourcen zählt, unterschieden. Die in den untersuchten Biogasanlagen gewonnenen Primärdaten und die ausgewählten, von der Datenbank Ecoinvent v. 3.4 erfassten Sekundärdaten wurden mithilfe des Berechnungsprogramms SimaPro Ph.D. v. 8.3.0 verarbeitet. Alle Ergebnisse wurden in Bezug auf eine funktionale Einheit, die als die Erzeugung der elektrischen Energie von 1000 MWh in der landwirtschaftlichen Biogasanlage definiert wurde, analysiert. Die vier betreffenden landwirtschaftlichen Biogasanlagen stellen repräsentative Beispiele für die einzelnen Arten von landwirtschaftlichen Biogasanlagen dar.

Ergebnisse: Die Ergebnisse der Analysen weisen darauf hin, dass die meisten negativen Umwelt-Beanspruchungen mit der Lieferung des Rohstoffes zu den Biogasanlagen verbunden sind. Dies geschieht hauptsächlich wegen der Beförderung des Rohstoffes auf weiten Entfernungen mit der Inanspruchnahme von schweren Lastkraft-Transportmitteln. Die Ergebnisse der Varianten-Analyse zeigen auf, dass der Transport von Gülle mittels eines Rohrleitung die 10-fache Reduzierung der Umweltschäden im Vergleich zum Transport der Gülle mit dem landwirtschaftlichen Trecker mit Behälter ermöglicht hätte.

Fazit: Die logistischen Aspekte der ökologischen Beanspruchung seitens der landwirtschaftlichen Biogasanlagen, die sich durch die Methode der Anlieferung des Rohstoffes voneinander unterscheiden, stellen die Hauptfaktoren dar, die die ökologische Effizienz am meisten beeinflussen. Die Beförderung von Rohstoffen, sowohl angesichts der Streckenlänge als auch der benutzten Transportmittel übt einen gravierenden Einfluss auf die Kennziffern der Umwelt-Beanspruchung seitens der landwirtschaftlichen Biogasanlagen aus. Die positive Beeinflussung der Umwelt dank der Erzeugung der elektrischen Energie in Anlehnung an das Biogas wird oft durch einen mangelhaften Transport von Rohstoffen oder ihre Beförderung auf weiten Entfernungen eingeschränkt. Es sind weitere Forschungen nötig, damit sich die Betreiber der Biogasanlagen vom Bedarf entsprechender logistischer Lösungen überzeugen können. Am besten wäre es, wenn sie in Anlehnung an die Ergebnisse der angeführten Analysen die Zertifizierung des Logistikmanagement-Systems im Bereich Materialfluss in ihren Biogasanlagen, zum Beispiel anhand des ISCC- oder REDcert-Systems, erwägen würden.

Codewörter: Analyse des Lebenszyklus, landwirtschaftliche Biogasanlage, erneuerbare Energie, ökologische Effizienz, Kennziffern der Umwelt-Beanspruchung

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