Environmental Engineering and Management Journal November 2014, Vol.13, No. 11, 2867-2874
http://omicron.ch.tuiasi.ro/EEMJ/

"Gheorghe Asachi" Technical University of Iasi, Romania

THE CARBON FOOTPRINT OF A BIOGAS POWER PLANT

György Szabó[1*], István Fazekas[1], Szilárd Szabó[2], Gergely Szabó[2], Tamás Buday[3], Mónika Paládi[1], Krisztián Kisari[4], Attila Kerényi[1]

[1]*University of Debrecen, Department of Landscape Protection and Environmental Geography, 4010 Debrecen, Egyetem square 1, Hungary*
[2]*University of Debrecen, Department of Physical Geography and Geoinformatics, 4010 Debrecen, Egyetem square 1., Hungary*
[3]*University of Debrecen, Department of Mineralogy and Geology, 4010 Debrecen, Egyetem square 1., Hungary*
[4]*Agricultural Ltd. of Tiszaszentimre, 5322 Tiszaszentimre, Erzsébet major 0131/14, Hungary*

Abstract

In our study, we examined the annual carbon footprint and energy balance of a Hungarian biogas power plant with a power output of 0.637 MW in 2013, with reference to the complete life cycle of the biogas production. The life cycle analysis (LCA) considered the emissions of greenhouse gases (GHG) during the production of feedstock and its transportation into the power plant, during the operation of the factory and during the process of rendering the discarded waste materials harmless. We established that the highest GHG emissions related to the feedstock production in which both the use of machines and N_2O release from the use of artificial fertilizers played an important role. In 2013, the power plant produced 4347.21 MWh electric power and 4607.89 MWh thermal energy. The carbon footprint of the complete energy production life cycle was 208173 kg CO_2 equivalents (CO_2e). If the regular Hungarian energy structure produced such a quantity of energy, GHG emissions would be 15 times higher. Therefore, the energy balance of the power plant is positive; in contrast to its 8955.10 MWh energy production, its energy requirements were merely 2720.26 MWh, of which 1520.60 MWh as thermal energy served to heat the digesters. Unfortunately, more than 50% of the produced thermal energy is currently wasted; therefore, in the future, it is important to find a solution for the proper utilization of this valuable energy.

Key words: biogas, carbon footprint, energy balance, greenhouse gas emission, life cycle analysis

Received: February, 2014; Revised final: October, 2014; Accepted: October, 2014

1. Introduction

Biogas production is one of the most economically and environmentally beneficial treatment solutions for biodegradable waste material (Gholikandi et al., 2014). In Hungary, the agriculture, food industry and the communal sectors produce a significant amount of organic waste every year (Fazekas et al., 2013). Currently, the actual energetic utilization rate of such waste is significantly lower than possible, even though it would promote the diversification of available energy sources and could also play an important role in the landscape development. Additionally, it could contribute to the suppression of fossil energy source use, to the neutralization of environmentally harmful toxic wastes, and to the reduction of GHG emissions. Furthermore, a considerable amount of artificial fertilizers and irrigation water could be saved with the utilization of the digested bio manure (Massé et al., 2011).

In 2013, in the 54 biogas power plants in Hungary, a total of 111 million m^3 of biogas was utilized energetically (Fazekas et al., 2013). Until 2003, the extraction and utilization of biogas occurred exclusively at a few sewage-treatment plants and newly built regional communal landfills. Despite favorable conditions, the building of biogas factories

* Author to whom all correspondence should be addressed: E-mail: szabo.gyorgy@science.unideb.hu; Phone: +36-52-512 900/22128; Fax: +36-52-512 945

that could energetically utilize agricultural waste materials was extremely slow before 2009, but because of the new supporting system, the sector started to develop exponentially in 2009. By 2014, the number of agricultural biogas power plants reached 34, and their output performance exceeded 31 MW_e, providing approximately three-quarters of the total national biogas power plant capacity. Typically, these low-capacity power plants are located near larger livestock farms, i.e., close to the liquid manure sources (feedstock for the production of wet biogas), such as the one in Tiszaszentimre, the chosen location of our investigation (Fig. 1).

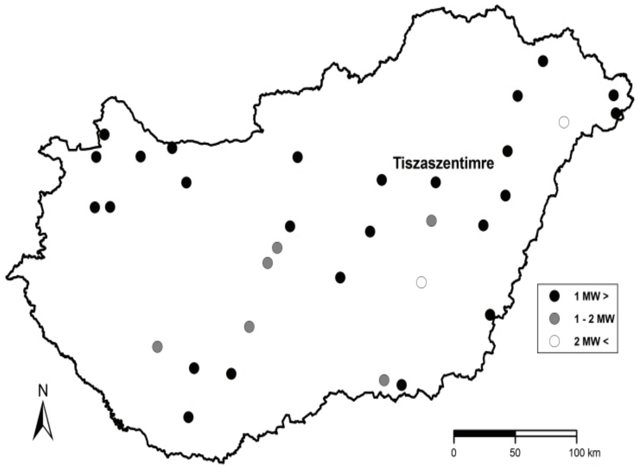

Fig. 1. Agricultural biogas power plants in Hungary in 2014

With the energetically utilized biogas in Hungary every year, approximately 66 million m^3 of natural gas is saved, the burn of which would result in a 114 thousand ton/year direct CO_2 emission, thus considerably increasing the country's carbon footprint (Fazekas et al., 2013).

A number of publications discuss the environmental effects of the energy-producing utilization of biogas, often including the investigation of the carbon footprint. Uusitalo et al. (2014) made comparative studies regarding the energy-producing utilization of biogas. The authors considered the conversion of three raw (feedstock) materials into biogas: biowaste, sewage sludge from sewage-treatment plants, and agricultural biomass. Their study aimed to compare the GHG emission values of the different biogas-producing raw materials. They concluded that biogas produced from agricultural biowaste was optimal for the carbon footprint. Hermann et al. (2011) studied the possible treatment methods for biodegradable organic biowastes.

Three different procedures concerning the carbon footprint were analyzed: anaerobic digestion, industrial composting, and home composting. It was established that anaerobic digestion causes the smallest carbon footprint; however, they noted that burning the organic waste could be a good alternative if it increased the energy efficiency of the refuse burners. The advantages of anaerobic digestion are also identified by Liu et al. (2012), who studied the possibility of anaerobic digestion of biowaste in China. It was established that the anaerobic digestion decreased GHG emissions in two ways. On the one hand, during traditional waste treatment procedures (disposal, burning), the GHG emissions are much higher. On the other hand, the fossil energy sources can be replaced by the biogas produced during the process. Lacour et al. (2012) also emphasized that GHG emissions are much lower during an anaerobic digestion of biowaste than in disposal at landfills. Upon investigating the utilization of organic manure (originating from livestock farming) for biogas production, Massé et al. (2011) established that both the renewable energy production and the bio manure (produced by digestion) would significantly decrease the carbon footprint of livestock-based farming food production. This is because the thermal and electric energy gained from the biogas would reduce the use of fossil energy sources and the bio manure would suppress/replace the use of artificial fertilizers. Furthermore, the bio manure viscosity is significantly lower than that of the original manure.

Therefore, it can be handled more easily, its weight is one-fifth that of the original manure, and its nutrient composition is much more favorable for the vegetation than that of the original manure (Massé et al., 1996). Globally, 18% of all GHG emissions originate from livestock farming, which includes direct CH_4 emission (from decomposition of manure), as well as N_2O emission that is released from the organic manure spread on the arable lands (Kebread et al., 2006). This ratio could be reduced if the waste originating from livestock farming could be used as much as possible for anaerobic digestion-based biogas production.

The aim of our study was to demonstrate, via the life cycle analysis of a biogas power plant's operation, the complete GHG emissions of the energetic utilization of biogases, i.e., the carbon footprint of a biogas factory.

To make a life cycle inventory, we identified the processes and activities that determine the “size” of the carbon footprint. Our aim was to collect in situ data of all relevant (energy demanding) activities relating to the power plant's operation and to enable exact calculations of the rates of actual energy consumption, which helped in drawing a high precision energy balance by considering the complete life cycle. Based on this aim, the total GHG emissions of the biogas power plant were compared to the emissions from the quantity of energy equivalent to the production of biogas produced by the average Hungarian energy structure.

2. Materials and methods

The biogas factory, owned by the Tiszaszentimrei Mezőgazdasági Kft. (Agricultural Ltd. of Tiszaszentimre), officially started operating on January 1, 2012. The power plant was based primarily on the nearby pig farm to utilize the produced liquid manure. The most important units of the factory include two digesters (diameter: 21 m, height: 6 m, volume: 2078 m^3) and a follow-up digester (diameter: 26 m, height: 6 m, volume: 3186 m^3). The produced biogas is stored in three integrated gas tanks with a total capacity of 2873 m^3. The biogas engine generator prepares the produced gas for utilization with a gas purifying, desulfurizing and washing system. The electrical capacity of the biogas engine generator is 637 kW, its efficiency is 40.1%, and its thermal efficiency is 682 kW with a 39.7% net efficiency.

The complete life cycle, i.e., the production of feedstock, its transportation into the factory, the power plant's operation, and the fate of the residue salvaged from the digesters, was taken into account in calculating the carbon footprint. In addition to the CO_2 produced during the process, all other GHG emissions were investigated. The PAS 2050 (2011) gives the Global Warming Potential (GWP) calculated for a 100-year period; with its help, we could convert these gases into CO_2 equivalents (CO_2e), and, by adding up these values, the total GHG emissions could be established.

The calculations of the emission values related to fuel consumption were based on the values given in the "Conversion factors (Energy and carbon conversions)" released by the Carbon Trust (2013). The calculations of the CO_2 emissions related to electric power utilization were based on the 0.370 kg CO_2e/1 kWh value established by the Hungarian energy structure (National Energy Strategy 2030, 2012). The energy devoted to the production of the raw materials produced to supply the power plant with energy, as well as their transportation into the factory, was also considered. Furthermore, upon calculating the carbon footprint, we also considered the N_2O released from the soil from the use of artificial fertilizers during the plant cultivation periods. The soils also release a certain amount of N_2O in the case of the natural vegetation (Horváth et al., 2010).

Thus, for the carbon footprint calculation, we only considered the quantity that was added as surplus to the natural emission. The estimates were based on the 1990–2010 Report of Greenhouse Gas Inventory (released by the EEA, 2012), as well as on particular measuring and DNDC (denitrification-decomposition) modeling results of Grosz (2010), whose research was performed in Hungary. From the investigation of several sampling locations of the Hungarian Great Plain, Grosz established 1.77 kg N_2O-N ha^{-1} $year^{-1}$ and 1.39 N_2O-N ha^{-1} $year^{-1}$ emissions for arable lands (treated with artificial fertilizers) and extensive grasslands (untreated), respectively. Because vetch and sweet sorghum, which are raw materials produced for the power plant, were treated with artificial fertilizers, we use the value of 1.77 kg N_2O-N ha^{-1} $year^{-1}$ emissions for calculations. We also calculated a hypothetical N_2O emission as if extensive untreated grasslands covered the area.

To determine the carbon footprint of the power plant, we considered the difference between the two values, expressed in CO_2 equivalents. For medick, hay and "Szarvasi-1" energy grass, no fertilizing or prior land cultivation occurred; therefore, the N_2O emissions originating from such areas were assumed to be equal to that of the natural vegetation and were omitted from the carbon footprint calculation of the power plant.

For the raw materials that got into the power plant as a byproduct or waste of any production processes with any other aim than providing energy for the factory, we only considered the CO_2 emissions directly linked with the transportation to the site. These byproducts and waste include the technological wastewaters, flotation sludge, other organic wastes of vegetable oil and canning factories, and organic and solid manure originating from the livestock farms and farmyards.

The energy requirements of the power plant's service facilities, which are supplied by the national electrical network, were also considered. The electrical and thermal energy produced by the factory itself ensured the energy needed for the operation of the power plant. This energy is generated by burning the CH_4 produced in the digesters while CO_2 is released. However, the quantity of released CO_2 cannot exceed the CO_2 bound from the atmosphere during the production of organic matter. Because the quantity of CO_2 bound during the synthesis of organic matter was omitted from our calculation, the CO_2 released by the power plant during the production of electrical and thermal energy was also disregarded in calculating the power plant's carbon footprint. Furthermore, the CO_2 emissions attributable to liquid manure and solid-state bio manure were also ignored. The reason for this exclusion is that the liquid manure originating from the nearby livestock farm must be considered when determining the carbon footprint of the given farm because the waste in question was produced there; the power plant only borrowed it from the livestock plant to produce biogas from its organic matter content.

Therefore, to determine the carbon footprint of the power plant, only the GHG emissions attributable to the pumping of the liquid phase were considered. The solid-phase manure was disregarded in the calculation because the annually produced amount was not permitted to be spread on the fields, so its full volume was recycled into the digesters; thus, it did not cause any surplus GHG emissions.

The amount of energy used for business travel related to the proper running of the power plant is considerable, although if compared to the previous items, it is of lesser significance. Because the headquarters of the maintenance service company is in Budapest, relatively long trips are required for maintenance. However, these factors were also considered in the calculation of the carbon footprint. The GHG emissions related to the commuting employees responsible for the production of feedstock and the operation of the power plant are negligible; therefore, they were not considered in the calculation of the carbon footprint. After determining the GHG emissions (given as CO_2 equivalents) for all phases, the power plant's carbon footprint was established as the CO_2 equivalent of the total GHG emissions during the complete life cycle of the process.

This carbon footprint was demonstrated by giving the size of the forest area that could bind the CO_2 released during the full life cycle of the biogas production in 2013. Calculating with the deciduous forests of Central Europe, 1 ha (hectare) of deciduous forest can bind approximately 5.2 t CO_2 per year (Stockholm Environment Institute, 2002).

3. Results and discussion

3.1. Greenhouse gases originating from feedstock production

The GHGs originating from the feedstock production in the power plant were considered only for the raw materials that were specifically produced for utilization in the power plant itself. In our case, these raw materials include sweet sorghum, vetch, medick, hay and energy grass. The above-mentioned plants were grown on a total 404 ha area.

The carbon footprint related to the feedstock production has two components: the CO_2 emission of the machines used for the plant cultivation and the surplus N_2O release observed in areas where artificial fertilizers were applied. Each plant had different rates of machine usage. For medick, hay and energy grass, machines were used only to harvest.

For vetch, sowing and harvesting occurred after application of 27% of a nitrogen fertilizer called "pétisó" (peti-salt, NH_4NO_3 + $CaMg(CO_3)_2$) (100 kg ha^{-1}) accompanied by a stubble plowing. For sweet sorghum, after stubble plowing, the area was plowed and harrowed, a compactor prepared the seedbed, and the area was fertilized with 27% peti-salt (200 kg ha^{-1}) in parallel with sowing.

Then, a chemical and mechanical weed-killing occurred, followed by the harvest itself. In the period from sow to harvest, the fuel consumption of the following machines was taken into account: MTZ80, MTZ82, MTZ 150, Jaguar 860, Ferguson Massey 6499, combine harvester, and JCB 643 front-end loader. The total fuel consumption of the above-mentioned agricultural equipment was 22614 liters in 2013 for a total of 58814 kg CO_2e emissions (Table 1).

It was difficult to establish how N_2O emissions increased on the 404 ha area, which was used to grow the above-mentioned plants, above the natural level because of the artificial fertilizing. Because we could not use measurement data in this case, we made estimations according to the descriptions in the "Materials and methods". The calculated emission values are summarized in Table 2.

Although we calculated with surplus emissions only for vetch and sweet sorghum, the more than 45.000 kg (given as CO_2e) is quite significant because of the high GWP index of N_2O (298 for a 100-year duration). The surplus N_2O emissions are consistent with the calculated values based on the method given in the GHG Inventory (EEA, 2012), according to which an average 0.01 kg N_2O-N may be released out of every 1 kg N found in the artificial fertilizer. In our case, it equals 48412 kg, expressed in CO_2e.

3.2. Greenhouse gases originating from feedstock transportation

The raw materials were transported to the power plant in Tiszaszentimre from different locations. The pig farm, breeding 6000 swine, in close vicinity to the power plant provides the largest quantity of raw materials; liquid manure is transported into the digesters by pumps via a pipeline. In 2013, this quantity was 12920 m^3.

Table 1. The GHG emissions of the machines used to produce feedstock for the power plant in Tiszaszentimre, in 2013

Grown plant	*Cultivated area (ha)*	*Produced quantity (kg)*	*Fuel used by the machines (l diesel oil)*	*kg CO_2 e/1 l diesel oil*	*GHG emissions (kg CO_2e)*
Sorghum	125	2517450	10082	2.6008	26221
Vetch	133	1105350	6126		15931
Medick	91	1025230	5466		14217
Hay	45	71960	184		480
Energy grass	10	68110	756		1966
Total:	**404**	**4788100**	**22614**		**58814**

Table 2. Changes in the annual N_2O emissions of the agricultural areas that provide feedstock supplies for the power plant, expressed as CO_2 equivalents (the GWP for 100-year time horizon for N_2O is 298, PAS 2050: 2011)

Type of feedstock	*Cultivated area (ha)*	*Nitrogen fertilizer (kg ha^{-1})*	*N_2O emissions (kg N_2O-N ha^{-1})*	*Total N_2O emissions (kg N_2O-N)*	*Total emissions (kg CO_2e)*	*Surplus emissions beyond the natural emissions (kg CO_2e)*
Vetch	133	200	1.77	235	110209	23661
Sweet sorghum	125	100	1.77	221	103580	22238
Medick	91	-	1.39	126	59217	0
Hay	45	-	1.39	63	29283	0
Energy grass	10	-	1.39	14	6507	0
Total:	**404**			**660**	**308797**	**45898**

The Agricultural Ltd. of Tiszaszentimre used its own arable lands (404 ha) to produce the sweet sorghum, vetch, medick, hay and energy grass that were carried into the power plant; in 2013, their total quantity was 4788.1 tons.The plants grew around the biogas factory within a 12-km radius zone. MTZ80, MTZ82, MTZ 150, Ferguson Massey 6499 and IFA type vehicles transported the crops into the power plant. Based on the fuel consumption of each vehicle type with and without a load, the total fuel requirement for transportation was 2135 L diesel oil. Approximately 5553 kg CO_2e of emissions can be expected from the use of the raw materials (Table 3).

In 2013, the power plant was offered maize cuttings from a canning factory and the biomass of a nearby field of frostbitten sweet corn, both for a reasonable price. Although the distances were considerable, the management of the power plant decided that the purchase and transportation of the feedstock would still be economical and profitable. As a result, 1687 tons of raw material was transported from the Canning Factory of Debrecen (100 km) and 502 tons from Abádszalók (17 km). Additionally, the digesters received 1589 tons of flotation sludge from the Canning Factory of Nyíregyháza (126 km) and 792 tons of the byproduct of biodiesel production (biodiesel waste) with high organic matter content from the Biodiesel Factory of Halmajugra (91 km) (Table 3).

3.3. GHGs produced during the operation of the power plant and its service facilities

Electric power provides a substantial amount of the energy required for the working of the power plant, including stirring in the feedstock and pumping it into the digesters, mixing and transferring between the main and follow-up digesters, cooling the gas engine, and heating the fermenters. Because the electrical and thermal energy generated by the power plant itself covers these energy requirements, the quantity of CO_2 produced was omitted from the calculation of the factory's carbon footprint for reasons detailed in the "Materials and methods".

For the service facilities, we considered the energy requirements related to 1) the power plant's administrative offices, 2) the employees' business trips, and 3) the roundtrip travels of the maintenance service company from Budapest.

The national power network supplies the electric current consumed by the power plant's serving units. From the invoices issued by EON (the national power supplier), the consumption in 2013 was 117685 kWh, which equals 43543 kg CO_2e, based on the 0,370 kg CO_2e/1 kWh value calculated by the Hungarian energy structure.

From the register books for business trips and the invoices issued by the maintenance company, we summarized the total distances travelled by the individual motor vehicles in 2013.

Then, with the help of the Carbon Trust's conversion factors and knowledge of each motor vehicle type used, we calculated the emission values, which totaled 7946 kg CO_2e.

3.4. The carbon footprint of the waste materials transported from the power plant

There are two types of waste leaving the power plant: 1) the liquid-phase and 2) the solid-phase waste, the so-called bio manure. The majority of the liquid-phase originated from the liquid manure of the nearby pig farm. This wet phase, the quantity of which almost equals that of the input liquid manure (12500 m^3) is pumped via a pipeline to a disposal site 200 m away. The energy requirement of the pump was considered in the calculation of the total electric power used by the power plant. Before the construction of the power plant, the liquid manure was collected directly on the disposal site. Because we disregarded the GHG emissions during the production of liquid manure as they belong to the pig-farming wastes, we also ignored the GHG emissions related to the liquid-phase leaving the digesters as they are considered when calculating the carbon footprint of the pig farm.

The situation would be similar for the organic (solid) manure, but in 2013, the power plant was still waiting for permission for the agricultural utilization of the solid-phase, the so-called bio manure. For this reason, the total 1955 tons of bio manure produced over the years was completely recycled into the digesters. Thus, there was practically no solid-phase waste in 2013. Therefore, no GHG emissions from the bio manure from the plants grown specifically on the power plant's own area as its source for raw materials are considered.

The waste oil from the motor of the biogas engine generator must be considered as one of the waste materials leaving the power plant; it is changed at the regular maintenance due every 6000 hours of operation. The power plant in Tiszaszentimre changes oil every three months; in 2013, a total of 3135 l waste motor oil was removed from the site. The transportation of waste oil, considered hazardous waste, from the power plant to the waste-processing site 257 km away was performed in two steps by a 2.4-ton container truck.

The oil is fully recycled; therefore, we only need to calculate the GHG emissions during transportation, which equals a total of 561 kg CO_2e.

3.5. Determination of the carbon footprint of the biogas power plant

Considering the complete life cycle of the power plant, we determined the GHG emissions in each phase, and summing the emissions from each phase gave the carbon footprint of the power plant for 2013, which was 208173 kg CO_2e (Fig. 2).

Table 3. The GHG emissions related to the transportation of feedstock by motor vehicles in 2013

Type of feedstock	*Average transportation distance (km)*	*Transported quantity (t)*	*Total distance covered (km)*	*Total fuel consumption (l)*	*kg CO_2e/1 l diesel oil*	*kg CO_2e*
Sweet sorghum	5.5	2517	2585	689	2.6008	1793
Vetch	7.5	1105	2115	574		1492
Medick	12.0	1025	3096	798		2075
Hay	3.0	72	114	28		73
Energy grass	8.0	68	176	46		120
Organic manure	6.5	2202	3328	802		2086
Maize silage	76.0	2212	12894	3868		10060
Flotation sludge & biodiesel waste	114.6	2381	24532	9813		25521
Total:		**11584**	**48840**	**16618**		**43221**

The emissions related to the production of feedstock for the power plant constitute the most dominant part of the carbon footprint. Here, in addition to the relatively high energy requirement of the agricultural machinery, the increase in the N_2O release (closely related to artificial fertilizing) also played an important role.

The carbon footprint of the transportation of feedstock into the power plant is also high because in 2013, approximately 35% of the carried raw materials arrived from a distance of more than 90 km, which accounted for 81% of the total GHG emissions during transportation. The feedstock transportation is disadvantageous both economically and for the carbon footprint. The carbon footprint of the power plant's operation is linked to the operation of the service units. Although the energy requirement for the operation of the power plant is considerable, especially the cooling of the gas motor and the heating of the digesters, it is covered by the electrical and thermal energy generated in the factory itself. Therefore, because of the above-detailed reasons, this did not increase the carbon footprint of the power plant.

We did not calculate the GHG emissions of either the liquid or solid-phase manure waste residue of the power plant because the liquid-phase originated from the liquid manure of the pig farm and after digestion, it was returned to the farm, whereas the solid-phase was fed back into the digesters. The relatively small emission compared to other phases is related to the removal and transportation of the waste oil from the biogas engine generator.

In 2013, the power plant produced 4347.21 MWh of electric power and 4607.89 MWh of thermal energy. If this energy was produced by the regular Hungarian energy structure, the emissions would have been 3313387 kg CO_2e instead of the 208173 kg CO_2e released by the power plant. The electrical energy production from biogas is far from being carbon neutral. However, compared to the traditional energy-producing structure, its carbon footprint is much smaller at 6.3%.

We determined the size of the forest-clad area that would be able to bind the GHGs emitted by the power plant in Tiszaszentimre during energy production. The size of the forest capable of absorbing the annual GHG emissions and, coincidently, the carbon footprint of the power plant is 40 ha.

3.6. Determination of the annual energy balance of the biogas power plant

In 2013, the quantity of biogas produced in the power plant of Tiszaszentimre was 2095890 m^3. A total of 1 m^3 of biogas enabled the production of 2.198 kWh of thermal energy and 2.074 kWh of electric current.

Thus, the annual energy production, the sum of both thermal energy and electric current, of the power plant was 8955.10 MWh (Table 4). For the annual energy consumption, we considered the fuel consumptions related to the production of thermal energy and electric power, transportation, maintenance and business trips.

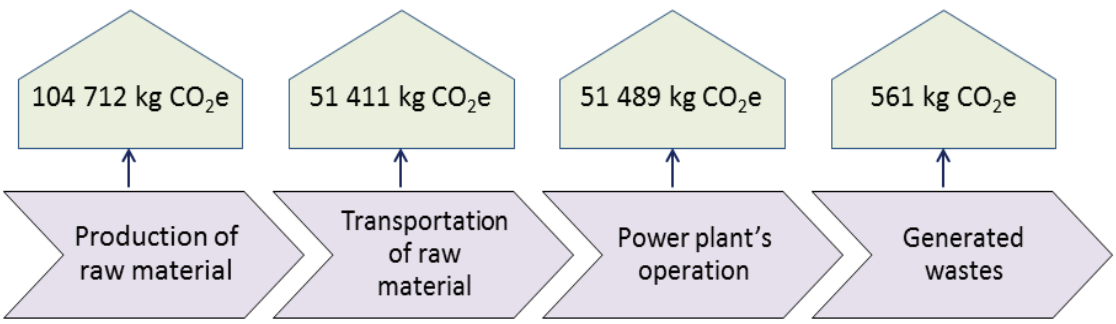

Fig. 2. The GHG emissions of the power plant complete life cycle, given in CO_2e

Thermal energy, which maintained the required temperature of the digesters, constituted about 56% of the 2720.26 MWh of total annual energy consumption. A unique feature of the biogas power plants is that this thermal energy is generated as a "byproduct" of their operation, and approximately one-third of it is returned to the digesters. Another special feature is that a significant part of the residual thermal energy often remains unexploited, or, at the very most, it is utilized for the winter heating of the livestock farm, as is the case at Tiszaszentimre. However, the majority is lost as thermal waste.

By calculating 11 kWh l^{-1} and 9 kWh l^{-1} as the heat values of diesel and petrol, respectively (Carbon Trust, 2013), the energy requirement of the utilized feedstock's production was 248.75 MWh and their transportation to site cost 182.79 MWh, whereas the operation and maintenance of the power plant required 33.31 MWh, also derived from fuel consumption.

Approximately 27% of the annual total energy consumption was from the power plant's own electric current use. In total, the operation-related energy consumption was approximately 30% of the energy produced by the power plant.

Table 4. The energy balance of the power plant in Tiszaszentimre in 2013

	Annual energy production (MWh)	***Annual energy consumption (MWh)***
Electric power	4347.21	734.81
Thermal energy	4607.89	1520.60
Fuels		464.85
Total:	**8955.10**	**2720.26**

4. Conclusions

In our study, we investigated the GHG emissions during the complete life cycle of the biogas production in the power plant in Tiszaszentimre. We established that the GHG emissions projected onto the complete life cycle were 208173 kg CO_2e in 2013.

The studied biogas power plant's production results in 93.7% less GHG emissions compared to the same quantity of energy generated by the regular Hungarian energy production structure. The most significant GHG emissions factor for the carbon footprint is the feedstock production. A disadvantageous feature is that several of the raw materials were transported into the power plant from distances greater than 90 km, which resulted in a four-fold increase in the carbon footprint compared to a transfer from a maximum 10-km distance.

The carbon footprint of the power plant could be reduced primarily by the optimization of the transport distances and, in the case of the produced feedstock, by minimizing the artificial fertilizing. The energy balance of the power plant is unequivocally positive.

The quantity of the annual produced energy is more than three times higher than the energy consumed during the complete life cycle of the biogas production. Some 56% of its own energy consumption is spent on heating the digesters. Presently, more than 50% of the produced thermal energy goes to waste. From an economical point of view, a key issue for the energy-producing sector is to find appropriate ways of effective utilization of the generated heat energy.

Acknowledgements

The present work is supported by the TÁMOP-4.2.2.A-11/1/KONV-2012-0041 project. The project is co-financed by the European Union and the European Social Fund.

References

Carbon Trust, (2013), Conversion factors (Energy and carbon conversions, 2013 update), On line at: http://www.carbontrust.com/media/18223/ctl153_conversion_factors.pdf.

EEA, (2012), Annual European Union greenhouse gas inventory 1990–2010 and inventory report, European Environment Agency, Copenhagen, Denmark, On line: http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2012.

Fazekas I., Szabó Gy., Szabó Sz., Paládi M., Szabó G., Buday T., Túri Z., Kerényi A., (2013), Biogas utilization and its environmental benefits in Hungary, *International Review of Applied Sciences and Engineering*, **4**, 129-136.

Gholikandi G.B., Jamshidi S., Hazrati H., (2014), Optimization of anaerobic baffled reactor (ABR) using artificial neural network in municipal wastewater treatment, *Environmental Engineering and Management Journal,* **13**, 95-104.

Grosz B.P., (2010), *Determining soil fluxes of GHGs (CO_2, N_2O, CH_4) in Hungarian agricultural and forest-clad areas* (in Hungarian), PhD thesis, ELTE, Budapest, Hungary.

Hermann B.G., Debeer L., De Wilde B., Blok K., Patel M.K., (2011), To compost or not to compost: Carbon and energy footprints of biodegradable materials' waste treatment, *Polymer Degradation and Stability,* **96**, 1159-1171.

Horváth L., Grosz B., Machonc A., Tuba Z., Nagy Z., Czóbel Sz., Balogh J., Péli E., Fóti Sz., Weidinger T., Pintér, K., Führer E., (2010), Estimation of nitrous oxide emission from Hungarian semi-arid sandy and loess grasslands; effect of soil parameters, grazing, irrigation and use of fertiliser, *Agriculture, Ecosystems and Environment,* **139**, 255-263.

Kebread E., Clark K., Wagner-Riddle C., France J., (2006), Methane and nitrous oxide emissions from Canadian Animal agriculture: a review, *Canadian Journal of Animal Science,* **86**, 135-158.

Lacour S., Chinese T., Alkadee D., Perilhon C., Descombes G., (2012), Energy and environmental balance of biogas for dual-fuel mobile applications, *Renewable and Sustainable Energy Reviews,* **16**, 1745-1753.

Liu X., Gao X., Wang W., Zheng L., Zhou Y., Sun Y., (2012), Pilot-scale anaerobic co-digestion of municipal biomass waste: Focusing on biogas production and GHG reduction, *Renewable Energy*, **44**, 463-468.

Massé D.I., Patni N.K., Droste R.L., Kennedy K.J., (1996), Operation strategies for psychrophilic anaerobic digestion of swine manure slurry in sequencing batch reactors, *Canadian Journal of Civil Engineering,* **23**, 1285-1294.

Massé D.I., Talbot G., Gilbert Y., (2011), On farm biogas production: A method to reduce GHG emissions and develop more sustainable livestock operations, *Animal Feed Science and Technology*, **166–167**, 436-445.

National Energy Strategy 2030, (2012), Mininstry of National Development, (in Hungarian), Budapest, Hungary.

PAS 2050, (2011), *Specification for the assessment of the life cycle greenhouse gas emissions of goods and services*, BSI London, United Kingdom, On line at: http://shop.bsigroup.com/upload/Shop/Download/PAS/PAS2050.pdf.

Stockholm Environment Institute, (2002), *A material flow analysis and ecological footprint of York,* On line at: http://www.sei-international.org/mediamanager/documents/Publications/Future/ Material_Flow_Analysis_york.pdf.

Uusitalo V., Havukainen J., Manninen K., Höhn J., Lehtonen E., Rasi S., Soukka R., Horttanainen M. (2014), Carbon footprint of selected biomass to biogas production chains and GHG reduction potential in transportation use, *Renewable Energy*, **66**, 90-98.