Fuchsz Máté

PhD thesis

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Economical and environmental impact analyses of biogas upgrade and utilization to natural gas quality biomethane

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Doctoral School

Name: Doctoral School of Environmental Sciences

Art of science: Environmental sciences

Head: Csákiné Dr. Michéli Erika
Head of Chair, professor
Doctor of the Hungarian Academy of Sciences
Szent István University, Faculty of Agricultural and Environmental Sciences
Institute of Environmental Sciences
Chair of Soil Science and Agricultural Chemistry

Supervisor: Dr. Kohlhéb Norbert
Associate professor
Szent István University, Faculty of Agricultural and Environmental Sciences
Institute of Environmental Sciences
Chair of Natural Protection and Landscape Management

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Signature of the Head of Doctoral School | Signature of the Supervisor

1 Background and Goals

Because of the very diverse and well-stored raw material base of the anaerobic digestion, biogas is a renewable energy source that is independent of external environmental elements (sun, wind) and can be used as a source of base load electricity or natural gas-quality biomethane production. Due to the large cost intensity of the biogas projects (construction and operation) without environmental incentives or subsidies are these investments not always viable. Due to the low feed-in electricity prices from biogas in Hungary the anaerobic digestion as a renewable energy is not widespread.

In 2011, in the European Union 35,856.4 GWh of electricity was produced from biogas (EurObserv'ER, 2012), in Hungary at the same time period, agricultural biogas plants produced only 92 GWh of electricity, compared to 2010 more than 70% growth (Magyar Energia Hivatal, 2012). In 2012, a further increase was expected because new anaerobic digestion plants were started. In Hungary the biogas based electricity production was only 0.25% of the 2011 total domestic electricity consumption (Központi Statisztikai Hivatal, 2016; Magyar Energia Hivatal, 2012), while in Germany more than 3% (EurObserv'ER, 2012). It can be seen that the domestic production of renewable energy – not only biogas use - is behind the Western European trends. In Hungary, several biogas plant was built to process agricultural by-products (slurry, dung), so unlike the European trends, AD plants used not only produced agricultural raw materials, like silage . In my opinion, it is socially preferable (low support in the electricity price) compared to the purely silage based electricity generation.

To increase the social acceptance of renewable energy sources and greater use, an often cited advantage of this type of energy production is the lack of negative effects on the environment. One of the main aim of this work was to develop a financial calculation and preferable subsidy prediction model, based on a modular designed biogas plant model system, where the environmental impacts of the biogas production, based on different agricultural by-products were taken into account. Modern life cycle analytical software and databases were used to achieve environmental impact assessment calculations, using the results, to compare the environmental effects of the natural gas quality biogas production to the use of natural gas. These environmental impacts have been calculated on the basis of aggregated and weighted indicators, so it was possible to predict, which types of substrate mixes used for the biogas production cause the least possible environmental impact.

Reducing the environmental impact of the energy production based on biogas against natural gas was possible in many cases. The partial substitution of fossil fuels among biogas is technically possible, the question is, at what cost? Primarily answers my work this question. I wanted to examine a variety of different materials-based (energy crops and agricultural by-products) biomethane production cost, taking into account the production cost reduction effects caused by the biomethane production of different size ranges. Important factors determining the final product price were also investigated, such as non-refundable investment subsidies or different raw materials and costs used in the production of biogas. In addition, aggregating the data of the production cost predictions, a potential biomethane feed-in tariff system was developed, which can be a guide, at what price can be produced biomethane economically under Hungarian conditions.

2 Materials and Methods

In my work the upgrade of the biogas to natural gas quality biomethane was examined specially under Hungarian conditions. For accurate results construction and operation data of Hungarian agricultural raw material based anaerobic digestion plant investments were used (Első Magyar Biogáz Kft., 2013) extended with own data collection. Using the FGSZ Zrt. (Natural Gas Transport Co.) gas network data (FGSZ Zrt., 2015), based on the possible summer minimum natural gas input to the local distribution network over the transmission points of the Hungarian natural gas transport network, the potential biogas purification capacities were determined. In my work I studied the financial feasibility and environmental effects of several different biogas production capacities based on different amounts of agricultural by-products. The main difference between the various models of plants was the raw material composition used in the anaerobic digestion: only energy crop based biogas production was compared with animal by-products (manure, slurry) and energy crop substrate mixes. The animal by-products have a total energy production of 10, 20 and 30% in the examined AD plant models.

A key element in the economic calculations is the investment costs. To determine the construction costs of a biogas plant it is necessary to calculate a list of the machines, buildings and other raw materials used during the erection of the AD plant. This list can be used to determine the material and energy flows of the construction, later the operational parameters. These data can be used in the life cycle assessment and in the feasibility calculations. The environmental impact assessment was calculated with the Gabi 6.0 life-cycle analysis software with the ecoinvent 3.0 database. For the economic calculations Microsoft Excel spreadsheet software was used. In this study 48 biogas plants with different operating scenarios (192 different versions) were modeled. I developed a biomethane feed in tariff system (HUF/MJ) for different hourly biogas purification capacities with or without investment subsidies. These feed in tariffs were calculated based on necessary prices per MJ energy to reach a positive net present value. The data were merged together and than in a back test for all 192 variations a 20 year long cash flow based feasibility were produced. These results could show what type of substrate mixes are feasible with the earlier determined feed in tariff system.

3 Results

Thesis 1: The bigger the biogas purification capacity of an anaerobic digestion plant, the better is the energy efficiency, regarding the production of 1 MJ biomethane, less energy is needed, without the effect of the raw materials used in the fermentation.

According to the life cycle analysis results, it can be said that to produce 1 MJ of biomethane with natural gas quality a total of 1.266 to 1.353 MJ raw biogas, an average of 1.295 MJ is necessary.

1. Table Raw biogas energy consumption to produce 1 MJ of biomethane (MJ/MJ)

	Energy consumption biomethane production (TJ/a)	Energy content of biomethane (TJ - 20 years)	Energy consumption of biomethane production (MJ/MJ)
BGA300 0%	1.118	881	1,269
BGA300 10%	1.187	889	1,335
BGA300 20%	1.192	895	1,332
BGA300 30%	1.220	902	1,353
BGA400 0%	1.512	1.175	1,287
BGA400 10%	1.531	1.184	1,293
BGA400 20%	1.538	1.193	1,289
BGA400 30%	1.581	1.202	1,315
BGA500 0%	1.874	1.469	1,276
BGA500 10%	1.874	1.481	1,266
BGA500 20%	1.940	1.492	1,301
BGA500 30%	1.986	1.503	1,322
BGA750 0%	2.806	2.203	1,273
BGA750 10%	2.844	2.221	1,281
BGA750 20%	2.832	2.237	1,266
BGA750 30%	2.869	2.254	1,273

The average energy efficiency or own energy consumption of biogas plants regarding the raw biogas energy content (brutto energy) to the produced biomethane energy content (net energy) is 28.41%. The highest average own energy use has a maximum of 30.9%, while the lowest value of the own energy consumption of a 750 Nm^3/h-capacity model plant has 26.29%. The average own energy consumption regarding the biogas upgrade capacity, compared the smallest and biggest examined model AD plants (in this case 300 and 750 Nm^3/h of biogas cleaning capacity) decreased by 15%.

Depending on the processed raw material composition can be said that the examined four different plant sizes in all but one case, the increasing amount of agricultural by-products has also increased the overall own energy consumption of the biogas plants. This increase is because of the low energy density of the processed manure, which leads to higher electrical and thermal energy (biogas as fuel) consumption resulted in an equal biogas production. The most energy efficient AD plants processed a mixture of manure and energy crops.

Thesis 2: The 100 year global warming potential (GWP) of biomethane production expressed in CO_2 equivalents g/MJ_{Hs} (CML2001 - Apr. 2015) has a lower environmental impact than natural gas.

The literature of the natural gas production life cycle inventories have a very wide range of 56-114 g CO_2 eq / MJ Hs environmental footprint (Burnham et al 2012; Howarth et al, 2011; Hultman et al, 2011; Jiang et... al, 2011;. and Stamford Azapagic, 2014; Stephenson et al, 2011;. Clavia and Weber, 2012).

According to my LCA calculations the emissions of the biomethane production are between -20.78 to 68.16 g CO_2 eq / MJ Hs. The processed raw material composition has a positive effect on the reduction of the CO_2 emissions: the more agricultural by-products are used, the lower is the GWP value. This is because of the fossile energy used for the energy crop production and the higher energy content of the raw biogas produced from animal by-products.

If we consider the amount of CO_2 emitted into the environment during the burning of natural gas - 54.16 g/MJ (own calculations) -, it shows that the production of biomethane in the most cases are more environmentally friendly than the use of exported natural gas.

2. Table The global warming potential of biomethane production, GWP100 of CO_2 equivalent (CML2001 - Apr. 2015) expressed in g / MJ in Hs

AD plant size	GWP_{100} CO_2 equivalent g/MJ_{Hs}
BGA300 0%	26,37
BGA300 10%	27,34
BGA300 20%	23,23
BGA300 30%	19,63
BGA400 0%	37,25
BGA400 10%	32,53
BGA400 20%	26,54
BGA400 30%	-20,78
BGA500 0%	45,58
BGA500 10%	36,80
BGA500 20%	35,07
BGA500 30%	30,88
BGA750 0%	68,16
BGA750 10%	59,22
BGA750 20%	46,13
BGA750 30%	37,75

The production of biomethane from a substrate mix of manure, slurry and energy crops, expressed as CO_2 equivalent, shows that these are environmentally better, than the only energy crop based biomethane production, such as the use of agricultural waste and other by-product sources in AD plants should be supported even with subsidies.

Thesis 3: The environmental potential of the biomethane production expressed in acidification and eutrophication potential have lower values, if the processed substrate mix contains also agricultural by-products than only energy crops.

Regarding the acidification potential, AD plants processing a substrate mixture of animal by-products (manure, slurry) and energy crops have a higher environmental impact, than only energy crop fermentation plants. This is due to the fact that even the crop production, because of the diesel fuel use, has a very high sulfur-dioxide equivalent emission, while the larger amount of animal by products were processed in these AD plants, mainly the spreading the higher amount of digestate onto the fields occurs a higher acidification potential due to its high emissions into the air.

3. Table Acidification and eutrophication potential of biomethane production

AD plant size	SO_2-equivalent g/MJ$_{Hs}$	PO_4-equivalent g/MJ$_{Hs}$
BGA300 0%	0,144	0,096
BGA300 10%	0,417	0,171
BGA300 20%	0,432	0,174
BGA300 30%	0,564	0,207
BGA400 0%	0,148	0,101
BGA400 10%	0,289	0,133
BGA400 20%	0,425	0,161
BGA400 30%	0,423	0,155
BGA500 0%	0,147	0,099
BGA500 10%	0,306	0,130
BGA500 20%	0,416	0,163
BGA500 30%	0,517	0,190
BGA750 0%	0,148	0,098
BGA750 10%	0,293	0,131
BGA750 20%	0,391	0,148
BGA750 30%	0,524	0,179

The eutrophication potential shows even a lower value for only energy crop fermentation AD plants. It is caused due to the environmental load of the higher amount of digestate and its nitrogen content produced by animal by-product fermentation plants. Higher energy content in the main substrate (like energy crops), cause a lower amount of digestate must be spread onto the fields. This cause an overall lower nitrogen load calculated per MJ produced energy in the biogas.

For the acidification potential and eutrophication potential, we can say that 1 MJ of energy has a lower environmental impcat, if only energy crops are used in the AD plants.

Thesis 4: There is a correlation between the daily amount of processed substrates (tons/day) and the investment cost of the complete AD plant and the upgrade unit, so a formula can be used to estimate the size of the investment costs.

Knowing the investment cost for a sufficiently large number of model biogas plants, it is possible to create an investment cost prediction prediction model. There is a correlation between investment costs of a biogas plant and the amount of the daily substrates, expressed in tons/day (Figure 1).

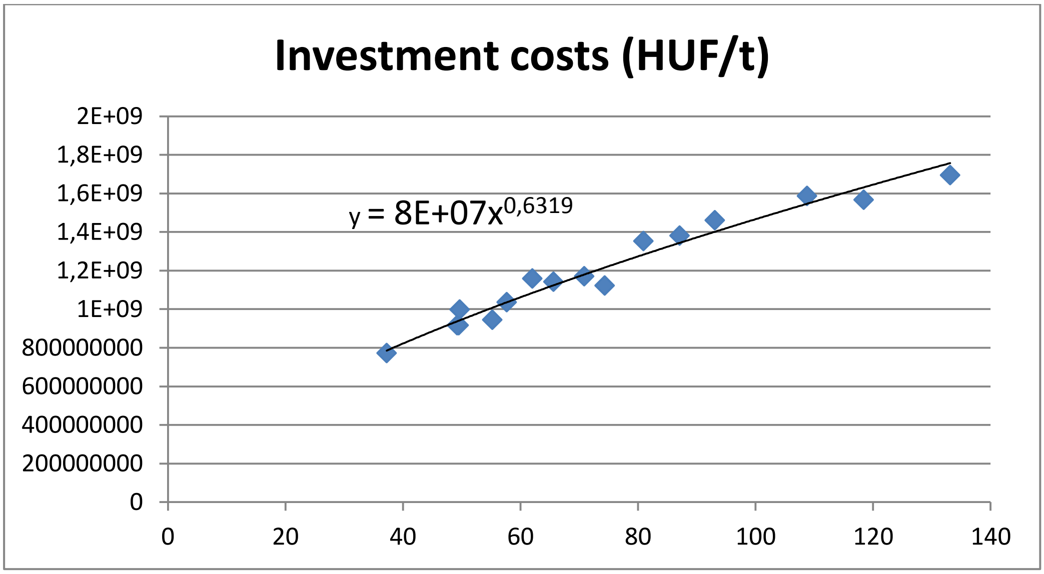

Figure 1. The correlation between the daily quantity of processed raw materials (t) and the investment costs (HUF)

If the daily amount of the processed material does not contains more than 30% animal by-products and the daily substrate ratio minimum is more than 37 tons, then according to the first equation formula can be estimated the investment cost of a biomethane production plant ("x" is the daily amount of substrates).

$$y = (8 * 10^7) * \ x^{0,6319}$$

Equation 1 Biomethane production plants expected investment cost (HUF)

Thesis 5: Based on the data were processed in the feasibility calculations of the model biogas plants, it was possible to create a biomethane feed in tariff system according to the biogas upgrading capacity, substrate composition and the rate of the non refundable investment subsidy.

In my work the economic indicators of 16 different biogas production capacities and substrate mix were examined. A total of 192 evaluation of economic efficiency were carried out. The most important parameters which have been modified during the calculations are the percentiga of the discount rate, the purchase price of the processed raw materials and the use of non-refundable investment subsidies. As a result, i created a biomethane feed-in tariff system in four different feed in capacity ranges, with two different realization of the investments: with or without investment subsidies.

The novel feed-in tariff system differs from the current Hungarian renewable electricity feed-in system, because the biomethane price differs regarding the production capacities. This method makes feasible the small scale biogas plants, based also on agricultural by-products, not only the big biogas production units.

4. Table Average cost of biomethane in case of different biogas upgrading capacities without investment subsidies

Upgrading capacity Nm^3/h	4,91% IRR	8,78% IRR	Base tariff HUF/MJ	Size bonus HUF/MJ	Price HUF/MJ
0-300	4,733	4,481	3,777	0,830	4,607
301-400	4,435	4,205	3,777	0,543	4,320
401-500	4,238	4,026	3,777	0,355	4,132
501-750	3,866	3,689	3,777	0,000	3,777

Table 4. shows a possible biomethane feed-in tariff system based on my economic calculations, without non-refundable investment grants.

5. Table Average cost of biomethane in case of different biogas upgrading capacities with investment subsidies

Upgrading capacity Nm^3/h	4,64% IRR	8,78% IRR	Base tariff HUF/MJ	Size bonus HUF/MJ	Price HUF/MJ
0-300	4,053	3,913	3,333	0,650	3,983
301-400	3,810	3,684	3,333	0,414	3,747
401-500	3,661	3,545	3,333	0,270	3,603
501-750	3,382	3,285	3,333	0,000	3,333

Table 5. shows a possible biomethane feed-in tariff system based on my economic calculations, with non-refundable investment grants. The price difference between the two types of biomethane feed-in tariff system is not

relatively high (13.3% -15.6%), despite the fact that the investment was calculated with a 50% non refundable investment subsidy. This shows, that the current regulatory system in Hungary, based on the investment subsidies, does not support significant reduction of the energy, produced from biogas.

Using the biomethane feed-in tariff system in Table 4, the internal rate of returns were calculated, showed in Table 6. These results show that biomethane production investments are only feasible, if the energy crop production costs are as low as possible. To avoid only energy crop based biomethane production, a minimum of 10% agricultural by-products regulation is preferable.

6. Table Internal rate of return (IRR) of the biomethane production, based on the calculated biomethane feed-in tariff system, in case of non refundable investment subsidy

Upgrading capacity	Substrate costs (HUF/t)	Agricultural by-product (manure) in the total energy production (%)			
		0%	10%	20%	30%
300 Nm^3/h	10.000	-6,32%	-7,72%	-2,16%	0,80%
	7.500	7,89%	3,93%	7,15%	8,52%
	5.000	20,51%	13,69%	15,80%	15,95%
400 Nm^3/h	10.000	-12,99%	-6,44%	-2,84%	0,48%
	7.500	4,25%	6,62%	7,32%	8,87%
	5.000	17,35%	18,04%	16,66%	16,91%
500 Nm^3/h	10.000	-15,93%	-5,23%	-5,06%	-0,95%
	7.500	3,91%	9,34%	6,08%	8,07%
	5.000	18,06%	22,57%	15,95%	16,59%
750 Nm^3/h	10.000	0,00%	-15,38%	-4,25%	0,04%
	7.500	2,06%	4,14%	9,64%	10,93%
	5.000	18,98%	18,24%	22,40%	21,42%

Thesis 6: Under market conditions it is possible to produce biomethane below 5 HUF/MJ Hs, without non-refundable investment grants.

According to Klinski in 2014 the biomethane production price within the 200-700 Nm3/h biogas purification capacity was at 7.8-8.9 €cents/kWh. This is from 6.71 to 7.66 HUF/MJ Hs. I expected at least 20% biomethane production cost reductions using cheap agricultural by-products for the biogas production. My calculations were made by two different discount rate, one following the WACC (Weighted Average Cost of Capital) model - taking into account the principle of market interest rates - at 4.91%, while the other was according to the 74/2009. Annex 4 1.1.4.1 Regulation (XII. 7) of the Hungarian National Energy Authority (KHEM) at 8.78% - this is the so called accepted maximum internal rate of return of an energy company selling products to the domestic costumers in Hungary. The results of the calculations are in Table 7 and Table 8.

7. Table Biomethane production cost price (HUF/MJ Hs) without a non-refundable investment grant, at 4.91% IRR

Upgrading capacity	Substrate costs (HUF/t)	Agricultural by-product (manure) in the total energy production (%)			
		0%	10%	20%	30%
300 Nm^3/h	10.000	5,168	5,333	5,045	4,877
	7.500	4,437	4,671	4,458	4,359
	5.000	3,706	4,010	3,870	3,842
400 Nm^3/h	10.000	5,087	4,882	4,759	4,586
	7.500	4,356	4,224	4,172	4,070
	5.000	3,625	3,565	3,585	3,554
500 Nm^3/h	10.000	4,913	4,573	4,652	4,460
	7.500	4,182	3,914	4,064	3,944
	5.000	3,451	3,255	3,477	3,428
750 Nm^3/h	10.000	4,626	4,471	4,149	4,000
	7.500	3,895	3,812	3,563	3,484
	5.000	3,164	3,153	2,976	2,968

8. Table Biomethane production cost price (HUF/MJ Hs) without a non-refundable investment grant, at 8.78% IRR

Upgrading capacity	Substrate costs (HUF/t)	Agricultural by-product (manure) in the total energy production (%)			
		0%	10%	20%	30%
300 Nm^3/h	10.000	5,389	5,594	5,304	5,142
	7.500	4,658	4,932	4,717	4,625
	5.000	3,927	4,271	4,129	4,108
400 Nm^3/h	10.000	5,301	5,103	4,999	4,831
	7.500	4,570	4,444	4,411	4,315
	5.000	3,839	3,785	3,824	3,798
500 Nm^3/h	10.000	5,111	4,763	4,878	4,690
	7.500	4,380	4,104	4,291	4,175
	5.000	3,649	3,445	3,704	3,659
750 Nm^3/h	10.000	4,793	4,650	4,324	4,187
	7.500	4,062	3,991	3,738	3,671
	5.000	3,331	3,332	3,151	3,155

It is good to see, that in most cases under Hungarian production circumstances, it is possible to produce the biomethane under the literature values, without investment support, thanks to cheap agricultural by-products.

Thesis 7: I calculated the total retail price growth rate of natural gas, in the case if 5% of the domestic natural gas consumption is replaced by biomethane.

I made calculations to predict the various social burden, if 5% of the domestic natural consumption is replaced by biomethane. According to the statistical data, the total Hungarian residential natural gas consumption in 2014 was 62,979,192.53 GJ of energy, approx. 1,799 billion m^3 (Magyar Energetikai és Közmű-szabályozási Hivatal, 2015b). In case of 1.696 HUF/MJ natural gas prices and a 5% biomethane share, calculated according to the production cost of the largest biogas upgrading capacities in this study, with non-refundable investment subsidies, with a biomethane cost of 3.333 HUF/MJ, the price of residential natural gas raises 4.83% - respectively, 1.778 HUF/MJ, see Table 9.

On the same scale of natural gas replacement, with the calculated biomethane price of without non-refundable investment subsidies, the calculated retail price of natural gas raises 6.14% to 1.800 HUF/MJ.

9. Table Retail natural gas price changes at 5% replacement rate with biomethane, with and without investment subsidies

	Price (HUF/MJ)	Price (HUF/MJ)
Biomethane	3,333	3,777
Natural gas	1,696	1,696
Average natural gas (Ft/MJ)	1,77785	1,80005
Difference (Ft/MJ)	0,08185	0,10405
Difference(%)	4,83%	6,14%

It should be noted that under the current Hungarian legislation of the retail gas price calculation, only due to the USD/HUF exchange rate changes can be a 5-10% change in the retail price (Magyar Energetikai és Közmű-szabályozási Hivatal, 2015a). The price of heating oil and diesel fuel (U.S. Energy Information Administration, 2015a, 2015b), respectively. Using the import natural gas price prediction model of the Hungarian authorities, the quarterly import natural gas price based on a HUF/USD exchanges rates (260 HUF/USD) in September 2015, a natural gas price of 2.668 HUF/MJ, at 280 HUF/USD exchange rate a price of 2.873 HUF/MJ import natural gas could be determined. This is stipulated by the law at 2.28272 HUF/MJ, shows an increase of 17 or 26%.

If the maximum of 750 Nm^3/h of biomethane production capacity of biogas plants is considered, more than 16 plants would be able to cover the Hungarian residential natural gas consumption of 5%.

4 Conclusions and Recommendations

The number of the agricultural raw materials processing biogas plants in Germany increased to 7874 in 2012, while the built-in electricity output was 3384 MWel (Fachverband Biogas eV, 2012). Meanwhile in Hungary there were only 31 agricultural biogas plants and the installed capacity was 28,46 MWel (Hungarian Energy Office, 2012). In 2012 and 2013, significant new biogas production capacity was not established in Hungary. The installed capacity related to 1000 inhabitant in Hungary is 2,84 kW, while the same value in Germany´s 41,39 kW.

The main aim of the thesis was to develop an objective-based quantitative model to calculate the environmental effects of the biogas production. The results will help to compare the environmental effects of different biogas production capacities, based on different raw materials, to fossil fuel based electricity power plants or to the natural gas production and delivery. Based on these environmental effects, it is possible to choose which biogas utilization should be supported, based on environmental policies.

For the production of 1 MJ biomethane was used 1.266 to 1.353 MJ raw biogas. By comparison, in the case of electricity generating biogas plants, this value is 9.6% and 14.05% (Fuchsz and Kohlheb, 2014). The results show that the lower energy density (livestock manure and slurry) processing AD plants regarding energy efficiency work worse than higher energy density energy crop utilization biogas plants. This drawback is compensated through the large biogas upgrading capacity, however the positive effect of a bigger AD plant regarding energy efficiency can not be observed. The actual energy efficiency difference between the different substrate based biogas plants is so marginal that a subsidy for all AD plants is reasonable.

Based on the results shown, the biomethane production results a very high carbon dioxide emission, -20.78 to 68.16 g CO_2 eq / MJHs. It is worth to mention that the CO_2 eq value per FU is lower if the biogas plant uses more animal by-products and not only energy crops. Based on the values of the natural gas production, transport and burning of it, the CO_2 emissions of the fossil gas are higher, than the locally produced biomethane emissions.

Examining a total of 6 environmental impact parameters it is clearly demonstrated that with the exception of the global warming potential (GWP100 CO_2 equivalent) the environmental impact of the animal by-product processing biogas plants are worse compared to the only energy crop processing AD plants. It is important to mention, that the main emission source is the digestate, especially the emissions during and after spreading the digestate on the arable land. These results illustrate the importance of proper manure / digestate application technique, since this operation causes the greatest emissions during the production of biogas. The use of animal by-products in the biogas production can argue that the manure itself, if it is not used in the biogas plants, also cause environmental load and such as at least decreased methane emissions can be expected during the anaerobic utilization.

The economic valuations of the AD plants were made using the calculation of the net present value (NPV) at cash flow basis. The suggestions to a biomethane feed-in tariff system were calculated using the NPV value of 0 of the observed AD plants. It is interesting that a higher discount rate (8.78%), in most cases, regardless of the down payment or the size of the investment subsidy already in the first or second year provided positive yearly cash-flows. In the case of a low discount rate (4.64% and 4.91%) levels for each tested investment period of 6-8 years resulted negative cash flows in the calculations. The biomethane feed-in prices were calculated with three discount rate (4.64%, 4.91% and 8.78%), with and without non-refundable investment subsidy. As a result, a total of 196 variants were calculated and from these values a potential biomethane feed-in price system was created.

However, in almost all cases if the energy crop prices are really low (5000 HUF/t) the IRR rates of all AD plants are nearly the same, the substrate mixture is unimportant – the use of low cost animal by-products can not cause an additional economical benefit. Therefore, in case of considering due to environmental policy objectives to support the development of a biomethane production system it is advised to exclude from the feed-in system the only energy crop processing AD plants and at least 10% of manure and other industrial, agricultural by-products should be processed regarding the amount of the total energy production.

Due to the life-cycle analysis there are other results of this study: the most of the emissions of the biogas production are from the digestate spreading, it is important to develop technologies that can reduce these emissions effectively. The biogas plant's total energy consumption relative to the end product´s net energy content during the biomethane production is higher than using the biogas in a CHP producing electricity and heat. Thus, when determining the environmental objectives, this type of energy production methods should be used in preference to bio-methane production.

Overall, we can say that taking into account the environmental impacts of biomethane production, the higher energy prices of the biomethane can not be backed up because of the positive effects on the environment. If it is important that the society uses more renewable energy, a small part (5%) of the locally used natural gas amount can be replaced by biomethane without high increase of the natural gas consumer prices. A larger proportion of biomethane in the natural gas is not recommended due to the lack of highly positive impact on the environment.

5 List of publications

1. ***Peer-reviewed full text scientific publications published in scientific journals (accepted for publication)***

1.1. Foreign language, international journals with impact factor

FUCHSZ M. – KOHLHEB N. (2014): Comparison of the environmental effects of manure- and crop-based agricultural biogas plants using life cycle analysis. *In Journal of Cleaner Production*. DOI: 10.1016/j.jclepro.2014.08.058.

1.2. Foreign language, international journals without impact factor

KOVÁCS A. - FUCHSZ M. (2011): Ungarn – Land des unbenutzten Potenzials. *Biogas Journal*, ISSN 1619-8913, XIV. évf. (2. sz.)

1.6. Hungarian, domestic journals without impact factors

FUCHSZ M. (2006): Német biogázüzemek gazdaságossági vizsgálata magyar árviszonyok között. *Gazdálkodás*, 50. évf. (5. sz.) 30. old.

2. ***Full text professional publications, studies published in non scientific professional journals (accepted for publication)***

2.1. Publications in non scientific professional journals

KOVÁCS A. – FUCHSZ M. (2006): Vitaindító a bioüzemanyagokról I. *Bioenergia*, I. évf. (2. sz.) p. 2-7.

KOVÁCS A. - FUCHSZ M. (2007): Vitaindító a bioüzemanyagokról II. *Bioenergia*, 2 (1) p. 2-4.

FUCHSZ M. (2008): Biogáz előállítás száraz fermentációval. *Bioenergia*, 3 (1) p. 11-14.

FUCHSZ M. – KOHLHEB N. – PORTELEKI A. (2008): A megújuló energiatermelés tervezési keretei és módszerei környezetgazdálkodási szemszögből I. *Bioenergia*, 3 (2) p. 19-20.

FUCHSZ M. – KOHLHEB N. – PORTELEKI A. (2008): A megújuló energiatermelés tervezési keretei és módszerei környezetgazdálkodási szemszögből II. *Bioenergia*, 3 (3) p. 13-15.

FUCHSZ M. (2008): A németországi EEG biogázra vonatkozó szabályozásának összehasonlítása a magyarországi rendeletekkel I. *Bioenergia*, 3 (3) p. 32-35.

FUCHSZ M. (2008): A németországi EEG biogázra vonatkozó szabályozásának összehasonlítása a magyarországi rendeletekkel II. *Bioenergia*, 3 (4) p. 26-32.

FUCHSZ M. (2008): Biogáz a földgázhálózatban - A földgáz minőségre tisztított biogáz (biometán) hasznosítási lehetőségei. *Hulladéksors*, 9 (11) p. 48-49.

KOVÁCS A. – FUCHSZ M. (2009): A biogázipar helyzete és perspektívái Magyarországon. Biogáz előállítás és felhasználás. Műszaki kiadványok 183. szám. p. 9-10.

KOVÁCS A. – FUCHSZ M. – HIDEG P. (2009): Biogáztisztítási technológiák. Biogáz előállítás és felhasználás. Műszaki kiadványok 183. szám. p. 53-55.

KOVÁCS A. - FUCHSZ M. (2010): Első lépések egy biogáz üzem tervezése során. Agro Napló Országos mezőgazdasági szakfolyóirat, XIV. évf. (1. sz.)

FUCHSZ M. – KOHLHEB N. (2013): Mezőgazdasági biogázüzemek környezeti hatásainak összehasonlítása életcikluselemzéssel. Magyar Energetika, XX. évf. (3. sz.) p. 44-48.

2.2. Publications in promotional journals

FUCHSZ M. (2006): Zöld utat a biogáznak Németországban. *Az Európai Unió agrárgazdasága*, ISSN 1416-6194, 11. évf. (5. sz.) p. 27.

3. ***Peer-reviewed books/notes (part) (printed or electronic media), promotional book***

3.8. Promotional book

FUCHSZ M. (2006): Energia? Természetesen. Budapest: Magyar Biogáz Egyesület. p. 20.

FUCHSZ M. – BAGI Z. (2009): Biometán. Budapest: Magyar Biogáz Egyesület. p. 42.

SOMOSNÉ NAGY A. (Szerk.) (2010): A biogáz szerepe a vidék gazdaságban. s.l.: Bács-Kiskun Megyei Agrárkamara, p. 55.

4. ***Congress publications (printed or electronic media, only with ISBN, ISSN number), or other validated publications***

4.2. Full-text publications, occasional (non-periodical publications), congress publication, foreign language, peer-reviewed

FUCHSZ M. (2007): Economic comparison of biogas plants under Hungarian price conditions. 15th European Biomass Conference and Exhibition. Berlin - Germany, ICC Berlin, 2007. május 7-11. Proceedings DVD ISBN 978-88-89407-59-X ISBN 3-936338-21-3

FUCHSZ M. (2008): Economic comparison of biogas plants under the new Hungarian price conditions. Multifunctional agriculture. Hódmezővásárhely – Hungary, 2008. április 24. ISSN 1788-5345

BAUM, S., NACHTMANN, K., HOFMANN, J., PAETZOLD, J., FALK, O., FUCHSZ, M. (2015). Pressureless and cryogenic conversion of biogas into liquefied biomethane and solid carbon dioxide. In: IBBK, Conference proceedings Progress in Biomethane Mobility, ISBN 978-3-940706-08-9, Schwäbisch Hall, Germany.

4.3. Full-text publications, occasional (non-periodical publications), congress publication, hungarian language, peer-reviewed

FUCHSZ M. (2006): Biogázüzemek gazdaságossági vizsgálata magyar árviszonyok között. Az alternatív energiaforrások hasznosításának gazdasági kérdései, Nemzetközi Tudományos Konferencia, Sopron, CD-kiadvány (ISBN 978-963-9364-82-0), 14 p.

4.4. One-sided foreign or hungarian language summary based on oral presentation or poster presentation, edited scientific journal or special edition

BAGI Z. - KOVÁCS A. - FUCHSZ M. – KOVÁCS K. L. (2008): Present state, experiences and development of biogas plants in hungarian agriculture. Klimatizacija, grejanje, hladjenje i ventilacija objekata u poljoprivredi. Becej – Szerbia, 2008. október 4. Biblid: 0354-2029 (2008)18: 5. p. 44-46.

5. Congress publications (printed or electronic media, without ISBN, ISSN number), or other non validated publications

5.1. Full-text publications, foreign language

KOHLHEB N. – FUCHSZ M. (2009): Bioenergy production for farm income diversification in Hungary. FAO Central Asia Agricultural and Rural Development Policy Forum, October 26-28, 2009, Ankara, Turkey

9. Other publications or studies

KAZAI et al. (2007): A biomassza energetikai alkalmazásának jövője, aktuális problémái

BAGI Z. – FUCHSZ M. (2010): SEBE – Sustainable and Innovative European Biogas Environment, Work package 4: Technology framework and research – Hungary. 2010.

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