IEA Bioenergy

Task 38

Greenhouse Gas Balances of Biomass and Bioenergy Systems

Greenhouse Gas Benefits of a Biogas Plant in Austria

Summary

The goal of this study was to quantify the greenhouse gas (GHG) and energy impacts of a biogas plant with closed storage of digested materials. The plant of "NegH Biostrom KEG" in Paldau in the state of Styria, Austria, was chosen because this plant uses closed storage facilities to store the material after removal from the digester. Feedstocks used are primarily crops, secondarily grass silage and animal manure. The study used life-cycle assessment (LCA) to determine the GHG and efficiencies of energy output of biogas plants, with and without closed storage.

Methane (CH_4) produced in the digesters and storage is used to produce 4 GWh electric energy and 7 GWh heat per year. Only 17 % of the heat is currently used. The total biogas production and methane concentration from the closed storage were measured for half a year and the annual production of 15.6 tons of CH_4 per year was estimated. A theoretical case was considered of a biogas plant using the same feedstocks but storing digested biomass in an open storage. It was assumed that open storage would result in CH_4 emissions to the atmosphere equal to those produced in the closed storage.

Carbon dioxide (CO_2), CH_4 and nitrous oxide (N_2O) emissions of the two biogas plants were compared to reference system I which delivered equivalent amounts of electricity and heat. The study also looked at CO_2-equivalent (CO_2-eq) emissions. In reference system electricity is assumed to be produced from a natural gas plant, and heat from oil and wood.

LCA results showed that GHG emissions of a biogas plant with open storage are 29 % higher than for one with a closed storage and approximately 2 % less energy is produced. The biogas plant with closed storage results in 1 ktons of CO_2-eq per year, 44 % less GHG emissions than the reference system I. The mitigation benefit is reduced to 27 % with open storage. Direct land use changes (changes in land use and related soil carbon changes on the site used for feedstock production) sequester 48 tons of CO_2 per year, reducing total GHG emissions in the Paldau biogas plant by 3.4 %.

For each ton of biomass feedstock used in the biogas plant with the closed storage, 292 grams of CO_2-eq are avoided. The biogas plant with an open storage, however, might avoid only 183 grams of CO_2-eq.

A sensitivity analysis showed that if even relatively small amounts of CH_4 (e.g. 5 %) escape from the storage or digesters, the GHG benefits of biogas plants are substantially reduced. A reference system II was developed to include total use of heat from the biogas plant Paldau. As a consequence GHG emission benefits increase significantly.

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Biogas Plant Paldau (Photo: P. Enzinger)

Scope

One reason for using biogas is to reduce GHG emissions. Biomass is a "carbon neutral" energy source from the perspective that CO_2 released in combustion is taken up again by growing plants. However, its use for energy may release additional GHG emissions, such as CH_4 from open storage of digestate, or N_2O from fertilised soils used for biomass production. In Austria, many new biogas plants use crops as feedstock, because farmers are seeking new markets for products. Due to feed-in tariffs in Austria, biogas is mainly used for production of electricity. The co-produced heat is not always used.

This study examined the GHG benefits of a biogas plant with closed storage, based on LCA. The main objectives of the study were to:

- Evaluate the effect of a closed-storage on GHG emissions and energy production from a biogas plant,
- Analyse GHG benefits of biogas plants using primarily crops in comparison to a reference system I in which electricity comes from a natural gas plant and heat from a mix of oil and wood.

The plant of "NegH Biostrom KEG" in Paldau in the state of Styria, Austria, was chosen for this study. All plant components – including the storage for digested materials – are sealed to prevent loss of gas and odours. The plant is operated with renewable feedstock, mainly crops (corn 2,028 t_{DM}/yr, maize silage 1,175 t_{DM}/yr and grass silage 370 t_{DM}/yr), plus a smaller amount of animal manure (pig manure 152 t_{DM}/yr, cow manure 18 t_{DM}/yr). Currently only 17 % of the heat produced by the plant is utilized.

Method

Measurements in the biogas plant storage

The methane production in the closed storage was measured over half a year, using a methane flow meter installed in the pipe connecting the gas storage bag with the digesters and storage. The measurements of the biogas produced showed an average value of 3.9 Nm^3 per hour, equivalent to 34,160 Nm^3 per year. Emissions from the biogas plant with closed storage were compared to one with an open storage, which was assumed to release CH_4 emissions equal to CH_4 produced in the closed storage.

The so-called "methane slip", which occurs due to incomplete combustion of biogas in the gas engines, was not measured directly, but taken into account using data from literature.

Biogas Flow Meter (Photo: P. Enzinger)

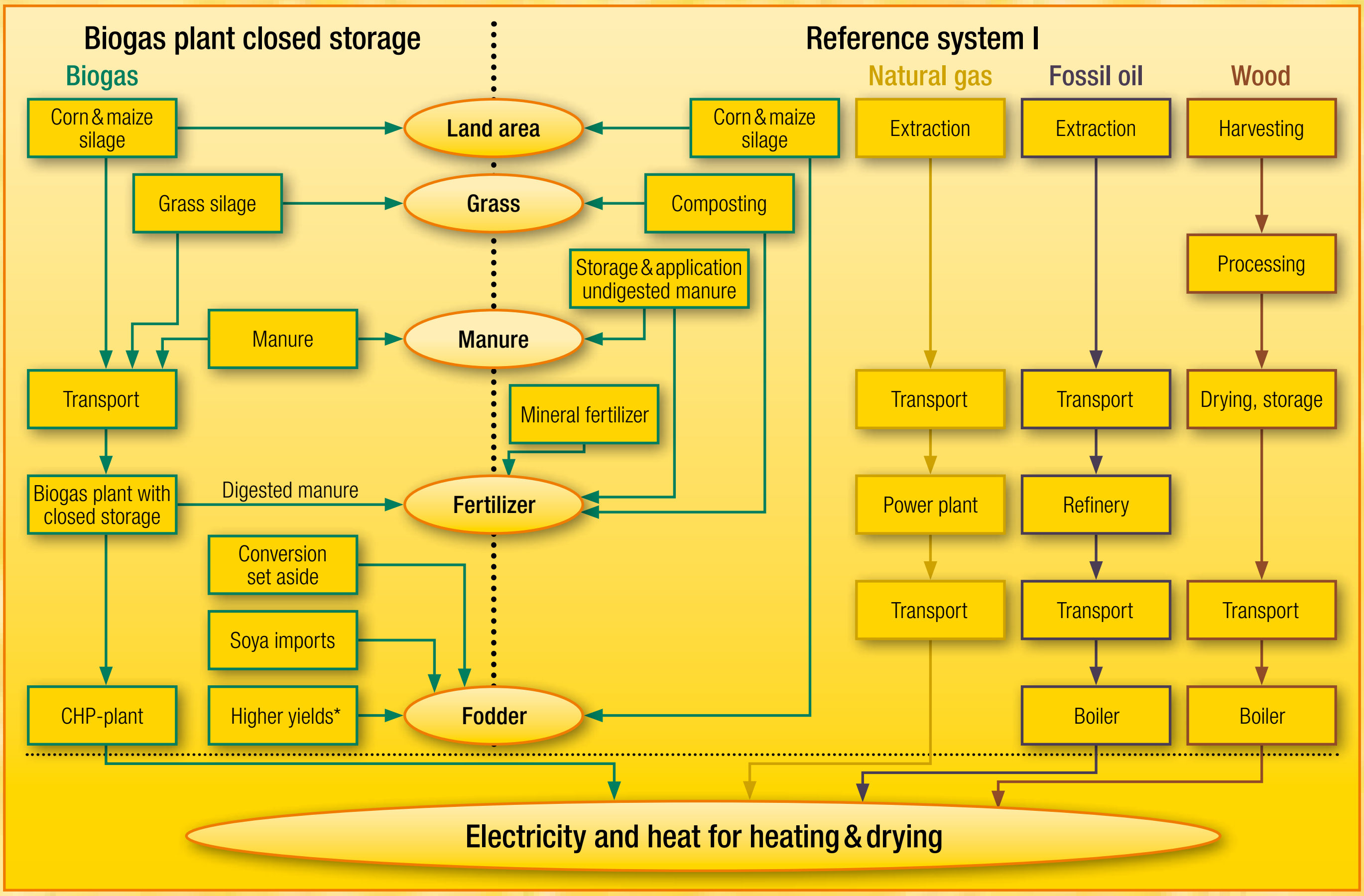

Figure 1: Process chains of the biogas pant with closed storage and of reference system I (this box includes additional fertilizer for increased yield of corn and maize silage)*


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Calculation of GHG emissions

The GHG calculations are based on an LCA following the international standards ISO 14 040 and 14 044 and the standard methodology for GHG balances of bioenergy systems, as developed in IEA Bioenergy Task 38. The software tool GEMIS (**G**esamt-**E**missions-**M**odell **I**ntegrierter **S**ysteme) developed by the Öko-Institut in Darmstadt / Germany was used for the calculations.

In the LCA, emissions of the GHGs carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) were calculated. Emissions of CH_4 and N_2O were expressed as CO_2-equivalent (CO_2-eq), using 100 year global warming potentials (Forster P. et al, 2007).

The LCA assumes a 20-year life time for the Paldau plant. CO_2 removed from the atmosphere through photosynthesis is assumed to balance CO_2 released during combustion of biomass, therefore no emissions are counted at the point of combustion, in accordance with the Guidelines of the IPCC (IPCC 2006).

In addition to CO_2 emissions due to cultivation and harvesting of crops, transportation, and construction and dismantling of plants, calculations included carbon stored due to direct land-use change (dLUC)[1]. In both biogas systems analyzed, dLUC occurs because set-aside land is converted to cultivate maize. Only changes in soil carbon were considered. For these calculations the Styrian Soil Carbon Database was used (Amt der Stmk. Landesregierung, 2004). In Austria set-aside land is often grassland so a grassland site was chosen to represent set-aside land. The conversion from grassland to cropland results in an increase in soil carbon because of low humus percentage in the grassland.

Emissions due to dLUC due to conversion of grassland to crop production were averaged over 20 years, which corresponds to the life-time of biogas plants such as Paldau. It was assumed that no dLUC occurs were wood is used for heat in reference system I, because it is assumed the wood is harvested from a sustainably managed forest. In the biogas systems, no CO_2 removals were attributed to the increased growth of forest compared to the reference system I enabled by the fact that the biogas plants supply heat previously supplied by wood. The reason is two-fold: the removals are negligible and Austria does not include carbon stock changes due to forest management in its Kyoto Protocol accounting.

Description of the three basic cases

The following three basic cases were analyzed:

- The existing Paldau biogas plant with a closed storage,
- A theoretical biogas plant similar to Paldau but with open storage,
- Reference system I: An equivalent amount of electricity is produced by a natural gas power plant and heat equivalent to heat use from biogas plant.

The lower biogas production in the biogas plant without closed storage results in lower electricity production. The electricity supply in the open storage is consequently supplemented with electricity from a natural gas power plant. Electricity from a natural gas power plant is also used in reference system I.

The quantity of heat produced in reference system I is the same as the quantity of heat currently used from the Paldau biogas plant (17 % of 7 GWh, ie 1.2 GWh). Heat is provided by four domestic oil heating systems and one domestic wood log heating system, the systems which were in use prior to the heat from the biogas plant. For the sensitivity analysis a reference system II was developed in which the amount of heat produced is equivalent to the total heat production of the Paldau plant.

System boundary

The process chains of the biogas plant with closed storage and of reference system I are documented in figure 1. Reference system I utilises the same amounts of: manure, land area and grass as the Paldau biogas plant and provides the same amounts of electricity, used heat and fodder. In the reference system I, the corn and maize silage is used for fodder instead of as an input to a biogas plant; undigested manure is used for fertilizer rather than as a biogas plant input, and grass silage is composted and used as a fertilizer instead of as biogas feedstock. In reference system I, set-aside land is mulched once a year. Heat and electricity are sourced from conventional energy sources. All the corresponding GHG emissions are considered in the LCA.

To account for the CH_4 and N_2O emissions to the atmosphere from the undigested manure, these were subtracted from the biogas plant calculations. As undigested animal manure is 20 percent less effective as fertilizer than digested manure, some synthetic fertilizer was included in the reference system I to provide equivalent fertilizer value as obtained from animal manure in the biogas system.

In the biogas systems the reduction in fodder supply is covered through a combination of conversion and fertilization of 53.6 ha of set-aside land, increased soya imports, and higher yields through additional fertilizer on original cultivated area (214 ha). Additional fertilizer plus additional land supply 60 per cent of the deficit, with the other 40 per cent addressed through soy imports (for more details, please see full report, pages 16 – 18: Woess-Gallasch et al, 2011). The digested grass from the biogas plants is also used as a fertilizer and is equivalent to the fertiliser value of the composted grass silage in the reference system I.

Functional unit

GHG emissions were calculated as tons per year. The values of the biogas plants were then calculated in terms of GHG emission reductions in comparison to reference system I, and expressed per unit of energy output (kWh) and per unit mass of biomass (t_{DM}).

1 Land-use change can be either direct or indirect. Land-use change is called direct if the change occurs on-site. This study only includes emissions from dLUC.

Courtesy of JOANNEUM RESEARCH

Results and discussion

Energy and biogas production

The biogas plant Paldau produces 270 Nm³ of biogas per hour, equivalent to 2,365 Mio Nm³ per year. The two 250 kW_{el} gas engines produce 4,300 MWh annually which is fed into the public grid. After subtracting the biogas plants' electricity requirements – 272 MWh – a net production of 4,029 MWh is achieved. The plant's gross heat production is 7,250 MWh, but heat available is only partly used (17 %).

The measurements of the biogas produced in the closed storage show a mean value of 3.9 Nm³ per hour, or 34,160 Nm³ per year. In the LCA calculations, the assumption was made that the storage remained closed also during material removal. The CH_4 concentration of the biogas in the storage was 63.8 % which is higher than that produced in the digester, which is 48.8 %. This means that 15.6 tons of CH_4 would be produced annually in the biogas plant storage under best management practices.

Greenhouse gas emissions

Table 1 shows the GHG emissions in tons per year.

Table 1: GHG emissions in tons per year

GHG emissions t/yr	CO_2	CH_4	N_2O	CO_2-eq
Biogas plant Paldau, closed storage	202	9.6	3.3	1,409
Biogas plant Paldau, open storage	233	25.2	3.2	1,818
Reference system I	2,224	10.9	< 0.1	2,502

Note: For calculation of total CO_2-eq emissions the global warming potentials of IPCC were used (Forster P. et al, 2007)

Figure 2 shows all these Greenhouse gas emissions. The biogas plant with closed storage has the lowest emissions, 1,409 t CO_2-eq/yr. If the emissions reductions due to dLUC are not considered, emissions from closed storage are 1,457 t CO_2-eq/yr (see Figure 3). Thus dLUC reduces total CO_2-eq emissions by 3.4 %. The biogas plant with an open storage results in 1,818 t CO_2-eq/yr. and the reference system I in 2,502 t CO_2-eq/yr.

Table 2 shows the GHG emissions per kWh produced, which is composed of 0.76 kWh_e and 0.24 kWh_{th}.

Table 2: GHG emissions in g per produced kWh

GHG emissions g/kWh	CO_2	CH_4	N_2O	CO_2-eq
Biogas plant Paldau, closed storage	38	2	1	266
Biogas plant Paldau, open storage	44	5	1	344
Reference system I	421	2	< 1	473
Reference system II more heat	806	2	< 1	930

Note: More information on reference system II please find below under "Sensitivity Analysis"

Table 3: GHG emission reductions of the biogas plant systems compared to the reference system I in g per produced kWh

GHG emission reductions to reference system I g/kWh	CO_2	CH_4	N_2O	CO_2-eq
Biogas plant Paldau, closed storage	382	< 1	-1	207
Biogas plant Paldau, open storage	376	-3	-1	129

Note: Each kWh is composed of 0.76 kWh_e and 0.24 kWh_{th} – negative values mean an increase of GHG emissions

Table 4: GHG emission reductions kg per t_{DM} of biomass feedstock compared to reference system I

GHG emission reductions to reference system I kg/t_{DM} biomass	CO_2	CH_4	N_2O	CO_2-eq
Biogas plant Paldau, closed storage	540	0.4	-0.9	292
Biogas plant Paldau, open storage	531	-3.8	-0.8	183

Note: Negative values mean an increase of GHG emissions

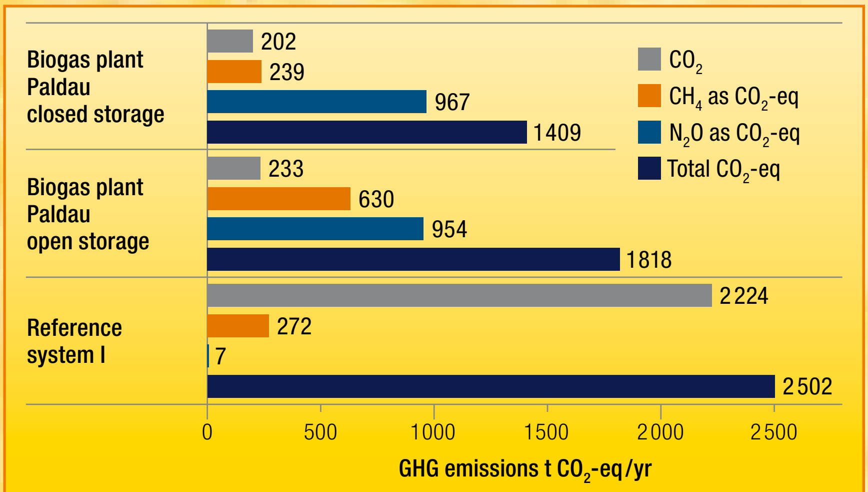

Figure 2: GHG emissions in CO_2-equivalent emissions per year.
Note: The CO_2 emission from biogas plants includes 48 tonnes of CO_2 sequestration from dLUC.

Table 3 shows the GHG emission reductions of the biogas plant systems compared to the reference system I in g per produced kWh.

In Table 4 the GHG emission reductions in comparison to reference system I have been calculated per ton of dry biomass feedstock (t_{DM}). For each tonne of biomass feedstock used in the biogas plant with the closed storage, 292 grams of CO_2-eq can be avoided. The biogas plant with an open storage, however, avoids only 183 grams of CO_2-eq.

Sensitivity analysis

In a sensitivity analysis, the effects of the following three parameters on GHG emissions have been estimated:

- Fraction of heat used: 100 % use of the heat generated by the biogas plant instead of only 17 % (optimized Paldau situation, reference system II),
- Feedstock mix: use of increased proportion of animal manure,
- Higher CH_4 emissions from open storage.

Figure 3 shows GHG emissions of reference system II and illustrates the impact of 100 % of heat use. Reference system II must supply more heat from fossil fuels and wood than reference system I to supply heat equivalent to full use of heat from the biogas plant. Consequently, reference system II has significantly greater GHG emissions than reference system I. The GHG emissions reduction of the Paldau biogas plant compared to reference system II is 3,511 t/yr of CO_2-eq, significantly higher if total available heat is used.

Where crops are the major feedstock and only a small percent of heat produced is used, relatively small increases in the percentage loss of methane can nearly nullify mitigation benefits from displacing the use of natural gas. If manure is used as the feedstock, greater methane losses (up to 18 per-cent) still bring benefits. The sensitivity analysis suggests that increased proportion of animal manure in the feedstock mix results in higher potential GHG emission benefits. These theo-retical results need to be substantiated through further studies of biogas plants in operation and linked reference systems.

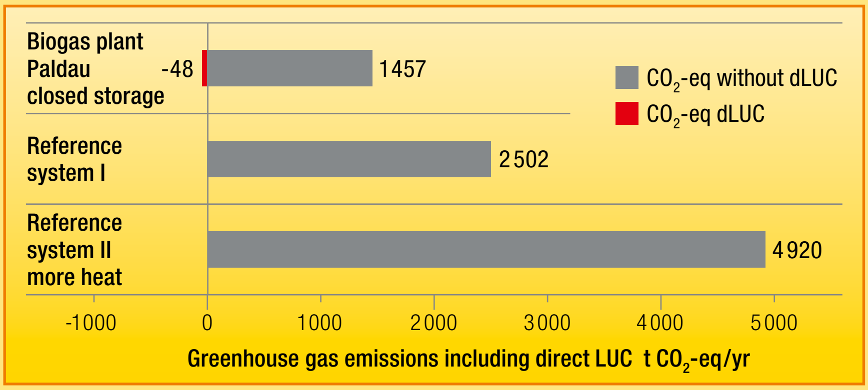

Figure 3: Total CO_2-equivalent emissions per year for the Paldau biogas plant and two reference systems (including 48 t CO_2 sequestered from dLUC for biogas plant).

Courtesy of JOANNEUM RESEARCH

Conclusions

Biogas plants can contribute to GHG emission mitigation. This analysis shows that GHG benefits are substantially higher if biogas plants have a closed storage and if all heat produced is utilised. The use of residues such as manure as feedstock results in higher emission reduction than use of crops that can cause GHG emissions, such as N_2O due to fertilizer application.

On basis of the results of this study it is recommended that new biogas plants have closed storage systems; that more priority is given to the selection of sites that enable the use of high percentages of heat produced, and that a high ratio of animal manure is used.

For more detailed information on this study, please see the full report (Woess-Gallasch et al, 2011), available at: www.ieabioenergy-task38.org/projects.

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IEA Bioenergy (www.ieabioenergy.com) is an international collaborative agreement, set up in 1978 by the International Energy Agency (IEA) to improve international cooperation and information exchange between national bioenergy research, development and demonstration (RD&D) programs. IEA Bioenergy aims to achieve a substantial bioenergy contribution to future global energy demands by accelerating the production and use of environmentally sound, socially accepted and cost-competitive bioenergy on a sustainable basis, thus providing increased security of supply whilst reducing greenhouse gas (GHG) emissions from energy use.

IEA Bioenergy Task 38 brings together research work of national programs in all participating countries on GHG Balances for a wide range of biomass systems, bioenergy technologies and terrestrial carbon sequestration. Emphasis is placed on the development of state-of-the-art methodologies for assessing GHG balances; demonstrating the application of established methods, supporting decision-makers in implementing effective GHG mitigation strategies. As one example of work, case studies have been conducted by applying the standard methodology developed by Task 38. The case studies have assessed and compared GHG balances of different bioenergy and carbon sequestration projects in the participating countries, and this Austrian case study is one example.

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