Greenhouse Gas Benefits of a Biogas Plant in Austria

Susanne Woess-Gallasch, Neil Bird, Peter Enzinger, Gerfried Jungmeier, Reinhard Padinger, Naomi Pena, and Giuliana Zanchi

JOANNEUM RESEARCH Forschungsgesellschaft mbH.
RESOURCES - Institute of Water, Energy and Sustainability,
Elisabethstr. 5
A 8010 Graz

Graz, 2010

IEA Bioenergy Task 38 Case Study Report

Projekt Nr.: RES.04-09.AF.019-01

Bericht Nr.: ENG-B-05/10

Freigegeben: Graz, am 10. Dezember 2010

JOANNEUM RESEARCH

R. Padinger	S. Woess-Gallasch
Forschungsgruppenleiter	Projektleiter

Table of Contents

Abstract

The goal of this study is 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 analysed. Results are based on measurements of methane produced in the closed storage tank and Life Cycle Assessment (LCA). Feedstocks for the biogas plant are primarily crops and secondarily animal manure. The plant has two main digesters and two secondary digesters in addition to the closed storage tank for digested biomass. Methane produced in the digesters and storage tank are used to produce approximately 4 GWh electric energy and 7 GWh heat per year. Only 17 % of heat produced is currently used.

Total Biogas production and methane concentration from the closed storage was measured during the period May – October 2006. Based on these measurements, an annual production of 15.6 tons of CH4 per year was estimated assuming tank cleanings were done without opening the tank, which represents best practice operation. Using these results, a theoretical case was constructed of a biogas plant using the same feedstocks but storing digested biomass in an open tank. It was assumed that open storage would result in methane emissions to the atmosphere equal to those produced in the closed storage tank. A comparison of these two cases shows the increased energy production and GHG emissions avoided by using closed storage.

The LCA analysis covered carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions due to construction, operation and dismantling of the energy systems; and the cultivation (including fertilizer use and land use change), harvest and transport of biomass raw materials as well as use of by-products. GHG impacts of the two biogas plants were compared to a reference system (reference system I) which delivered equivalent amounts electricity and heat. In the reference system, electricity is assumed to come from a natural gas plant, and heat from a combination of oil and wood, which was the case prior to operation of the Paldau biogas plant.

The results show that:

- Open storage results in total LCA GHG emissions 29 % higher than closed storage.
- Due to increased CH_4 production and higher CH_4 concentration in the biogas coming from closed storage, open storage produces 1.9 % less energy than closed storage.
- Closed storage plant results in 1,409 tons of CO_2-eq per year, which is 1,094 tons or 44 % less GHG emissions than the reference system. Open storage reduces emission by 685 tons per year, or 27 %.
- This equates to emissions savings of 292 kg CO_2-eq per t dry biomass for the closed storage system and 183 kg for the open storage.

Direct land use changes (onsite) sequester 48 tons of CO_2 per year, reducing total GHG emissions in the Paldau plant by 3.4 %.

A sensitivity analysis showed that if even relatively small amounts of CH_4 (e.g. 5 %) escape from the storage tanks or digesters, the GHG benefits of biogas plants are substantially reduced. If all heat produced by the biogas plant Paldau can be used, GHG emission benefits increase significantly.

1. Introduction

Biomass digestion for production of biogas is currently being promoted as a technology that can reduce **G**reen**H**ouse **G**as (**GHG**) emissions. Biomass is a renewable energy source, but its use for energy may release GHG emissions to the atmosphere. For example, in the case of a biogas plant methane emissions can be released due to open storage of digested material. In Austria, many new biogas plants use purpose-grown crops as feedstock, because farmers are seeking new markets for products. The production of crops for use in the biogas plant also releases GHG emissions, such as N_2O due to fertilizer application. Due to high feed-in tariffs in Austria, biogas is mainly used for production of electricity, which results in heat as a co-product.

Most biogas plants in Austria currently do not use closed storage facilities to store the material after removal from the digester. The question has arisen as to whether closed storage should be used for such systems due to expected advantages such as increased energy production and reduced releases of GHGs.

This study examined the GHG benefits of closed storage based on life-cycle analysis. The main objectives of the study were to:

- Evaluate the effect of a closed-storage system on GHG emissions and energy production from a biogas plant,
- Analyse GHG benefits of biogas plants using primarily purpose-grown crops in comparison to a reference system 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, and maize silage 1,175 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.

The methane production in the closed storage tank was measured just under six months. On the basis of these measurements, the annual biogas production in the storage tank was estimated. Emissions from the closed storage plant were compared to a system with open storage which was assumed to release methane emissions equal to methane produced in the closed storage tank.

New analyses show that methane loss during combustion of biogas – referred to as the “methane slip”- is higher than expected. The methane slip was not directly measured in this study, but was taken into account based on data from literature.

Both biogas plants - open and closed storage - were compared with a reference system (Reference system I). The reference system provides electricity and heat equivalent to those provided by the biogas plant but through the means used prior to establishment of the plant. Electricity comes from a natural gas plant, and heat is provided by oil and wood. Crops are used for animal feed and untreated manure for fertilizer, instead of as inputs to a biogas facility.

Leakage effects were considered and a sensitivity analysis was undertaken. Where crops are used for energy production instead of animal feed, reductions in feed supply are made up through increased maize production on set aside land, and imported soy meal.

In a sensitivity analysis the following options were considered:

- A second reference system (Reference system II) where 100% of heat produced by the biogas plant is used (e.g., for residential heat and biomass drying).
- Use of a higher fraction of animal manure,
- Higher CH_4 emissions under open storage conditions.

This English report builds on a study funded by the Styrian "Landesenergieverein" (Woess-Gallasch S. et al, 2007) by adding consideration of GHG emissions due to direct land-use change associated with conversion of set aside land to maize production.

2. Description of the biogas plant Paldau

The biogas plant Paldau is located in Pöllau, which is part of the municipality of Paldau (see photograph 6.1 page 29 and 6.7 page 31). Owner and operator of the plant is the company "NegH Biostrom KEG". Nearly 2.4 million m^3 of biogas are produced by the plant annually, according to data from 2005. In 2005 and 2006 approximately 4 GWh of electricity were fed into the grid. In addition, 7.25 GWh of heat were produced but only 1.3 GWh of this was used.

The biogas plant Paldau consists of 2 main digesters, 2 secondary digesters and a closed storage tank for digested material. It has been operating since 2001. The biogas is used to produce electricity and heat using 2 gas engines (250 kW_{el} each). For further details of the plant see Figure 2.1. Electricity is fed into the public grid. As there is limited local demand for heat, only 17 % is utilized, for heating nearby farm houses and stables and for drying maize for animal fodder.

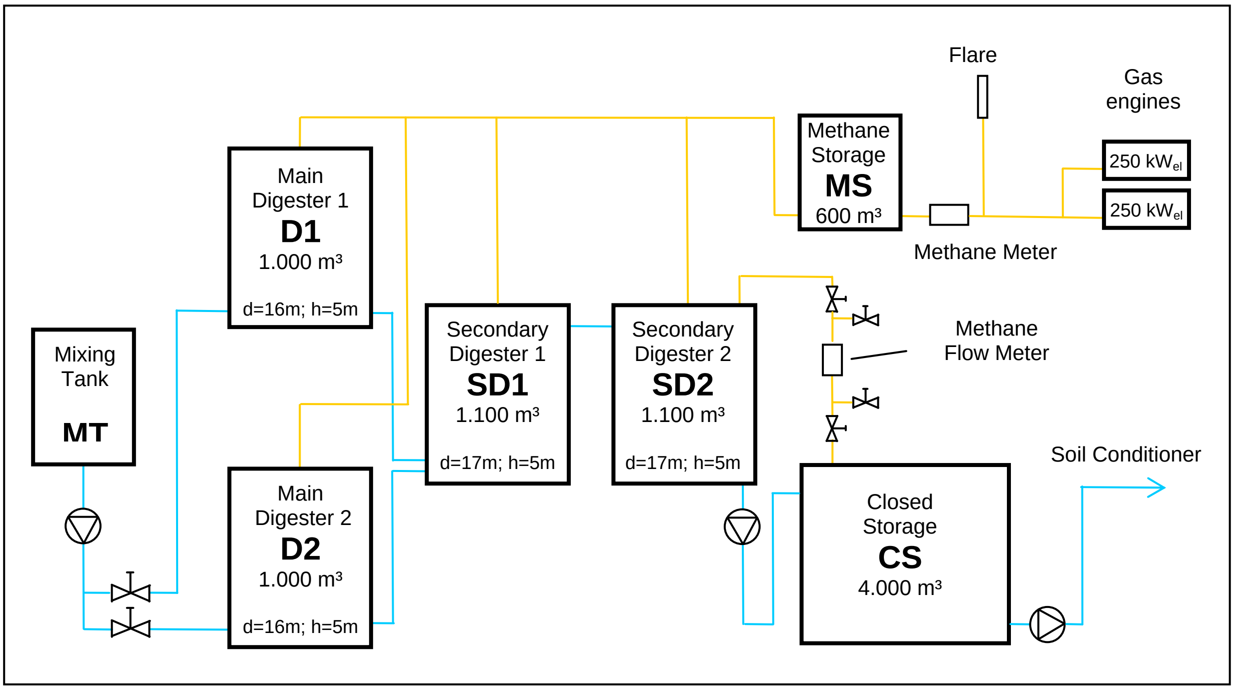

Figure 2.1: Scheme of the Biogas Plant Paldau

Material feedstock per year (2005) is 3,120 t_{DM} of corn, 2,670 t_{DM} of maize silage, 740 t_{DM} of grass silage, 3,040 t (= 152 t_{DM}) of pig manure and 300 t (= 18t_{DM}) of cow manure. The maize silage is stored in 2 drive-in open silos (see photograph 6.5 page 30), which are loosely covered with plastic. The maize silage (water content of 32 %) is stored in 2 standing silos. (see photograph 6.2 page 29) All digesters and the closed storage tank for the digested material are installed underground.

The animal manure used in the biogas plant Paldau is delivered by five farmers situated close to the plant In two cases the manure is delivered by a pipeline (1,800 m^3/a). Three farmers deliver the manure by tractor in barrels (1,240 m^3/a). The diesel consumption due to tractor transport is included in the LCA analysis. Approx. 8.7 tons of corn and 15 m^3 of animal manure (from pigs and cows) are stirred daily in the underground mixing tank (see photograph 6.3 page 29 and 6.4 page 30). The mixed material is delivered hourly to the two main digesters. Other materials - maize and grass silage - are fed directly into the main digesters without pre-mixing (approx. 7.5 – 8 tons every 6 hours). After 64 days in the main digesters, the substrate enters into the first secondary digester. After 35 days in the second secondary digester, the digested material is pumped into a closed tank where the digested material is stored (see CS in Figure 2.1). The closed storage tank (see photograph 6.7 page 31) is emptied every six months, and the material is spread on pasture. A maximum of 700 m^3 of digested material can be removed daily. The closed storage tank includes two stirring devices which operate 4 times daily, one hour each time.

Methane is recovered not only from the digesters but also from the closed storage tank. Biogas recovered from the tank is fed back to the secondary digester through a gas pipe. All biogas recovered is stored in a bag with a capacity of 600 m^3. The temperature in the digesters ranges from 40 to 50 °C. No heating is necessary. In summer cooling by cold water is sometimes necessary. The two gas engines have a nominal power of 250 kW_{el} each and together consume 270 m^3/h of biogas. The heating value of the biogas is 5 kWh/m^3. This results in an electric conversion efficiency of 37 %.

For more details on the Biogas Plant Paldau see also the report in German, available under: www.noest.or.at/intern/dokumente/188_THG_Biogas_Endbericht.pdf

3. Measurements in the biogas plant storage tank

Measurements of biogas produced in the closed storage tank were conducted from March 17th through October 9th 2006. The measurements of the biogas produced show an average value of 3.9 Nm^3 per hour, equivalent to 34,160 Nm^3 per year. Due to operator inexperience, the tank was opened for semi-annual cleaning first from the beginning of April 2006 through May 10th and again starting September 20th. Using best practices, this cleaning, during which all digested material is removed, would be carried out with the tank remaining closed.

To measure the methane produced in the closed storage tank, a methane flow meter (type 005 GD 100/1 company: ESTERS Elektronik) was installed in the pipe connecting the gas storage bag with the digesters and storage tank (see photograph 6.8 page 31). Measurement data were collected and stored automatically every 10 seconds by a computerized data acquisition system (see photograph 6.10 page 32). Data visualization was managed by software DASYLab.

Results of measurements from 27 March until 9 October 2006 are shown in Figure 3.1. Data from the period between the two complete evacuations of the storage tank – from 15 May to 19 September 2006 – were used for the analysis. A few electrical current values were lost due to power failures during heavy thunderstorms. However, the total sum of gas emitted during these periods was measured correctly by the mechanical gas meter and these mechanical measurements were transferred into the final data log. There were also a few short periods when the storage tank was opened and partially emptied to fix problems with the stirring devices.

The average volume of gas produced from the storage tank from 15 May to 19 September 2006 was 3.9 m^3/h. The CH_4 concentration of the biogas in the storage tank was 63.8 %, which was significantly higher than the CH_4 concentration of the biogas from the main digesters (48.8 %). As a result, the storage tank produces 15.6 tons of CH_4 annually which is 1.9 % of total CH_4 produced by the plant (821 tons), although the tank only produces 1.46 % of the total biogas.The reason for the different concentrations lie in biochemical details of the fermentation process which were not investigated in this project. The CH_4 emissions from open storage systems depend on the retention time of the material in the digesters (hydraulic retention time HTR). The HTR in the biogas plant Paldau is more than a hundred days, which is quite long. In plants with a shorter retention time in the digesters, the CH_4 emissions during the storage phase would be higher as less of the biomass carbon content would have been converted to CH_4 in the digestion stage. However, many newly constructed plants have long digester retention times, similar to those in Paldau.
More details on meter technology and on measurements are available in the report in German, available at:
www.noest.or.at/intern/dokumente/188_THG_Biogas_Endbericht.pdf.

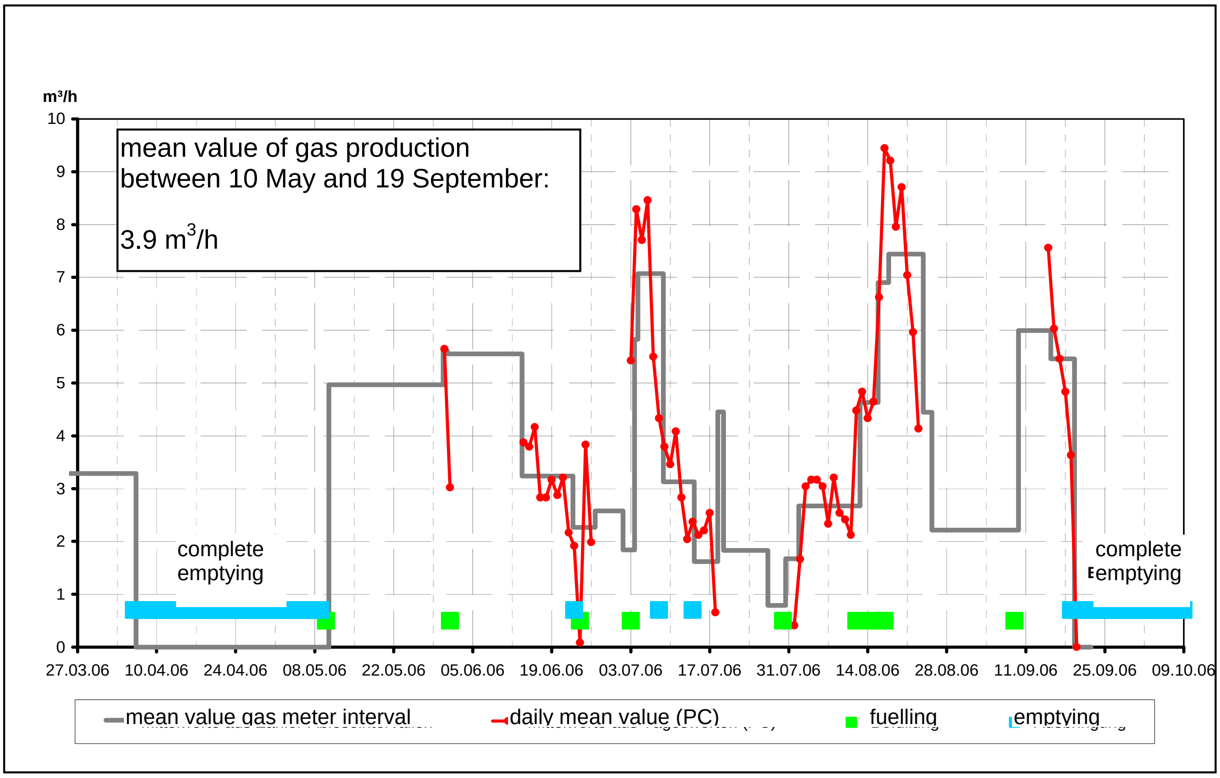

Figure 3.1: Gas production during the whole period of measurements

4. GHG Emissions of the biogas system

A LCA was conducted to quantify GHG emissions of biogas systems using the results of measurements from the Paldau closed storage tank. After explaining the study's goals, this section discusses the methodology used, data sources, and system boundaries. These discussions are followed by descriptions of the cases analyzed – closed and open storage plus two reference cases – including the system boundaries. Finally results are presented.

4.1 Background and aims

Primary goals of the study were to quantify the GHG emissions of a biogas plant that uses dedicated crops and, in particular, to quantify the CH_4-emissions which can be avoided by closed rather than open storage of digested materials. The GHG emission benefits of a biogas plant using closed storage were compared to a biogas plant with open storage and to reference system in which an equivalent amount of heat and power is delivered primarily from fossil resources. Energy efficiency of both systems was also investigated.

In a sensitivity analysis the effects of the following 3 parameters on the GHG emissions were estimated:

- 100 % use of heat, (Reference System II)
- Increased use of animal manure,
- CH_4 emissions from open storage;

4.2 Methodology

The GHG calculations are based on a LCA following the international standards ISO 14040 and 14044 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, and expressed as CO_2-equivalent emissions (CO_2-eq). The contributions of CH_4 and N_2O to the greenhouse effect were calculated as CO_2 –equivalent using the Global Warming Potentials as established by the International Panel on Climate Change in the Fourth Assessment Report (Forster P. et al, 2007);

- Carbon dioxide (CO_2): 1 kg CO_2 = 1 kg CO_2-eq.
- Methane (CH_4): 1 kg CH_4 = 25 kg CO_2-eq.
- Nitrous oxide (N_2O): 1 kg N_2O = 298 kg CO_2-eq.

The LCA assumes a 20-year life time for the Paldau plant and that CO_2 removed from the atmosphere through photosynthesis balances CO_2 released during combustion of biomass, and therefore no emissions are counted at the point of combustion as established in the Guidelines of the IPCC (UNFCCC 2006a).

In addition to CO_2 emissions due to cultivation and harvesting of crops, transportation, and construction and dismantling of plants, calculations included carbon stock change due to direct land-use change (dLUC)[1]. Where grasslands are converted to cultivated land, CO_2 emissions can occur due to loss of soil carbon. In both biogas systems analyzed dLUC occurs because set aside land, which is often grassland, is converted to cultivate maize. Emissions due to dLUC were calculated in adherence with requirements of the European Union Directive 2009/28/EC on the promotion of the use of energy from renewable sources (Directive 2009/28/EC, 23 April 2009) and guidance of the IPCC (IPCC, 2006). These losses are averaged over 20 years, which corresponds to the life-time of biogas plants such as that at Paldau. It is assumed that no land use change occurs where wood is used for heat in Reference Case I. No CO_2 removals were attributed to the increased growth of forest compared to the reference system enabled by the fact that the biogas plants supply heat previously supplied by wood. The reasons are two-fold: the removals are negligible and Austria does not include carbon stock changes due to forest management in its Kyoto protocol reporting.

CH_4 emissions were calculated in both the reference system and in the biogas systems. In the reference system, emissions from natural gas recovery, production of electricity, and animal manure used as fertilizer were included. In the biogas systems CH_4 emissions due to digested animal manure and the methane slip were calculated. In the open-storage system, CH_4 emissions linked to the supplemental natural-gas based electricity needed supply equivalent energy were also included.

Emissions from manure were based on the following parameters: 1 kg cow manure causes 2.41 g of CH_4 emissions, and 1 kg of pig manure 2.16 g of CH_4 emissions (Amon, 1998). Undigested animal manure is assumed to be 20 percent less effective as a fertilizer than digested manure (Amon, 1998, Boxberger et al. 2002) Since the focus of the study is on GHG emissions attributable to production of energy, CH_4 emissions due to storage and use of animal manure for fertilizer in Reference system I were not included in the Reference system calculations, but instead, an equivalent amount of CH_4 was subtracted from the biogas plant accounts.

The so-called “methane slip”, which occurs due to incomplete combustion of the biogas in the engine generators, has been evaluated using results from literature (see Chapter 4.3, page 13 for further information).

In the case of N_2O emissions from soils, the LCA includes the additional N_2O emissions due to increased fertilizer used to achieve increased crop yields for the biogas cases (see also pages 14 and 17). The N_2O emissions from soils due to use of synthetic fertilizers are calculated using the emission factors (mean value) proposed by IPCC in Guidelines 1997 (see blue line in Figure 4.1). For growing of corn, 237 kg of N fertilizer per ha and for growing of maize silage 228 kg of N per ha fertilizer have been assumed (see Table 4.2). The LCA also includes other N_2O emissions that occur, for instance, during combustion of natural gas or biogas.

[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 direct land-use change.

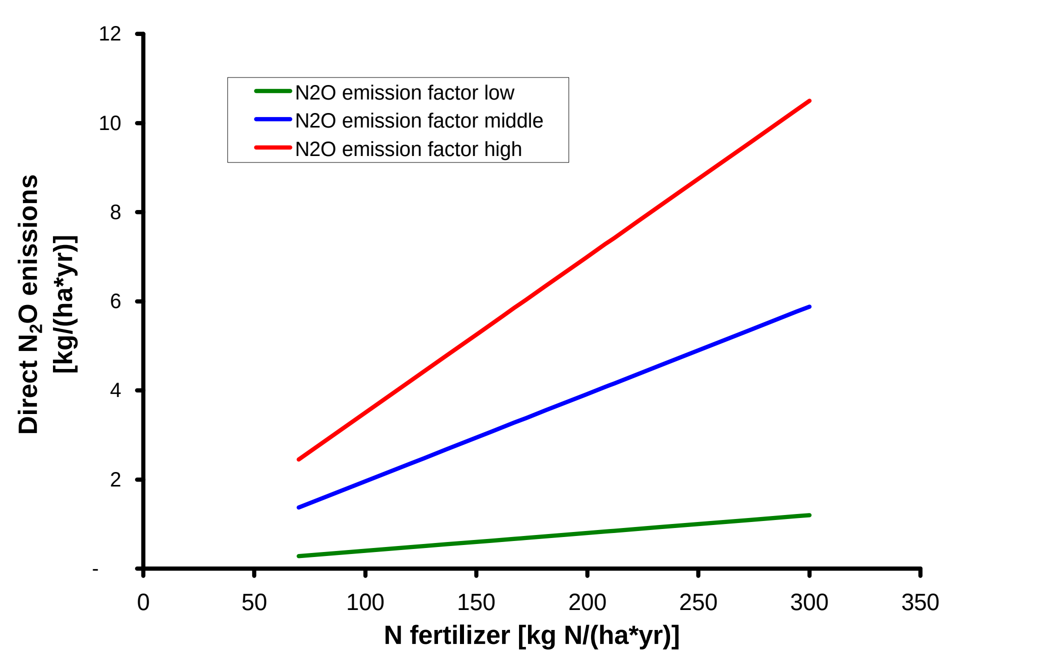

Figure 4.1: Direct N_2O emissions from soils depending on N fertilizer use in kg N/(ha*yr), N_2O factor from IPCC (IPPC 1997).

4.3 Data

Data collection occurred over a two-year span, 2005 and 2006. Collected data included data on crop and manure production and transport and methane production in the closed storage tank. Data for dLUC and the methane slip were derived from literature.

4.3.1 Crop data

LCA calculations use crop production data collected for the year 2005. Maize silage, corn, and grass silage, as well as a small amount of animal manure from pigs and cows, are used as inputs to the biogas plant. The quantities of the feedstock are documented in Table 4.1.

Table 4.1: Annual feedstock of the biogas plant Paldau

Material input	**t/yr**	**t_{DM}/yr**
Maize silage	2,670	1,175
Corn	3,120	2,028
Grass silage	740	370
Manure from pigs	3,040	152
Manure from cows	300	18

The quantities of crops, the associated area, cultivation and harvest data, and transport distances from farms to the biogas plant were collected from each of the 36 farmers. Grass silage comes from meadows in the vicinity of the biogas plant, as does the animal manure. Collected data include:

- Diesel used during cultivation, harvest, and transport to biogas plant

- Fertilizers and pesticides

Mean values were calculated based on the collected data. In Table 4.2 the data on cultivation, harvest and transport of the crops are documented.

Table 4.2: Data for growth, harvest and transport of plant materials used

Growth, harvest and transport	maize silage	corn	grass silage
Area ha/yr	49	219	30
Harvest t/yr	2,670	3,120	740
Yield t/(ha*a)	55	14	24
Water content %	56%	35%	50%
Yield t_{DM}/yr	1,175	2,028	370
Yield t_{DM}/(ha*yr)	13	9	
Diesel consumption l/(ha*yr)	57	57	15
N Fertilizer kg/(ha*yr)	228	237	0
P Fertilizer kg/(ha*yr)	41	47	0
K Fertilizer kg/(ha*yr)	401	47	0
Pesticide kg/(ha*yr)	3	3	0
Transport t km/yr	4,801	33,912	2,940
Mean distance to biogas plant in km	2	11	4

DM: Dry Matter

4.3.2 Land-use change data

For the calculation of the GHG emissions from dLUC, only changes in soil carbon were considered. No change in biomass carbon stocks was attributed to the conversion of set-aside land to croplands. In Austria, most set-aside land is grassland that is regularly mowed or ploughed (W. Krainer, personal communication). Under these circumstances the live biomass on set-aside land is assumed to be the same as on annual cropland.

To calculate soil carbon, the Styrian Soil Carbon Database was used (Amt der Stmk. Landesregierung, 2004). The Styrian Soil Carbon Database includes sampled values for percent of humus by depth from some 200 soil sample sites (Figure 4.2). From this database, samples near Paldau for both cropland and grassland were selected.

The sample values are shown in Table 4.3. The percentage of humus was converted to total soil organic carbon (SOC) per hectare by using the bulk densities shown in the table and a Humus/C ratio of 1.72 (W. Krainer, personal communication).

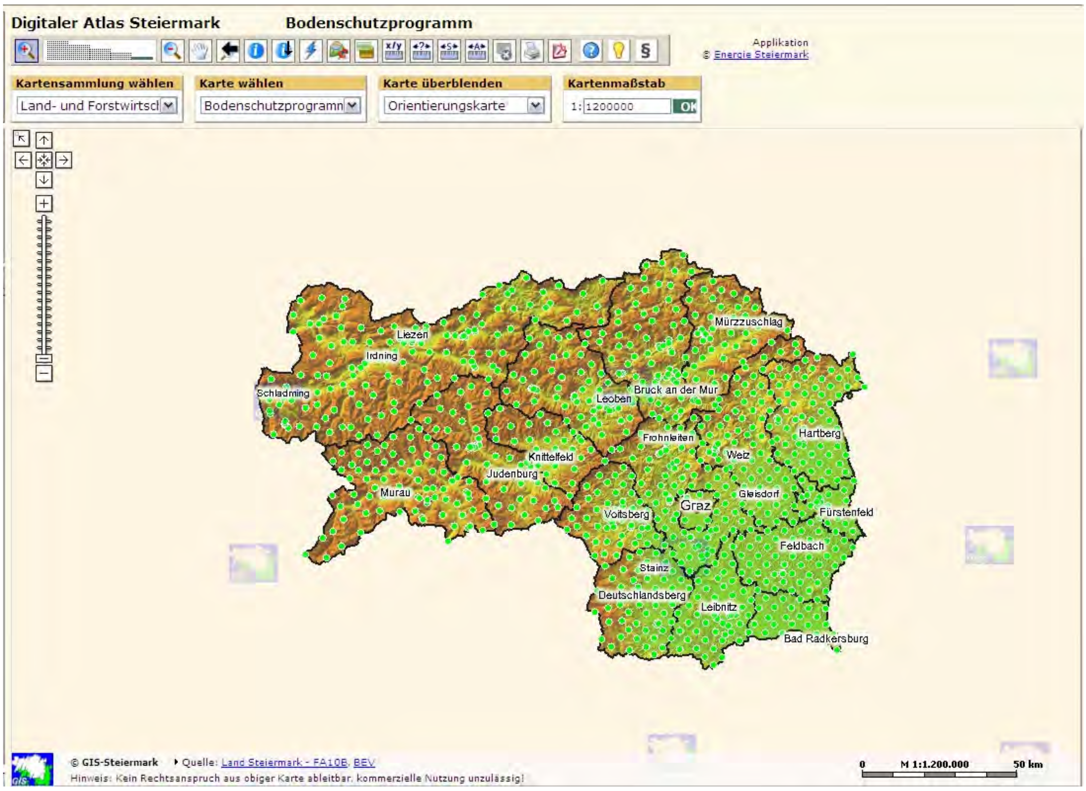

Figure 4.2: Styrian Digital Atlas – Soil Carbon Database

Bulk densities were calculated with pedo-transfer functions[2] by Hollis (1989), resulting in densities ranging from 1.25 to 1.4 g/cm^3 at depths of 20 to 50 cm. The SOC for the top 30 cm (the standard depth used) was estimated by adding SOC in the 0-20 depth to that at 20-30 cm, calculated as a proportion of the SOC at 20-50cm.

Table 4.3: Styrian Soil Carbon Database: Data for areas surrounding Paldau

Site no.	Type	Sampled depth (cm)	Humus (%)	Clay (%)	Silt (%)	Sand (%)	Bulk D. (g/cm3)	Interval SOC (t/ha)	Cumulative SOC (t/ha)
FBA5	Cropland	0-20	2.6	14	50	36	1.39	41.88	41.88
		20-50	1.5	16	41	43	1.38	36.10	77.97
		50-70	0.9	21.0	49.0	30.0	1.4	14.3	92.3
		0-30	**2.2**	**14.7**	**47.0**	**38.3**	**1.4**		**53.9**
FBC4	Cropland	0-20	3.1	26	62	12	1.29	46.60	46.60
		20-50	2.2	31	61	8	1.25	47.86	94.46
		50-70	2.0	31.0	62.0	7.0	1.2	28.1	122.6
		0-30	**2.8**	**27.7**	**61.7**	**10.7**	**1.3**		**62.6**
FBC5	Cropland	0-20	2.15	18	48	34	1.43	35.67	35.67
		20-50	1.3	19	49	32	1.40	31.65	67.32
		50-70	1.3	19.0	54.0	27.0	1.3	19.8	87.1
		0-30	**1.9**	**18.3**	**48.3**	**33.3**	**1.4**		**46.2**
FBX12	Grassland	0-5	4.5	25	42	33	1.18	15.43	15.43
		5-20	2.2	21	44	35	1.35	25.98	41.41
		20-50	1.0	29.0	45.0	26.0	1.4	23.7	65.1
		0-30	**2.2**	**24.3**	**44.0**	**31.7**	**1.3**		**49.3**

To estimate the SOC change between set-aside land and cropland, the grassland sample, FBX12, was chosen to represent set-aside land as no value for set-aside land is available and grassland is the most common form of set aside land in Austria (W. Krainer, personal communication). The SOC in cropland was calculated as the

[2]Pedo-transfer functions are used to estimate bulk density from soil properties such as texture plus carbon content.

average value between the samples FBA5, FBC4 and FBC5. The result is an average SOC in cropland of 54.2 ±8 tC/ha in the first 30 cm.

4.3.3 Energy- and biogas-production data

The biogas plant produced circa 270 Nm^3 of biogas per hour, equivalent to 2,365 Mio Nm^3 per year, assuming the tank remained closed throughout. In the year 2005, the two 250 kW_{el} gas engines produced 4,300 MWh which were fed into the public grid. After subtracting the biogas plants' electricity requirements – 272 MWh – a net production of 4,029 MWh was achieved. The plant's gross heat production was 7,250 MWh, of which 1,259 MWh were used (17 %). In Table 4.4 the annual quantities of biogas, electricity and heat used for the LCAs for the three Cases investigated are documented.

Table 4.4: Annual biogas, electricity and heat production

Examined cases	Biogas M Nm^3/yr	Electricity MWh/yr			Heat MWh/yr			
		Cogen gas engines	Natural gas combined cycle power plant	Sum	Cogen gas engines	Extra light oil central heating	Wood log stove	Sum
Biogas plant closed storage (Paldau)	2.4	4,029	0	4,029	1,259 of 7,250	0	0	1,259
Biogas plant open storage	2.3	3,952	77	4,029	1,259	0	0	1,259
Reference system I	0	0	4,029	4,029	0	1,209	50	1,259

natural gas combined cycle power plant
cogeneration gas engine

The available heat from the Paldau biogas plant is only partly used. In a first step, five farm houses and dwellings near the biogas plant were connected to the plant to use the heat for room and barn heating. This resulted in 107 MWh used per year. The operators of the biogas plant tried to find additional opportunities to use available heat and in autumn 2006 a 800 kW capacity maize drying facility was installed. The facility operates two months a year, using 1,152 MWh of heat per year. With this addition, 1,259 MWh of heat are used but this still only represents 17 % of the total available heat: 7,250 MWh per year. The operators continue to look for additional heat uses.

The measurements of the biogas produced in the closed storage tank show a mean value of 3.9 Nm^3 per hour, or 34,160 Nm^3 per year if the storage tank remained closed (see Chapter 3, page 6 for further details). In the LCA calculations made in this report, the assumption was made that the storage tank remained closed during material removal[3]. Thus the calculations are based on best-practise operation of a closed biogas plant. The CH_4 concentration of the biogas in the storage tank 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 tank under best management practices.

[3] It is not necessary to open the storage tank to remove the digested materials, as done by the operators

4.3.4 Methane-slip data

Some analyses show that gas-powered combined heat and power plants have a so-called "methane slip", due to incomplete combustion. As a result, the flue gas contains some methane which is released into the atmosphere. The extent of methane slip is mainly dependent on the CH_4 content of the gas, the technical construction of the engine and the size of the plant. GE Energy Jenbacher Gasmotoren (GE Energy Jenbacher Gasmotoren, 2005) developed a thermal post treatment system called "CL.AIR" to reduce C_nH_m and also other emissions (such as CO and HCHO).

A summary of literature on methane slip together with results of methane concentration measurements in flue gases of biogas-powered combined heat and power plants in Austria, Denmark, and Germany is shown in Table 4.5.

The measured values are between 280 and 2,333 mg/Nm^3. This analysis uses the methane slip value of 1.79 percent - the value from BOKU, Austria - because it is a representative value for Austrian biogas plants. The resulting methane concentration of 1,100 mg/Nm^3 lies in the middle of the spectrum of the values documented in Table 4.5. Application of the 1.79% value to the Paldau plant results in CH_4 emissions of 14.6 tons per year. The impacts of methane slip on GHG balances of this study are discussed in section 4.5.2, pages 20 - 21.

Table 4.5: Results of Methane Slip Measurements in Gas Engines

Literature source	**kW_{el} of gas engine**	**CH_4-concentration in biogas in Vol %**	**CH_4-concentration in flue gas in mg/Nm^3**	**Comments**
Bayrisches Landesamt für Umwelt, 2006, Germany	30 – 340	55	290 [1)]	[1)] This value is for C_nH_m concentration, which largely corresponds with CH_4 concentration.
Danish Gas Technology Centre 2004	Not specified	65	880-920 [2)]	[2)] A value of 2.200 - 2.300 mg/Nm^3 C_nH_m was measured for natural gas. A conversion factor of 0.4 for biogas use is indicated. By applying this factor, the values 880 - 920 mg/Nm^3 are obtained.
FTU 2007, Austria Measurements of 4 different Biogas-CHP engines, Not published	348 249 130 130	64 61 60 60	861 2,333 280 293	
Report of BOKU, IFA-Tulln, 2007, Austria, Institute of Biotechnology Not published	500	55	1,100 [3)]	[3)] A methane slip of 1.79 % CH_4 is reported. This percentage was converted to its mg/Nm^3 equivalent, assuming a 5% O_2 concentration in the flue gas.

4.4 System boundaries for LCA analyses and description of cases

Figure 4.3 provides simplified, schematic diagrams of the three basic cases:

- The existing biogas plant Paldau with a closed storage,
- A theoretical biogas plant similar to Paldau but with open storage,
- A Reference System I: no biogas plant. An equivalent amount of electricity is produced by a natural gas power plant and an equivalent amount of heat from oil and wood.

The lower biogas production in the biogas plant without a closed storage results in lower electricity production. The electricity supply in the open storage case 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. In Reference system I, heat is delivered equivalent to that currently used from the Paldau plant.

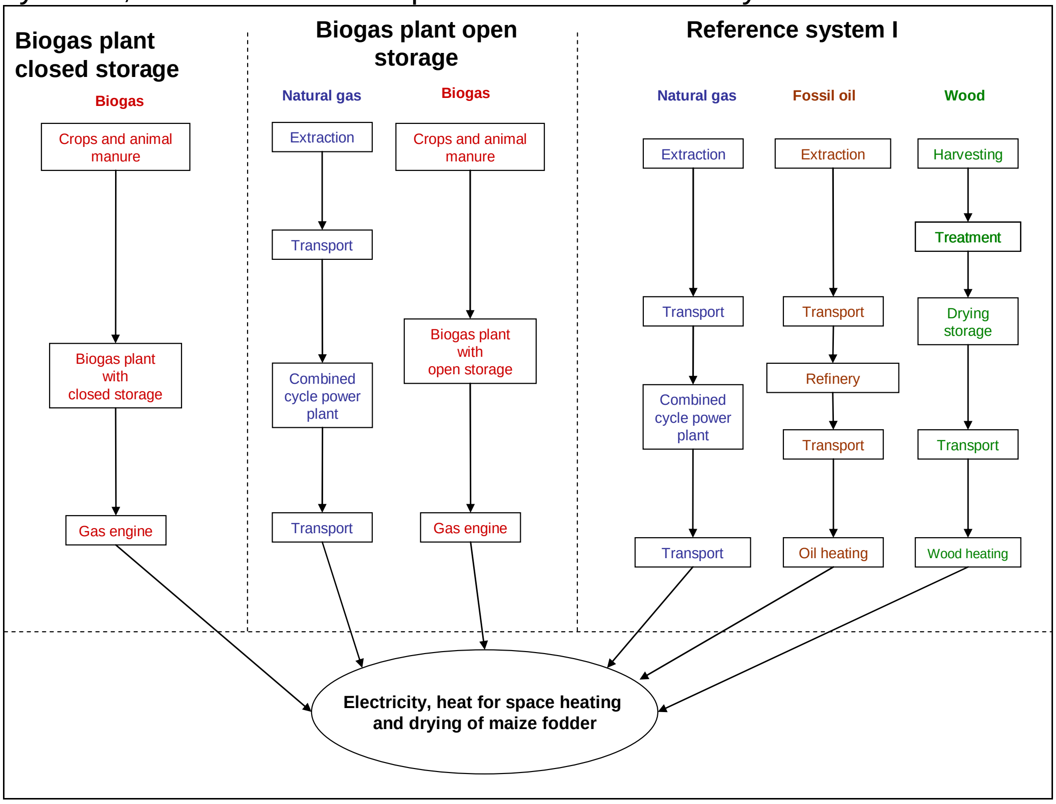

Figure 4.3: Schematic of the 3 considered basic cases (simplified)

Since only 17 % of the available heat from the biogas plant is used, the level of heat represented in Reference system I was set at that of current use. For the sensitivity analysis an optimized Reference system II was developed in which all produced heat is utilized (see Chapter 4.5.5. page 24 for further information).

As functional unit GHG emissions were calculated in tons per year. These values were then converted in terms of GHG emission reductions in comparison to reference system, and per unit of energy output (kWh) and per ton of biomass (t_{DM}).

4.4.1 Biogas plant with closed storage (Paldau)

Figure 4.4 shows system boundaries for the Paldau biogas plant and Reference Case I. The ovals common to both systems (centre of diagram) are used to portray that the two cases utilize same amounts of: manure, land area, grass.

The case of fertilizer is somewhat complex. To equalize crop growth between the reference and biogas case, some synthetic fertilizer has to be used in the reference case. This is due to the lower effectiveness of undigested animal manure compared to digested. Further, to produce the same amount of fodder in both cases, some synthetic fertilizer is also needed - and has been included in - the cultivation of corn and maize silage step in the biogas plant value chain. This is needed to produce the required higher per hectare yields. See pages 16 and 17 for further discussion of these issues. The Reference case produces the same amount of electricity and used heat as the Paldau case.

LCA estimates of GHG emissions cover emissions from: (a) cultivation and harvesting of biomass including emissions from fertilizers (b) transport of resources to electricity production or heat use-facilities, (c) combustion of biomass or fossil fuels, and (d) constructing and dismantling of the energy plants. In the Paldau case, emissions from direct land use change (dLUC) are included, and in the Reference case emissions from extraction and refining of fossil fuels are included. Digested manure from the biogas plant is used as a fertilizer, substituting for a combination of synthetic fertilizers and undigested manure in the reference system. As mentioned previously, CH_4 emissions that occur in Reference system due to storage and use of untreated manure have been subtracted from LCA calculations.

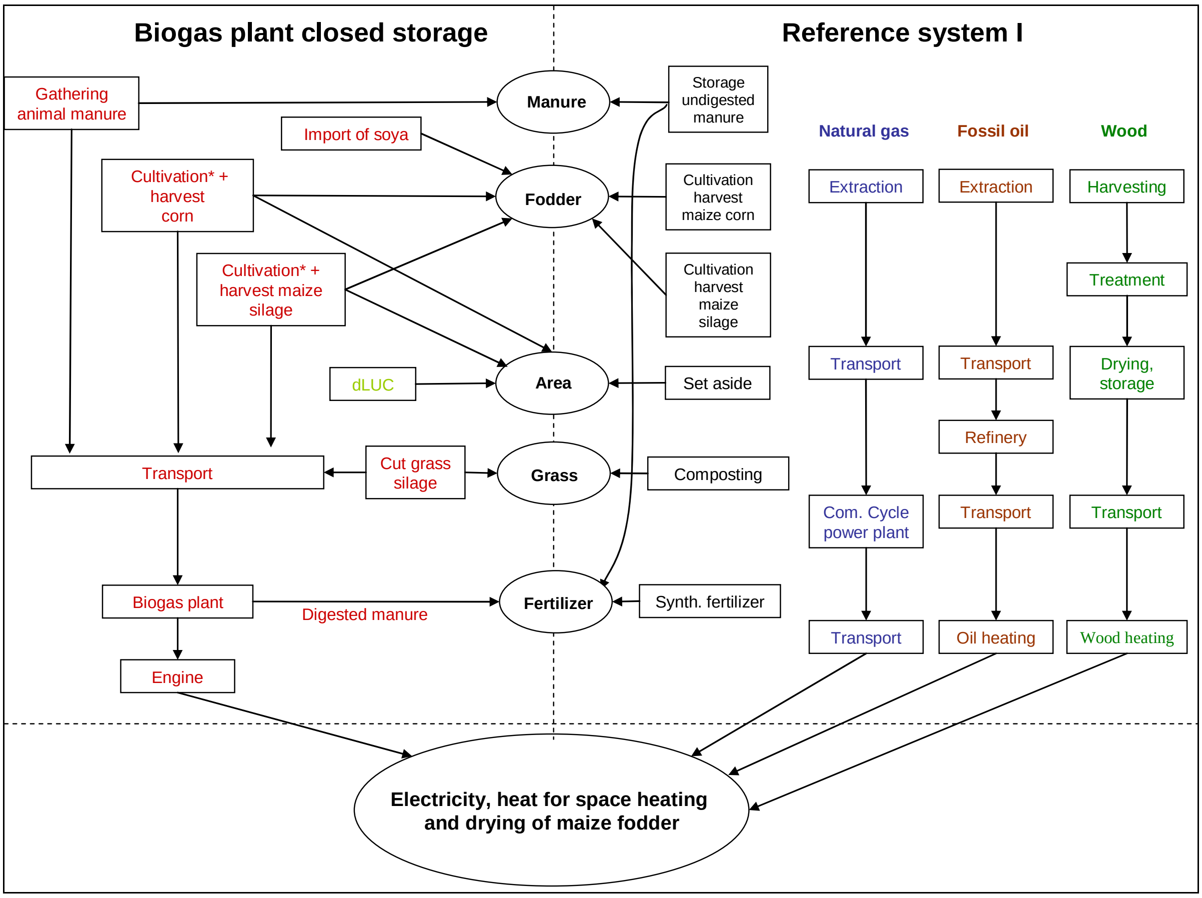

Figure 4.4: process chains of the biogas plant with closed storage and of reference system I (* These boxes include additional fertilizer for increased yield of corn and maize silage)

Animal manure used in the Paldau plant is delivered by pipeline (1,800m^3/a) from two farms and by tractor (1,240 m^3/a) from three farms. The energy use for pipelines (electric pump) is low and has not been included.

Since maize silage and corn previously used for fodder is sent to the biogas plant, the reduction in fodder supply is made up 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 cover 60 percent of the deficit with the other 40 percent addressed through soy imports.

Tab. 4.6: Source of animal fodder replacing biomass utilized for biogas

	Set aside land	Agricultural land use		Sum
		Substitution of animal fodder by soya imports	Substitution of animal fodder by increased yield	
Corn	20%	40%	40%	100%
Maize silage	20%	40%	40%	100%

4.4.2 Biogas plant with open storage

Figure 4.5 illustrates the process chains and system boundaries of a biogas plant using inputs identical to those of the Paldau system but using open storage. Measurements show that in an open system 34,160 m^3 less biogas is available for use by the gas engines per year. This results in generation of 76.000 kWh less electricity. This deficit is made up through electricity from a natural gas plant. The attendant emissions are thus included in the system boundaries of the open-storage case.

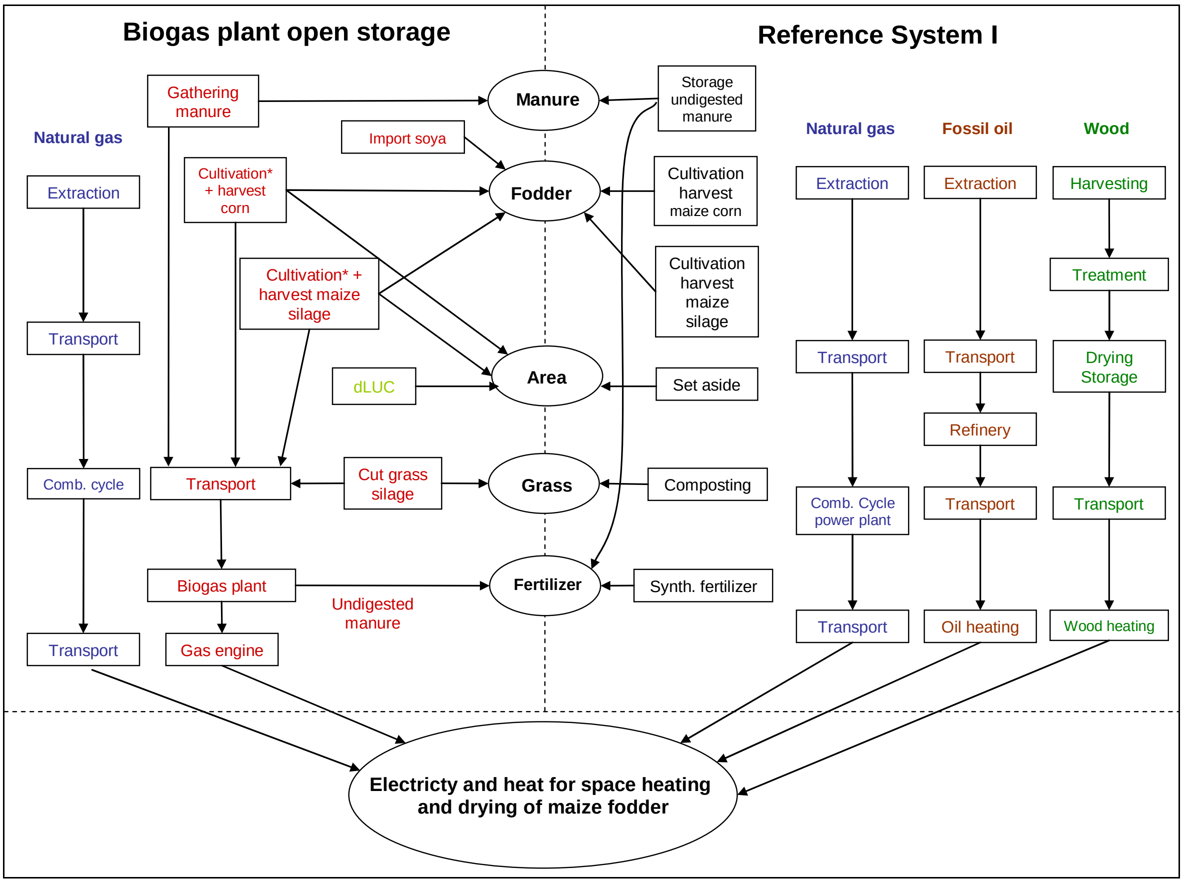

Figure 4.5: process chains of the biogas plant with open storage and of reference system I. (* These boxes include additional fertilizer for increased yield of corn and maize silage)

4.4.3 Reference systems

4.4.3.1 Reference system I

The process chains and system boundaries of Reference system I are shown in Figures 4.4 and 4.5. As mentioned in section 4.4.1, Reference system I utilises the same amounts of: manure, land area and grass as the Paldau case and provides the same amounts of electricity and used heat, and animal fodder. See page 14-15 for a discussion of fertilizer use.

In the Reference case, 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 is composted and then used as fertilizer instead of as an input. In Reference case I, set-aside land is mowed once a year and the cut grass left as mulch. Heat and electricity are sourced from conventional energy sources. All the corresponding GHG emissions are considered in the LCA.

In the Reference case, the cow and pig manure is stored undigested and then used as fertilizer for the cultivation of maize silage and corn. The CH_4 and N_2O emissions to the atmosphere from the undigested manure are not included in Reference system I GHG calculations and equivalent amounts are subtracted from biogas plant GHG calculations. As undigested animal manure is 20 percent less effective as fertilizer than digested manure (Amon 1998, Boxberger et al, 2002), some synthetic fertilizer was included in the Reference system to equalize the systems in this respect.

As electricity consumption in Austria is increasing, a new power plant would be needed if the electricity produced by the biogas plant were not available. Natural gas combined cycle power plants are being used to meet increased demand across Austria, including in the Styrian power plant park which supplies power to the region in which Paldau lies. Therefore, electricity to match that supplied by the Paldau plant was assumed to come from a natural-gas combined-cycle plant.

In Reference system I, heat is provided by four domestic oil heating systems and one domestic wood log heating system. These are the systems which were in use prior to the availability of the heat from the biogas plant. The additional atmospheric CO_2 removals that would occur by leaving the wood in the forests are not included in the biogas plant GHG calculations. For drying maize, a traditional oil-based dryer is used in the reference system.

4.4.3.2 Reference system II

For a more complete evaluation of the possible benefits of a closed-storage biogas plant, the analysis included consideration of full utilisation of produced heat. Reference system II has been developed to show the impacts under conditions in which all produced heat from the biogas plant is utilised. The electricity is the same as in Reference system I, but more heat needs to be produced in Reference system II to match total heat output from the biogas plant. In Reference system II, 7,250 MWh/yr of heat are included as compared to 1,259 MWh/yr in Reference system I. Oil heating and wood-log heating systems are used in the same proportion as in Reference system I. The forest carbon stock change is excluded from the analysis.

4.5 Results

The following sections describe the GHG emissions calculated in the Life Cycle Inventory analysis in the following order:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)

GHG emissions were first calculated in tons per year. To determine overall GHG emission impacts, tons of emissions are converted into their CO_2 equivalents (CO_2-eq) using the factors listed in section 4.2.

4.5.1 Carbon dioxide emissions (CO_2)

This subsection first provides the CO_2 results from dLUC and then briefly presents other CO_2 contributions to the LCA. The difference between the SOC in cropland and grassland (4.9 t C/ha) is positive, meaning that on average there is a carbon sequestration (net removals of CO_2 from the atmosphere) when land is converted from grassland to cropland (Figure 4.6). This result is based on the Styrian Soil Carbon Database which has been judged more appropriate to represent local conditions than the IPCC default values.

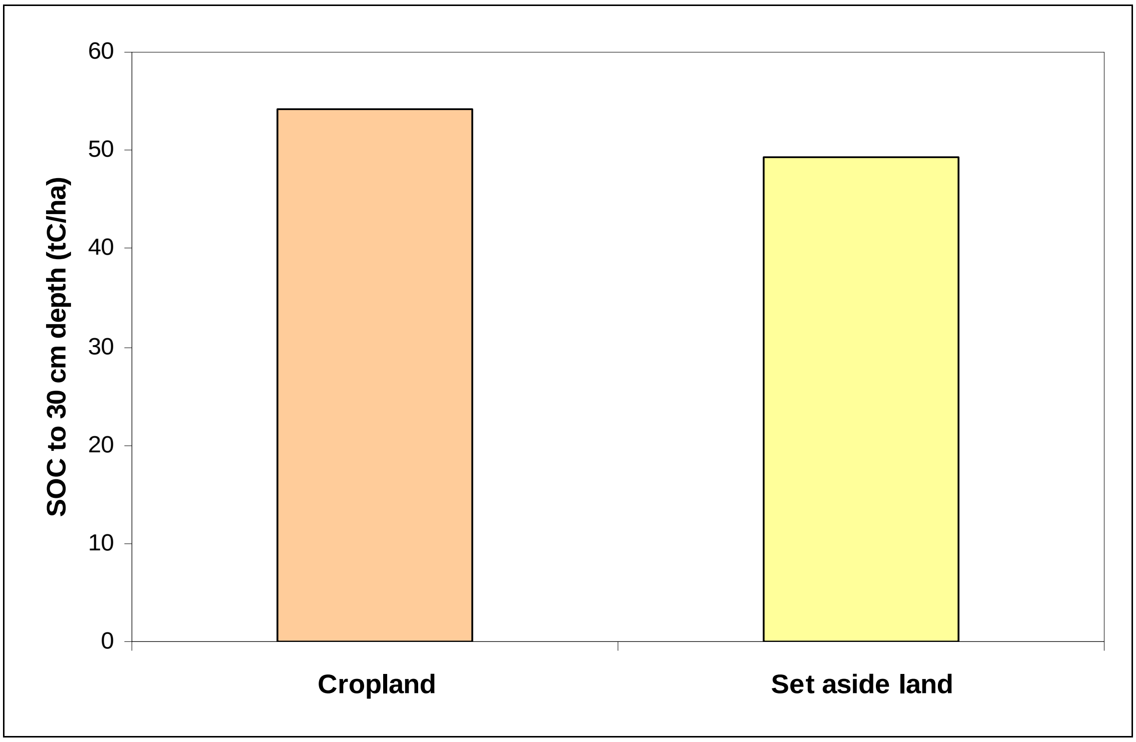

Figure 4.6: Soil Organic Carbon (SOC) for cropland and set aside land (grassland)

If the IPCC Guidelines (IPCC, 2006) default values are used to calculate the SOC change due to the conversion, a carbon stock decrease would be assumed to occur. Using IPCC default values, the SOC would decrease from 77.9 to 65.5 t C/ha when set-aside is converted to cropland. However, IPCC default values are based on global databases that include very variable conditions (±90% nominal error for the reference soil organic carbon stocks, IPCC 2006). The Styrian Soil Carbon Database values suggest either that grasslands are located on poor or degraded soils or that management practices are in place with significantly more beneficial soil carbon impacts than is generally the case. When distributed over a 20 year period, the increase in SOC is 0.25 t C/ha/yr or 0.90 t CO_2/ha/yr. For the entire area of 53 ha of land converted, these results in annual removals of approximately 48 tons of CO_2.

CO_2 emissions also derive from the use of fossil energy, required along the full biogas chain: e.g. for cultivation, harvest and transport of the used energy crops, and for the transport of the animal manure. In the case of the closed-storage biogas plant these amount to 251 t CO_2/yr and in the open storage case to 282 t CO_2/yr per year. The open storage plant system results in 31 t CO_2/yr more emissions due to the need to source some electricity from the natural gas combined cycle power plant. Reference system I results in a total of 2,224 t CO_2/yr, due to large amounts of fossil energy used for electricity and heat production.

As shown in Figure 4.7, CO_2 emissions of the closed storage biogas plant are 86% lower than those of the Reference case; those of the biogas plant with open storage are 85% lower. The carbon sequestration related to dLUC (shown in orange) constitutes 19 percent of the total CO_2 emissions of the Paldau biogas plant. Thus they make a non-negligible contribution to its net emission profile. Taking these "negative" emissions into account, the Paldau unit emits 202 t CO_2/yr, which is the lowest value of all considered cases.

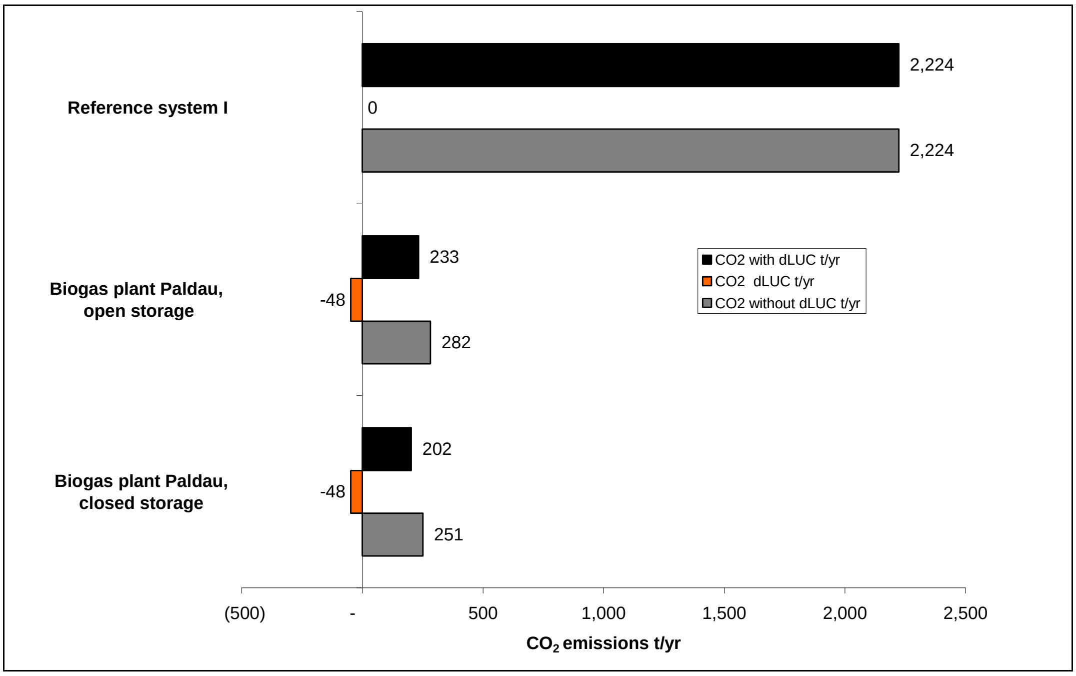

Figure 4.7: CO_2 emissions with specification of 48 tons sequestrated by dLUC in the energy systems of the biogas plants

4.5.2 Methane emissions (CH_4)

As shown in Figure 4.8, the closed-storage biogas plant has CH_4 emissions of 9.6 t/yr. This figure includes 14.6 tons due to the methane slip (see chapter 4.3.4, page 13) and the quantity subtracted to allow for the difference in methane emissions from manure handling between the biogas and reference cases (see chapter 4.4.31, page 17). The open-storage biogas plant emits 25.2 t CH_4/yr. These higher CH_4 emissions are mainly due to methane losses from open storage of biomass after digestion in the primary and secondary digesters. Without the methane slip, the biogas plant with open storage has CH_4 emissions of 10.9 tons per year. The CH_4 emissions of Reference system I, excluding emissions from the undigested manure are 10.9 t/yr. These include CH_4 emitted during natural gas extraction, electricity production, and from gas pipelines.

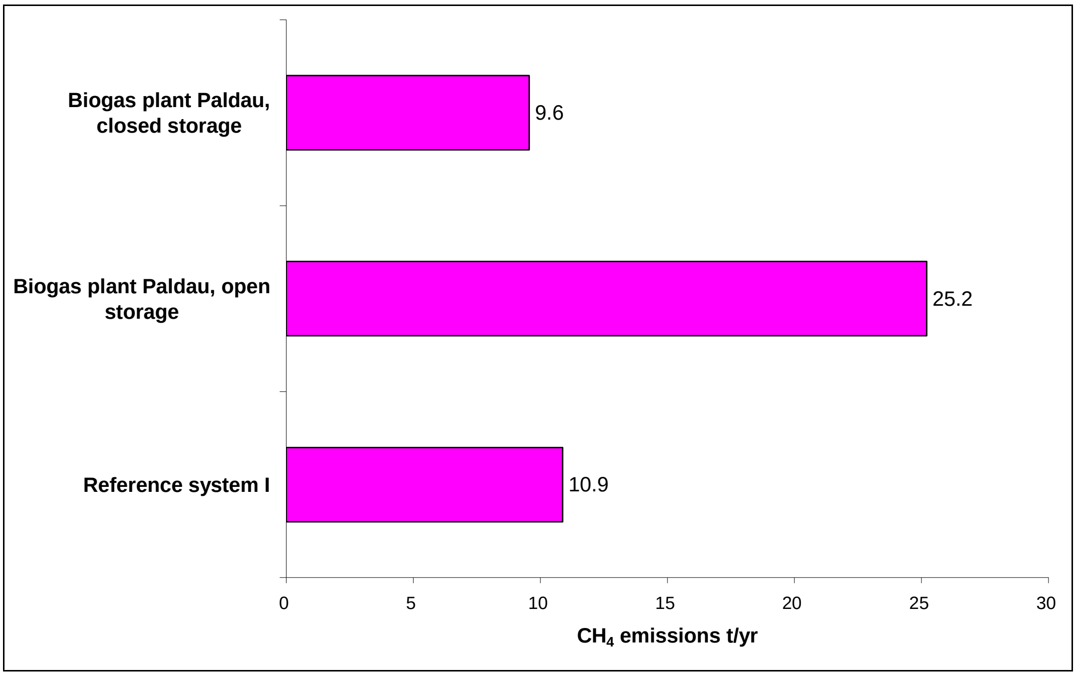

Figure 4.8: CH_4 emissions including a methane slip of 1.79 %

4.5.3 Nitrous oxide emissions (N_2O)

The N_2O emissions are mainly caused by denitrification of nitrogen fertilizer applied to crops.

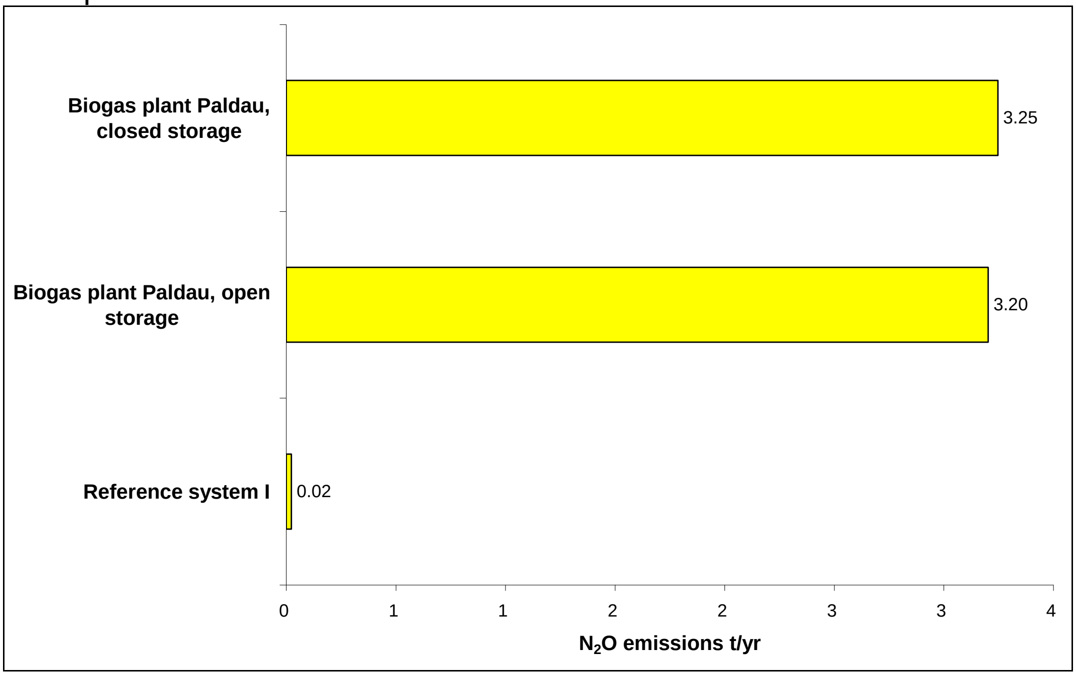

Figure 4.9: N_2O emissions

Only the N_2O from additional fertilizers applied in the biogas cases is included. Those of the biogas cases amount to 3.25 tons per year for the system with closed storage, while that of the case with open-storage plant are slightly lower at 3.20 tons per year (see Figure 4.9). Since N_2O emissions from combustion of biogas are higher than from the combustion of natural gas, N_2O emissions are lower for the biogas plant with open storage because some electricity is produced from natural gas (see Table 4.4 on page 12). There is a small emission in the reference system due to combustion of natural gas.

4.5.4 Greenhouse gas emissions: CO_2-equivalent emissions (CO_2-eq)

Conversion of emissions from various gases to their CO_2-equivalents enables a comparison of all systems across all examined GHGs. Table 4.7 shows the GHG emissions and the resultant total CO_2-eq using the conversion factors shown in Chapter 4.2, page 7.

Table 4.7: CO_2, CH_4, and N_2O emissions, and CO_2 -equivalent emissions

GHG emissions t/yr	CO_2 t/yr	CH_4 t/yr	N_2O t/yr	CO_2-eq. t/yr
Biogas plant Paldau, closed storage	202	9.6	3.25	1,409
Biogas plant Paldau, open storage	235	25.2	3.20	1,818
Reference system I	2,224	10.9	0.02	2,502

Figure 4.10 shows all GHG emissions in CO_2-eq (CH_4 and N_2O emissions are expressed in CO_2-equivalents). The closed storage plant has the lowest emissions, 1,409 t CO_2-eq/yr. If the emissions reductions due to dLUC are not considered, closed storage emissions would be 1,457 t CO_2-eq/yr (see Figure 4.11). Thus dLUC reduces total CO_2-eq emissions by 3.4 %. The biogas plant with an open storage results in 1,818 tCO_2-eq/yr and the Reference system I in 2,502 t CO_2-eq/yr.

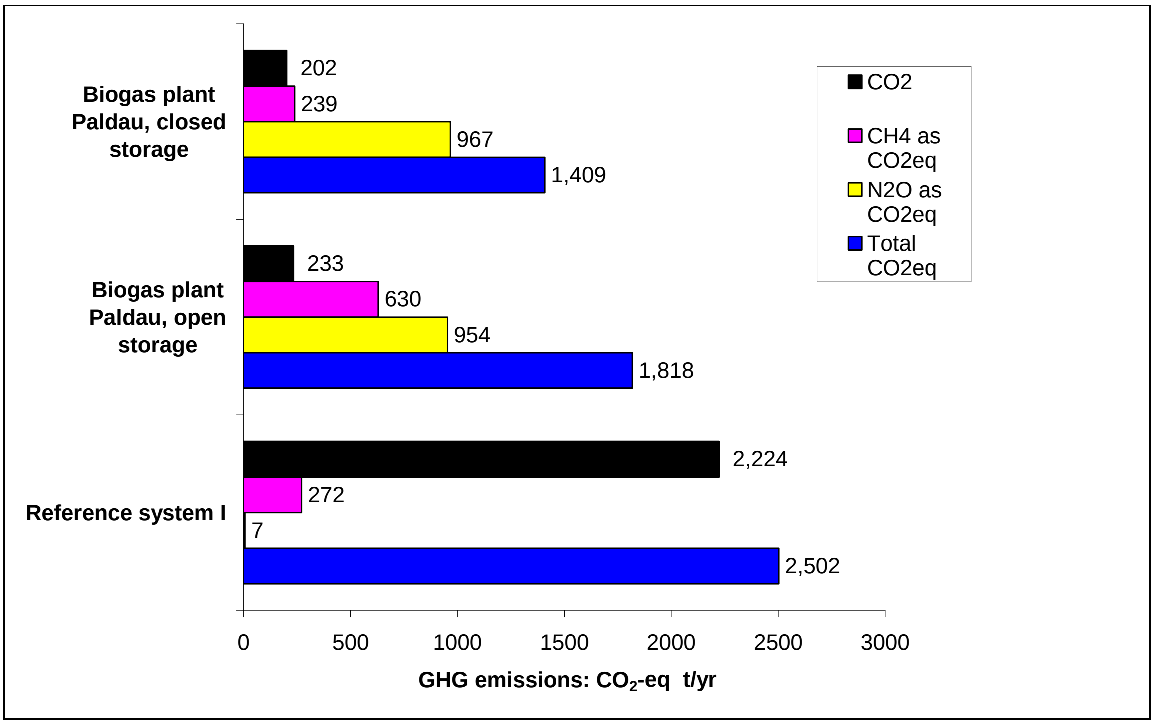

Figure 4.10: GHG emissions in CO_2-equivalent emissions per year.

Note: The 48 tons of CO_2 emission reductions from dLUC are included in biogas plant calculations.

The CO_2-eq emissions of the closed storage plant are 44 % lower than those of Reference system I and those of the open storage are 27 % lower. The difference between the two biogas plants is mainly attributable to the release of CH_4 emissions from open storage of the digested materials.

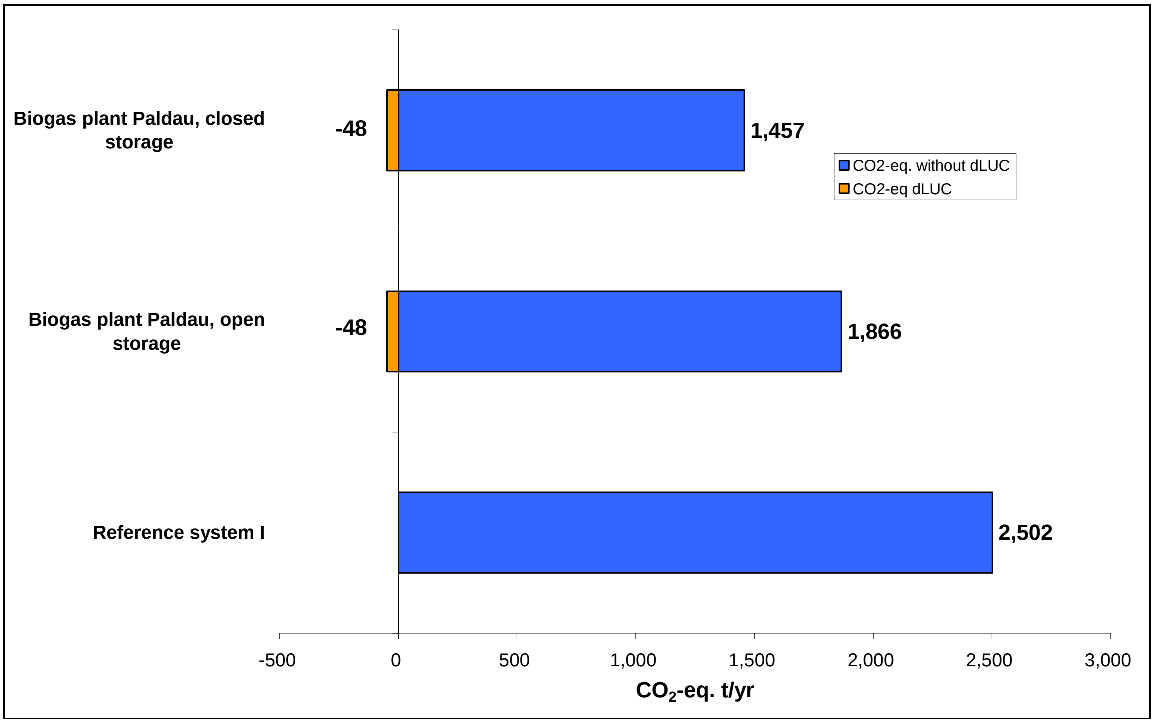

Figure 4.11: Total GHG emissions in CO_2 equivalent emissions per year including impact of dLUC

Table 4.8 shows GHG emission savings per year to produce energy equivalent to that of Reference system I. As can be seen, there is a large reduction in CO_2. The closed storage system provides a small reduction in CH_4 emissions (1.3 t/yr) but open storage results in more CH_4 emissions than Reference system I. For both biogas plants, N_2O emissions are higher than in the Reference system because of additional nitrogen fertilizer needed to achieve higher yields of maize silage and corn. Combining these results, closed storage provides total GHG emission reductions of 1,094 t CO_2-eq/yr. and open storage 685 t CO_2-eq/yr compared to the Reference system.

Table 4.8: GHG emission reductions t/yr in comparison to reference system

GHG emission reductions t/yr in comparison to reference system I	CO_2 t/yr	CH_4 t/yr	N_2O t/yr	CO_2-eq. t/yr
Biogas plant Paldau, closed storage	2,021	1.3	-3.22	1,094
Biogas plant Paldau, open storage	1,989	-14.3	-3.18	685

Tables 4.9 and 4.10 show the GHG emissions, and emissions reduction, respectively, per kWh produced. These calculations assume that each kWh output comprises 0.76 kWh_e and 0.24 kWh_{th},, based on the relative distribution between the energy outputs characteristic of the Paldau plant. Table 4.9 shows the results for the two biogas plants and Reference system I. Total GHG emissions are: 266 g CO_2-eq

per kWh, 344 g CO_2-eq; and 473 g CO_2-eq for the closed, open and Reference systems respectively.

Table 4.9: GHG emissions per kWh

GHG emissions g per kWh	g CO_2 / kWh	g CH_4 / kWh	g N_2O / kWh	g CO_2-eq. / kWh
Biogas plant Paldau, closed storage	38	2	1	**266**
Biogas plant Paldau, open storage	44	5	1	**344**
Reference system I	421	2	0	**473**
Reference system II more heat	806	2	0	**930**

Note: Each kWh is composed of 0.76 kWh_e and 0.24 kWh_{th}

Table 4.10 shows the GHG emission reductions of the biogas plant systems compared to the Reference system I in g per unit of energy output.

Table 4.10: GHG emission reductions per kWh compared to Reference system I

GHG emission reductions per kWh in comparison to reference system I	g CO_2 / kWh	g CH_4 / kWh	g N_2O / kWh	g CO_2-eq. / kWh
Biogas plant Paldau, closed storage	382	0	-1	207
Biogas plant Paldau, open storage	376	-3	-1	130

Note: Each kWh is composed of 0.76 kWh_e and 0.24 kWh_{th}

In Table 4.11 the GHG emission reductions in comparison to Reference system I have been calculated per ton of dry biomass feedstock (t_{DM}). For each ton 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.

Table 4.11: GHG emission reductions kg per t_{DM} of biomass feedstock compared to reference system I

GHG emission reductions per t_{DM} biomass (reference system I)	kg CO_2 / t	kg CH_4 / t	kg N_2O / t	kg CO_2-eq. / t
Biogas plant Paldau, closed storage	540	0.4	-0.9	292
Biogas plant Paldau, open storage	532	-3.8	-0.8	183

4.5.5 Sensitivity Analysis

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

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

Figure 4.12 shows GHG emissions of Reference system II and illustrates the impact of the use of 100% of the heat of the Paldau plant. Reference system II, like Reference system I, has no biogas plant. Under these conditions, 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.

In Figure 4.12 the total CO_2-eq emissions for Reference system II and I are shown along with emissions of the biogas plant Paldau, closed storage.

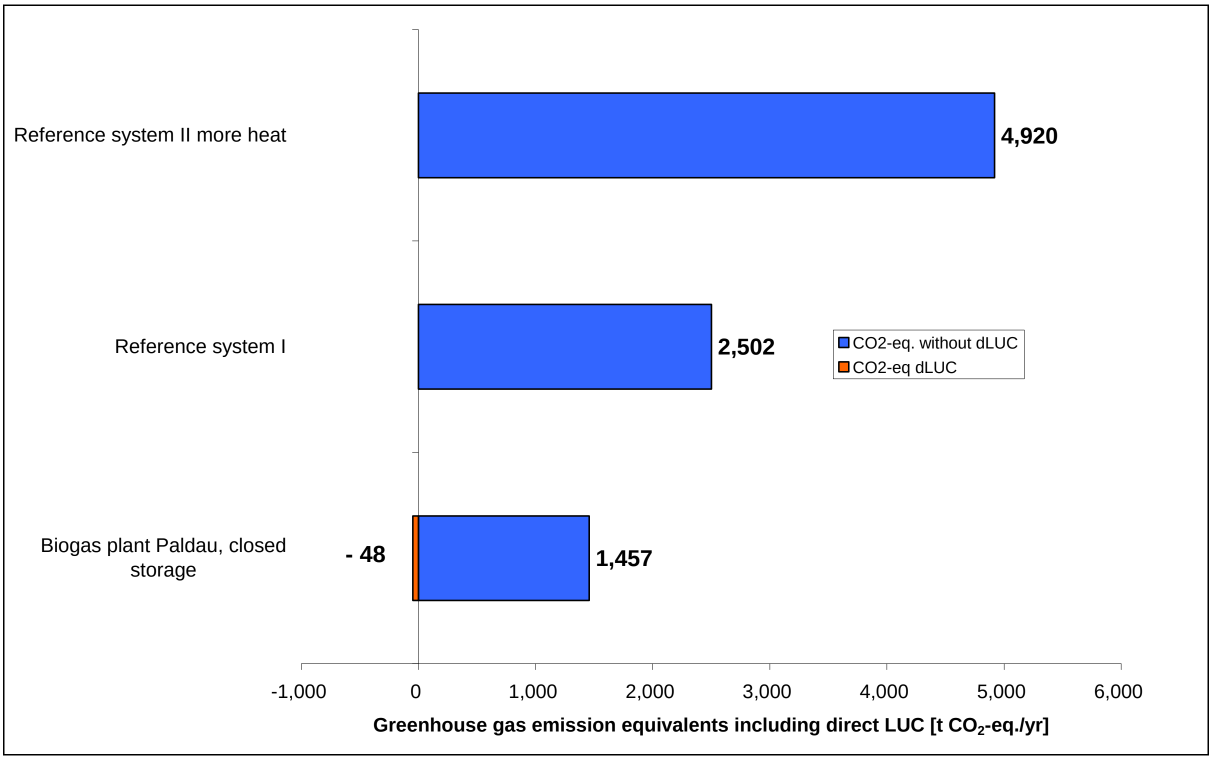

Figure 4.12: Total CO_2-equivalent emissions per year for the biogas plant Paldau and two reference systems (with specification dLUC for biogas plant)

Reference system II results in emissions of: 4,612 t CO_2/yr; 11.6 t CH_4/yr and 0.06 t N_2O/yr. Table 4.12 compares emissions from the biogas plant Paldau to these emissions.

Table 4.12 : GHG emission reductions in t/yr and total in CO_2-eq/yr compared to Reference system II

GHG emission reductions t/yr in comparison to reference system II	**CO_2 t/yr**	**CH_4 t/yr**	**N_2O t/yr**	**CO_2-eq. t/yr**
Biogas plant Paldau, closed storage	4,410	2.1	-3.19	3,511

Note: Positive numbers represent reductions; negative numbers emission increases

In Table 4.13 the GHG emission reductions of the biogas plant Paldau compared to the Reference system II are shown in terms of grams per unit of total energy produced. The use of all heat produced by the biogas system results in a new distribution (one-to-two) of emissions between the two forms of energy (0.36 kWh_e and 0.64 kWh_{th}.)

Table 4.13: GHG emission reductions through deployment of the biogas plant Paldau in comparison with Reference system II in grams per kWh.

GHG emission reductions per kWh in comparison to reference system II	g CO_2 / kWh	g CH_4 / kWh	g N_2O / kWh	g CO_2-eq. / kWh
Biogas plant Paldau, closed storage	834	0	-1	664

Note: Each kWh is composed of 0.36 kWh_e and 0.64 kWh_{th}

Table 4.14 shows the GHG emission reductions of the biogas plant Paldau in kg per t_{DM} of biomass feedstock in comparison with Reference system II. Comparing the figures for the biogas plant Paldau, closed storage, in Table 4.14 to those in Table 4.11 reveals that significantly greater GHG emission reductions result per unit of biomass input if all available heat from the biogas plant is used. Given the multiple demands on land and biomass, efficient use of biomass is an important consideration.

Table 4.14: GHG emission reductions through deployment of the biogas plant Paldau in kg per t_{DM} of biomass feedstock in comparison with reference system II

GHG emission reductions per t_{DM} biomass (reference system II)	kg CO_2 / t	kg CH_4 / t	kg N_2O / t	kg CO_2-eq./t
Biogas plant Paldau, closed storage	1,178	0.5	-0.9	938

Figure 4.13 shows results of the analysis examining both, use of higher percentage of manure in the feedstock mix and higher losses of methane from the biogas plants. Increasing percentage of CH_4 emission losses are shown on the x-axis and total GHG emissions on the y-axis.

Looking first at changes in feedstock mix, the diagonal green line represents biogas plants using the mix of crops and manure used by the Paldau plant. The diagonal black line represents use of 100 % manure and is based on Jungmeier et al., 1999. Emissions are lower in a 100% manure-based system biogas system because CH_4 and N_2O emissions from fertilizer application and manure storage are avoided. The dashed diagonal lines show emissions if the methane slip is reduced to zero. The horizontal blue line represents emissions in Reference system I: the horizontal red line shows Reference system II.

The diagram shows what happens as CH_4 losses in the biogas plants increase. Assuming the Paldau plant has zero CH_4 losses, an increase to 5 % loss would bring its emissions up to those of Reference system I (red dot P1). Since it is assumed that the open storage system starts with the CH_4 losses of 1.9 %, if losses increase by three percent the open storage system will also have emissions equal to Reference system I. However, if a closed storage plant uses 100 % manure (black diagonal line), it could withstand CH_4 losses of some 18 % before its emissions would equal those of Reference system I (red dot P2). Similarly, the Paldau plant could withstand CH_4 losses of about 15.5 % if the heat was fully used before its emissions would exceed those of a system without a biogas plant (Reference system II) (P3). A closed storage plant based on 100 % manure could have CH_4 losses of some 28 % for the same circumstances (P4).

Only points P1 and P3 were calculated in the LCA. Points P2 and P4 are based on rough estimations, which would have to be verified by LCA assessments of such biogas plants.

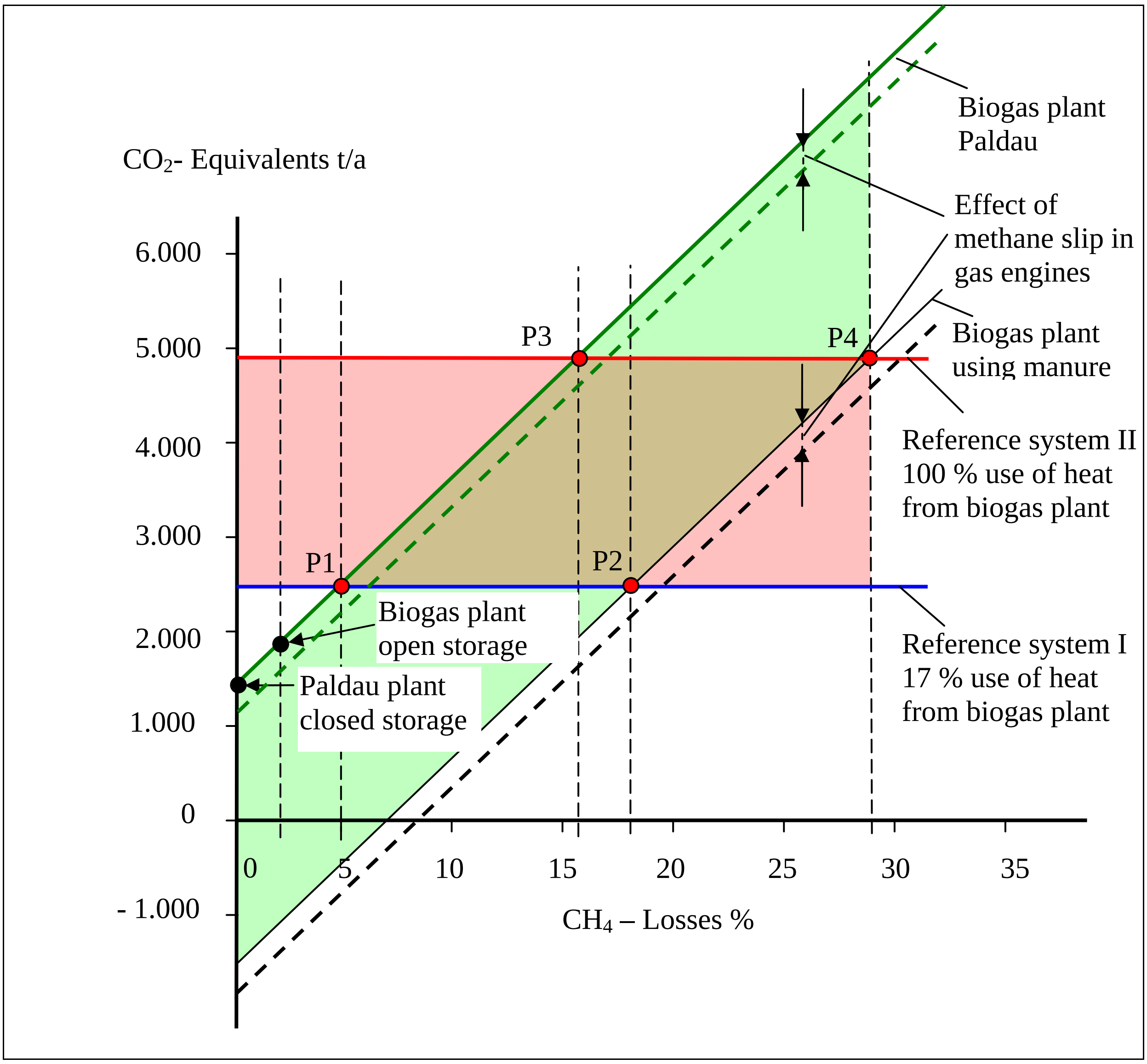

Figure 4.13: CO_2-eq emissions versus CH_4 losses.
Note: values in x-axes shown are percent of total CH_4 production lost

5. Summary and Conclusions

This study examined life-cycle GHG emissions of biogas plants, based on data from a closed storage plant operated by "NegH Biostrom KG" in Paldau. Biogas production from the closed storage tank was measured from May to October 2006, the production period between removals of digested materials from the storage tank. The average value of the measured gas production over this period was 3.9 Nm^3/h, corresponding to a value of 34,160 Nm^3 or 15.6 tons of CH_4 per year.

The GHG impacts of the Paldau plant were compared to two other options: a biogas plant with open-air storage and a Reference system I which provides equivalent amounts of electricity and heat to that used in the biogas systems, from traditional sources (a gas-fired power plant, heating oil, and wood). It was assumed that if the digested materials had been stored in an open storage tank, 34,160 Nm^3 of CH_4 per year would have been discharged into the atmosphere. In addition, due to reduced production of useful methane for combustion, electricity from traditional sources would have to be used to reach the same energy output, leading to further emissions. Comparison of the biogas plants with the reference system documents the GHG benefits of biogas technology for producing energy: Paldau's emissions were 1,409 t CO_2-eq/yr; open-storage plant's emissions were calculated to be 1,818 t CO_2-eq/yr; and Reference system I emissions were calculated to amount to 2,502 t CO_2-eq/yr.

Significant results of the analysis include:

- Open storage results in 29 % higher CO_2-eq emissions than closed storage.
- Open storage results in 1.4 % lower biogas production than closed storage.
- Electricity and heat output from an open biogas plant is 1.9 % less.
- Compared to provision of an equal amount of electricity and used heat from traditional sources (Reference system I), the closed biogas plant reduced total GHG emissions by 44 % (1,094 t CO_2-eq/yr) and open storage by 27 % (685 t CO_2-eq/yr).
- This equates to emissions savings of 292 kg CO_2-eq per t dry biomass for the closed storage system and 183 kg for the open storage.

Meanwhile the Federal Ministry of Economy and Work published a technical document for the assessment of new constructed Biogas plants (BMWA, 2007), in which it is recommended to have a closed storage tank for the digested material.

A sensitivity analysis examined the impacts of full use of the heat produced by the biogas plant Paldau and increased losses of methane. If all heat produced by a biogas plant can be used, GHG emission benefits increase significantly as does efficiency of use of biomass. Where crops are the major feedstock and only a small percent of heat produced is used, relatively small (5 percent or less) increases in the percent of methane losses can nullify benefits compared to a no biogas plant system. If manure is used as the feedstock, greater methane losses (up to 18 percent) still bring benefits. The sensitivity analysis suggests that increased percents of animal manure in the feedstock mix results in higher potential GHG emission benefits. These theoretical results need to be substantiated through further studies of plants in operation.

Consequently, support for biogas plants should not be based solely on electricity generated. Opportunities to use available heat should be taken into consideration. In Austria, the amendment of the RES-Electricity Law of February 2010 (Ökostromverordnung 2010) has started to address these issues. Operators now receive a CHP bonus of 2 cent for every kWh heat, require an efficiency factor for biomass used of 60 %, and stipulate a minimum share of 30 % animal manure in biogas plants.

Joanneum Research is continuing work on LCA of biogas plants, looking for factors that contribute to their successful operation in Austria, to GHG emission reductions, and to sustainable production of heat and power. New results can be expected from this work (Pucker J. et al, 2010).

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. In Austrian agriculture large amounts of animal manure are still not digested, resulting in substantial, detrimental GHG emissions.

6. Photographs

Photograph 6.1: Biogas Plant Paldau

Photograph 6.2: Standing silos for corn and cover of underground main digester 1.

Photograph 6.3: Underground mixing tank of Biogas plant Paldau

Photograph 6.4: View into the underground mixing tank of the biogas plant Paldau

Photograph 6.5: Two drive-in open silos for maize and grass silage

Photograph 6.6: The daily silage container

Photograph 6.7: Closed storage tank of digested material (concrete cover)

Photograph 6.8: Biogas flow meter of company ESTERS Elektronik, Type 005 GD 100 / with data processor GVPA-303-GDR, for measurements of the biogas flow from the storage to the other part (secondary digester) of the biogas plant.

Photograph 6.9: data processor GVPA-303-GDR Exia

Photograph 6.10: Computational data aquisition system

References

Amon T 1998: Reduktionspotentiale für klimarelevante Spurengase durch dezentrale Biomethanisierung in der Landwirtschaft. BOKU-Wien, Hrsg. Bundesministerium für Umwelt, Jugend und Familie, ISBN 3-901 305-97-1. Wien, 1998.

Amt der Steiermärkischen Landesregierung, FA10b 2004: Bodenschutzbericht, Graz, 2004.

Bayrisches Landesamt für Umwelt (Hrsg.) 2006: Emissions- und Leistungsverhalten von Biogas-Verbrennungsmotoren in Abhängigkeit von der Motorwartung. LfU-Projekt Nr. 1325, Augsburg 2006

BMWA 2007: Technische Grundlage für die Beurteilung von Biogasanlagen. Wien 2007.

BOKU, IFA-Tulln, Inst. für Biotechnologie 2007: Aufbau eines Bewertungssystems für Biogasanlagen – „Gütesiegel Biogas". EdZ Projektnr. 807742 (unveröffentlichte Version). Tulln, 2007.

Boxberger J., Amon T. Weber A.: Biogasnutzung im Kontext von Agrar-, Umwelt- und Energiepolitik. BOKU, Wien, 2002.

Directive 2009/28/EC on the promotion of the use of energy from renewable sources, 23 April 2009.

Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

FTU Mitteilung 2007: Zusammenfassung über die Messungen der FTU an Gasmotoren (unveröff.). Wien, 2007.

GEMIS 1994: Gesamt-Emissions-Modell Integrierter Systeme Version 2.1 - Erweiterter Endbericht, Öko-Institut, Darmstadt 1994.

GEMIS-Österreich 1998: Datensatz GEMIS-Österreich zusammengestellt vom Ökologie Institut Darmstadt, Österreichisches Ökologie Institut und JOANNEUM RESEARCH, herausgegeben vom Umweltbundesamt Wien, Wien 1998.

Hollis J.M., Woods S.M. 1989: The measurement and estimation of saturated soil hydraulic conductivity. SSLRC Research Report, Silsoe, Beds. 1989.

Kristiansen P.G., Jensen J.K., Nielsen M. and J. B. Illerup 2004: Emission Factors for Gas Fired CHP Units < 25 MW. Danish Gas Technology Centre, C0402, 2004

Jungmeier G. et al 1999: Treibhausgasbilanz der Bioenergie. Vergleich der Treibhausgas-Emissionen aus Bioenergie-Systemen und fossilen Energiesystemen, Joanneum Research, IEF.96014-01, Graz, 1999.

IPCC 1997: Greenhouse Gas Inventory Reference Manual. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Reference Manual, Volume 3. London.

2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4. Agriculture, Forestry and Other Land Uses. Prepared by the National Greenhouse

Gas Inventory Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

IPCC 2010: www.ipcc.ch.

Pucker H, Jungmeier G., Siegl S., Kirchmayr R., Ebner-Ornig , F-J. Pötsch, Bochmann G. 2010: Ökobilanz-Biogas - Erfolgsfaktoren zur nachhaltigen Nutzung der Biogastechnologie am Beispiel ausgewählter G. Biogasanlagen. Graz, 2010.

UNFCCC, 2006a. Report of the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol on its first session, held at Montreal from 28 November to 10 December 2005. Addendum Part Two: Action taken by the Conference of the Parties serving as the meeting of the Parties to the Kyoto Protocol at its first session. http://unfccc.int/resource/docs/2005/cmp1/eng/08a03.pdf.

Woess-Gallasch S, Enzinger P., Jungmeier G, Padinger R., 2007: Treibhausgas-Emissionen aus Biogasanlagen. Endbericht. Bericht Nr. IEF-B-10/07, Graz, 2007.

Acknowledgement

We thank Mr. Wolfgang Krainer from the Office of the Styrian Government, Agricultural Test Centre (FA10b), who provided us the soil data (data from the Styrian Digital Maps, Soil Protection Program) for the calculation of the GHG emissions related to direct land use change.

We are also grateful to Mr. Michael Laaber and Mr. Rudolf Braun from IFA-Tulln, Department for Agrobiotechnology, for their review and useful information concerning the German report, which entered also into this report (Mr. Rudolf Braun is National Team Leader of IEA Bioenergy Task 39 on "Energy from Biogas").

Many thanks also to the reviewers of the English report, Annette Cowie from National Centre for Rural Greenhouse Gas Research, Australia and Ana Kojakovic from Energy Institute Hrvoje Pozar, Croatia.

Finally we appreciate the generosity of Mr. Helmut Neumeister, the operator of the Biogas Plant Paldau, in providing us with the needed information.

The Austrian participation of the Tasks in IEA Bioenergy is financed by the Austrian Federal Ministry of Transport, Innovation and Technology (bmvit), Department of Energy and Environmental Technologies.

bmvit Bundesministerium für Verkehr, Innovation und Technologie

IEA FORSCHUNGS KOOPERATION

FFG