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# Factors of Influence on the Greenhouse Gas Balance of Agricultural Biogas Plants

*The greenhouse gas (GHG) emissions for electricity generation from biogas were ascertained by data from five modern agricultural biogas plants. The whole operation was assessed from the cultivation of renewable raw materials to the energy conversion in the CHP. The GHG emissions of the biogas plants were considerably lower than the emissions of power plants of the German power station mix. Measures for a best as possible GHG balance of agricultural biogas plants are proposed.*

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**Keywords**

Greenhouse effect, biogas, renewable raw materials, energy

Biogas technology is a means of generating electricity and heat from organic residues and renewable primary products (RPP). Presently, energy generation from biogas is still often costlier than from fossil resources. However, negative environmental impacts are reduced compared to conventional energy production. Currently, the main public focus in this respect is on the emission of greenhouse gases (GHG). To build up the biomass, which is digested to biogas, carbon dioxide is absorbed from the atmosphere. Therefore combustion of the biogas does not contribute to global warming. However, within the process chain, fossil fuels are used to some extent, particularly for the production and transport of RPP.

## Objectives and Methodology

This investigation aims to specify and quantify the main sources of GHG during electricity production from biogas. These emissions were determined for five state-of-the-art agricultural biogas plants with different designs and input materials. For the case of biogas technology, emissions of carbon dioxide from fossil fuels and methane are the main contributors to global warming. *Figure 1* shows GHG emissions considered in the analysis for the process steps of “production of RPP”, “biogas production”, and “energy production in a combined heat-and-power-unit (CHPU)”.

Over a period of about 300 days, continuous measurements of parameters such as biomass input, biogas volume and energy production were taken at five biogas plants. In addition, short-term measurements (e.g., exhaust gas emission analysis) and individual experiments (e.g., biogas test with digestate) were performed. In those cases, where emissions could not be directly determined, the calculations were based on literature data, such as for energy and fertilizer use for RPP [2]. GHG emissions are specified in kg, respectively g $CO_2$-equivalents.

Since biogas is currently utilized mainly for electricity production, the reference unit chosen for this analysis is one kilowatt-hour electric energy (1 $kWh_{el.}$). GHG emissions of electricity production were compared to the German grid average. All environmental impacts were attributed to electricity production. Therefore, for the off-heat from the CHPU utilized outside of the biogas plant, a bonus was calculated based on the corresponding average German grid $CO_2$-emissions from heat production (326 $g \cdot kWh_{thermal}^{-1}$ [1]). A bonus for the digestion of animal manure was given as proposed by the Intergovernmental Panel on Climate Change (IPCC) [3]. This bonus accounts for avoiding methane emissions during extended open storage of animal manure.

## Results

The results of the analysis are summarized in *Figure 2*, where each column represents one individual biogas plant. Columns in the positive range show emissions of GHG, columns in the negative range show bonuses. The narrow column in the center reflects the overall balance for each biogas plant, as the sum of emissions and bonuses. GHG emissions in kg $CO_2$-equivalents$\cdot kWh_{el.}^{-1}$ increase from plant 1 through 5 (from left to right).

GHG emissions from the production of renewable primary products (RPP) vary bet-

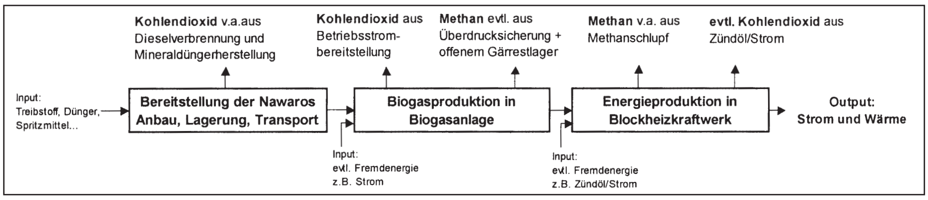

*Fig. 1: Greenhouse gases during energy production from biogas: carbon monoxide from fossil sources and methane*

ween crop species. The two major sources of GHG are the exhaust gas emissions of the machinery used for sowing, harvesting, transporting and conserving the RPP and the emissions from the production of fertilizer and soil conditioner (lime). The production of inorganic nitrogen fertilizer requires a large energy input and is thus responsible for most of the GHG emissions. The harvesting of grass is comparably energy-intensive, due to several harvests per year. Compared to other energy crops, the production of grass silage is therefore marked by a high share of GHG emissions from Diesel combustion. However, since grass can be grown without mineral fertilizer (in addition to digestate), its equivalent emissions from fertilizer production are far lower than those of other RPP. The production of maize silage with respect to organic dry matter generates less GHG emissions, compared to whole-crop silage of grain or corn-cob-mix. While per hectare, the production of corn-cob-mix and grain causes less emissions than that of maize silage, specific emissions with respect to organic dry matter are higher, due to considerably lower yields.

Specific GHG emissions from the production of the input materials for plants 2 through 5, which use mainly energy crops range from 98 g $CO_2$-equiv.•$kWh_{el.}^{-1}$ for plant 3 to 145 g $CO_2$-equiv.•$kWh_{el.}^{-1}$ for plant 4 (average 116 g $CO_2$-equiv.•$kWh_{el.}^{-1}$). Typically, higher emissions are positively correlated to a lower share of maize and grass silage in the mix of input materials. In plant 1, about one third of the dry matter input is from animal manures. Since for animal manure only the energy input for transport is considered, specific emissions are very low, compared to energy crops.

GHG emissions from the construction of the biogas plant were estimated from the climate footprint of the building materials used [1]. The climate footprint describes the GHG emissions, which occur from supplying the building materials. If depreciated over the 20-year technical lifetime of the biogas plant, these emissions amount to less than 10 g $CO_2$-equiv.•$kWh_{el.}^{-1}$.

Plants 1 and 5 obtain the electrical energy for running the biogas plant from the grid, while plant 2 uses part of its own electricity production for this purpose. Plants 3 and 4 are supplied with electricity from small hydro power installations, for the most part. As a result of these different configurations, specific GHG emissions from electricity consumption of the biogas plants vary between 0 and 36 g $CO_2$-equiv.•$kWh_{el.}^{-1}$. Principally, operating the biogas plant with electricity from the grid increases GHG emissions.

Direct methane emissions include unburned methane in the exhaust gas and methane emissions from the pressure relief valves or – if applicable – the open storage tank for digestate. Methane emissions from imperfect combustion of the biogas are dependent on engine type. Based on measurements at CHPU identical in construction, specific emissions of 10 to 40 g $CO_2$-equiv.•$kWh_{el.}^{-1}$ were assumed. Storage of the digestate in open tanks can contribute to substantial GHG emissions. For plant 4, which is the only one with an open storage tank, methane emissions of 44 g $CO_2$-equiv.•$kWh_{el.}^{-1}$ were estimated from a biogas test of digestate. Other emissions of methane such as from diffusion through digester soft-covers or due to overpressure could not be quantified and were estimated to a figure of 1 % of total methane produced.

The bonus for heat use amounts to between 0 g $CO_2$-equiv.•$kWh_{el.}^{-1}$ (plant 1) and 140 g $CO_2$-equiv.•$kWh_{el.}^{-1}$ (plant 3). The bonus for digesting animal manure accounts for between 0 g $CO_2$-equiv.•$kWh_{el.}^{-1}$ for plant 4 and 150 g $CO_2$-equiv.•$kWh_{el.}^{-1}$ for plant 1.

The climate footprint of an individual biogas plant is calculated as the sum of emissions and bonuses (*Fig. 2*). Electricity production in plant 1 avoids GHG emissions of 140 g $CO_2$-equiv.•$kWh_{el.}^{-1}$. In this case, the emissions during construction and operation of the plant and from producing the input materials are more than offset by saving fossil fuels for heating and avoiding methane emissions during animal manure storage. With specific emissions of 160 g $CO_2$-equiv.•$kWh_{el.}^{-1}$, plant 5 exhibits the largest climate footprint which is, however, still far below the German grid average of 640 g $CO_2$-equiv.•$kWh_{el.}^{-1}$.

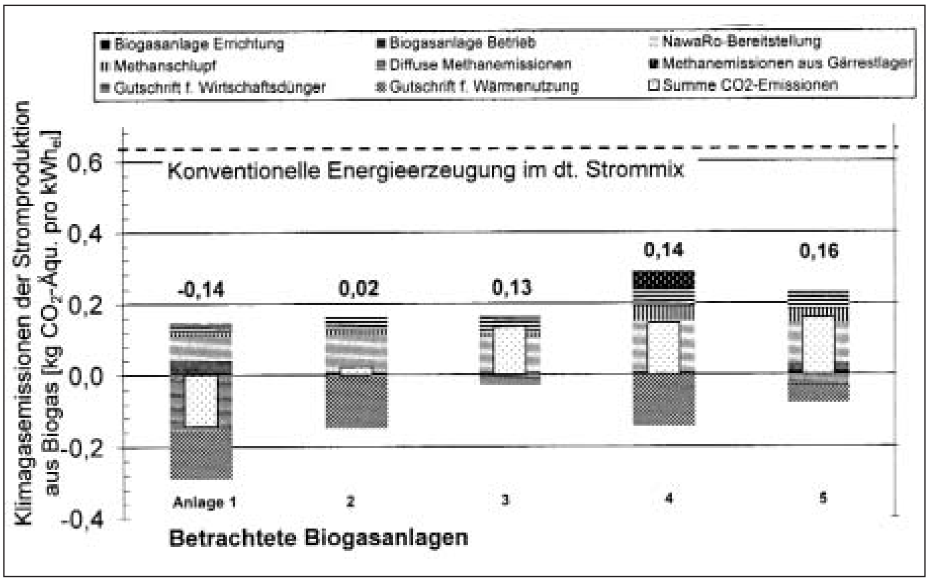

*Fig. 2: Comparing greenhouse gas emissions of electricity generation in the examined biogas plants with conventional power plants*

## Conclusions

Specific GHG emissions from electricity production in the five biogas plants analyzed are considerably lower than the current German grid average. Based on the comparative analysis, the climate footprint of agricultural biogas plants can be improved further mainly by the following measures:

- Maximizing the use of animal manure as input material
- Maximizing the external utilization of thermal energy
- Minimizing direct methane emissions from pressure relief valves and open storage tanks
- Using the electric energy produced from biogas to run the plant rather than obtaining electricity from the grid.

## Literature

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