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Greenhouse gas balance and resource demand of biogas plants

For ten agricultural biogas plants, a detailed balance of greenhouse gas emissions (GHG) and cumulated energy demand (CED) was calculated. Compared to the reference system based on fossil resources, electricity production in the biogas plants avoids GHG emissions of 573 to 910 g $CO_{2\text{-eq}} \cdot kWh_{el}^{-1}$. Without accounting for the substitution of electricity from the reference system, GHG emissions range from -85 g to 251 g $CO_{2\text{-eq}} \cdot kWh_{el}^{-1}$. With savings of 2.31 to 3.16 $kWh_{fossil} \cdot kWh_{el}^{-1}$, the CED of the biogas plants was also much lower compared to the fossil reference system.

Keywords
Biogas plant, emissions, cumulated energy demand, greenhouse gases

Abstract
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The primary objective of producing energy from biogas is the reduction of the use of fossil energy carriers and associated emissions of greenhouse gases. On this background, actual greenhouse gas balances and cumulated energy demand of ten biogas plants with different designs were determined, also to check whether there is room for improvement.

Modeling of real-world biogas plants

Using the software umberto®, a computer-based model for calculating material and energy flows for biogas plants and upstream agricultural production processes was developed. The goal of this model is to determine greenhouse gas and energy balances for individual biogas plants in reality. The model covers all processes that are relevant for energy production from biogas and their associated material and energy flows. To do this, the process of biogas production and utilization was subdivided into the following sections:

- Production, transport and ensilage of energy crops and transport of animal manure,
- operation of biogas plant,
- treatment of digested residue,
- construction of biogas plant and
- upstream processes (supply of electricity, fuel and mineral fertilizer).

To determine overall greenhouse gas emissions, all relevant emissions that leave the balance envelope were added up. The cumulated energy demand includes the primary energy content of all fossil energy carriers that are supplied from outside of the balance envelope [1; 2].

The main product of the biogas plants that were analyzed is electrical energy. Therefore, all material and energy flows were specified per one kilowatt hour of electrical energy fed into the grid. Beside electrical energy, thermal energy and fertilizer are produced. In the material balance, these products were treated as credits. The results were compared to a reference system for electricity supply. According to [3], electrical energy from biogas substitutes electricity that is produced from power plants fired with natural gas (30 %) and coal (70 %). On average, this electricity has a carbon footprint of 825 g $CO_{2\text{-eq}} \cdot kWh_{el}^{-1}$ and a cumulated energy demand of 2.55 $kWh_{fossil} \cdot kWh_{el}^{-1}$.

Data set

Detailed technical information on the biogas plants can be found in [4]. The data set used for this study covered the year 2007. During this time period, the material and energy flows were continuously monitored or determined from single measurements. Material flows that could not be measured were estimated based on literature. In the following, data sources and assumptions are described in brief.

Renewable raw materials (energy crops): Data on cultivation, harvest and storage from [5; 6] using average yields and tillage; crop specific ammonia losses during spreading of digested residue and fertilizer demand; nitrogen emission factor for nitrous oxide (with respect to N in mineral fertilizer and digested residue): 1.0 % [7].

Operation of biogas plant: Daily values of material input, energy demand, biogas production and electricity output; electricity supply of biogas plant from either own production, grid or own small hydro power plant; direct emissions of biogas plant: 1 % of total production, with flare: 0.25 %.

Emissions of co-generation unit (CGU): Measured on site or at CGU identical in construction; losses during transfer and transformation to public grid: 1 % of total electricity production.

Construction of biogas plant: Amount of concrete, asphalt, steel and brick; district heating pipelines were not included.

Treatment of digested residue: Estimation of methane emissions from open storage tank based on batch-test for residual biogas potential (20 °C).

Results for individual biogas plants

To highlight the differences between individual biogas plants, the results are presented without including the substitution of electricity in the above-stated reference system. Additional sankey diagrams are shown for plants E and G (**figures 1 and 2**). As opposed to **figure 3**, the fossil energy demand for biogas plant construction which is comparatively small is not shown in the sankey diagrams.

Plant A: Relatively low methane emissions; marginal credits for animal manure treatment and heat use.

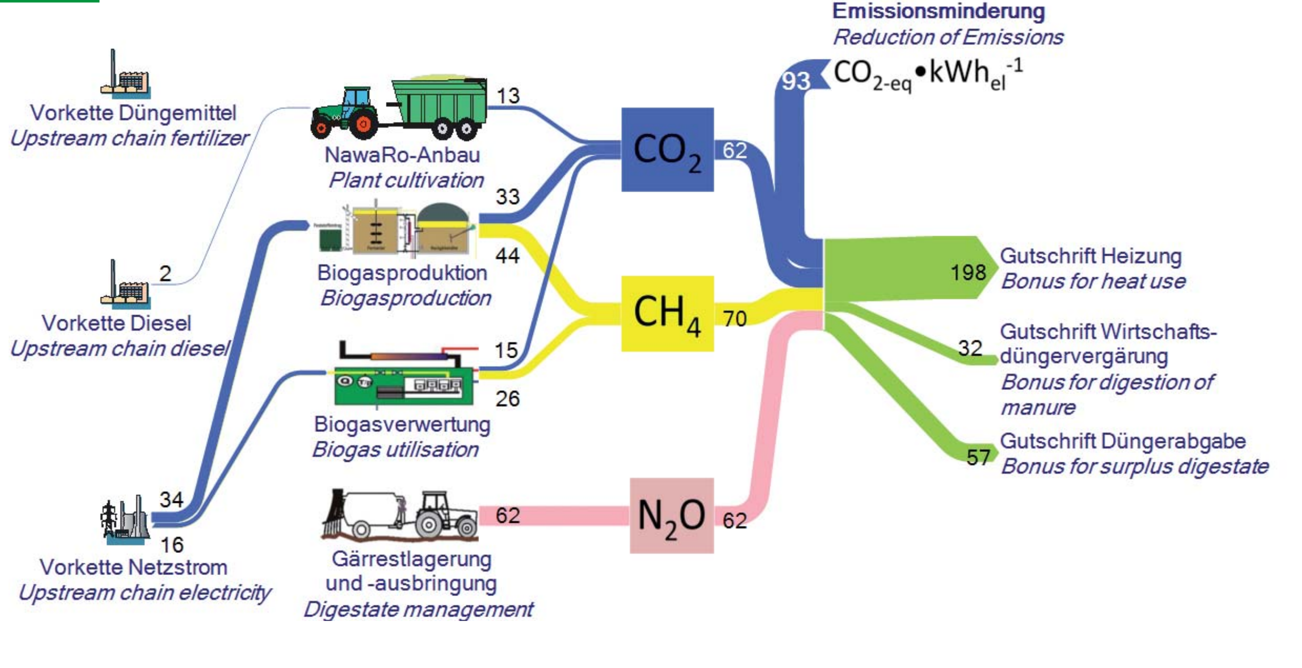
Plant B: High emissions from plant operation (high electricity demand, high emissions from open storage of digestate); production of energy crops without additional mineral fertilizer; nitrogen fixation due to the use of clover grass silage → credit for surplus digested residue that is supplied to other organic farms; low share of animal manure in input; no heat use.

Plant C: Plant uses own electricity (surplus feed-in), therefore no emissions from grid electricity; very low direct methane emissions from CGU and due to additional flare; high credits for heat use.

Plant D: No animal manure in input; intermediate level of heat use; high emissions from energy crop production due to relatively poor quality of silage and unstable digester biology.

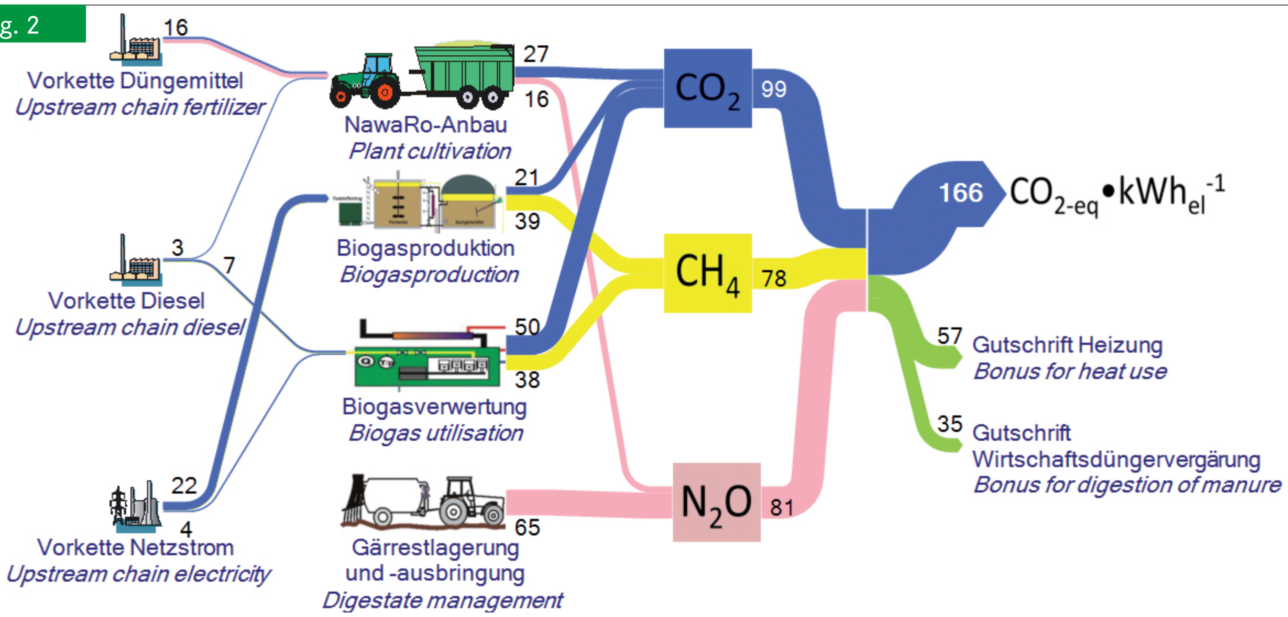
Plant E: Best GHG balance of all ten plants with net savings of 85 g $CO_{2\text{-eq}} \cdot kWh_{el}^{-1}$; high share of poultry manure in the input saves energy for crop production; no additional mineral

Fig. 1



Sankey diagram of greenhouse gas balance for plant E

Fig. 2



Sankey diagram of greenhouse gas balance for plant G

fertilizer needed (**figure 1**); credit for surplus digested residue; high level of heat use.

Plant F: High share of poultry manure in input saves energy for crop production; no mineral fertilizer used; very good heat use; flare; high methane emissions from CGU; digested residue is separated: Only emissions from liquid phase were considered for GHG balance.

Plant G: Regular treatment of animal manure from own livestock; intermediate level of heat use; high methane emissions from CGU; high demand of fossil resources during plant operation (electricity supply from grid, fuel oil) (**figure 2**).

Plant H: Acceptable level of heat use; high methane emissions from CGU; electricity supply of biogas plant in part from own small hydro power plant, in part from public grid; open storage of digested residue; CGU with high demand for fuel oil.

Plant I: Relatively high level of heat use; small share of animal manure in input; methane emissions from open storage tank for digested residue correspond to 65 g $CO_{2\text{-eq}} \bullet kWh_{el}^{-1}$.

Plant J: Credits for treatment of animal manure and heat use: 99 g $CO_{2\text{-eq}} \bullet kWh_{el}^{-1}$; open storage tank for digested residue.

Conclusions

Compared to the reference system based on fossil energy carriers, all of the ten biogas plants save considerable amounts of GHG ranging from 573 to 910 g $CO_{2\text{-eq}} \bullet kW_{hel}^{-1}$ (**table 1, figure 3**). If the substitution of electricity from the reference system is not considered, the results range from a net credit of 85 g $CO_{2\text{-eq}} \bullet kWh_{el}^{-1}$ to emissions of 251 g $CO_{2\ eq} \bullet kWh_{el}^{-1}$. The GHG balances of the individual plants are very diverse and can change over the course of time. Effective ways to improve the GHG balance of an existing biogas plant are increasing the amount of heat use, covering the storage tank for digested residue or switching from diesel to plant oil for pilot-injection engines.

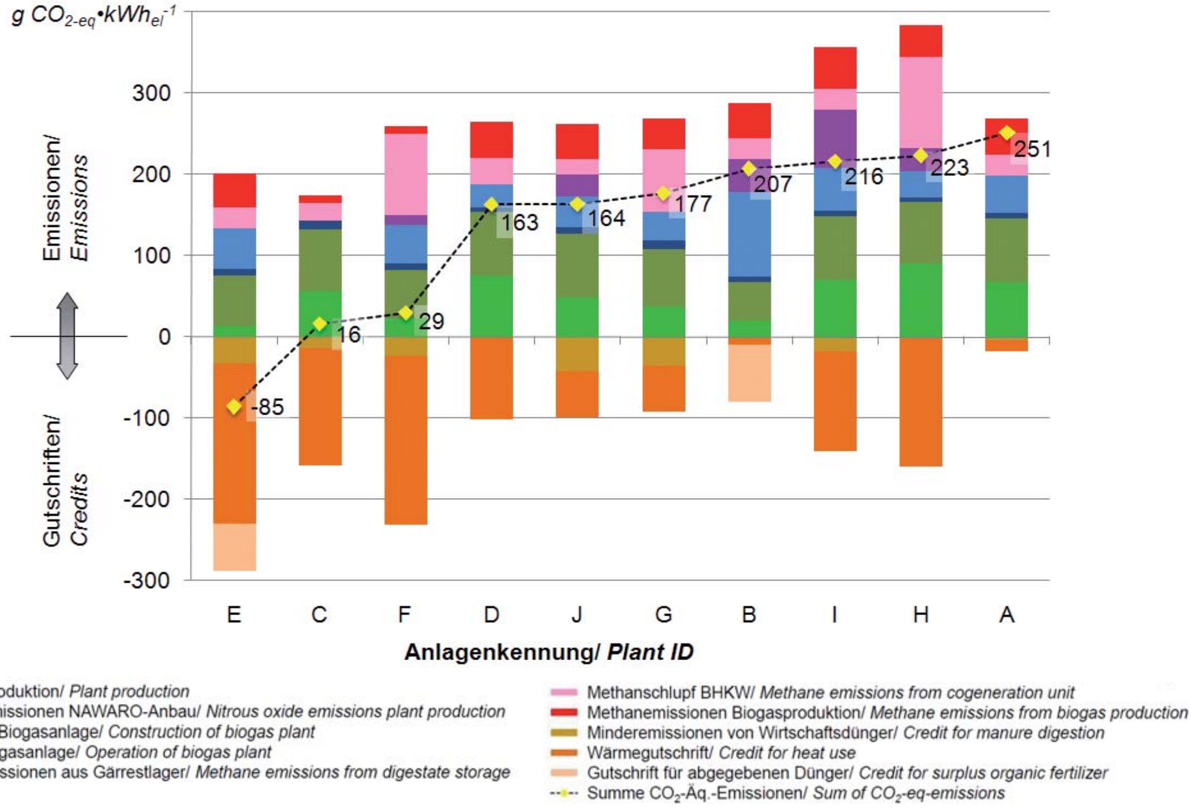
As the CED values show, electricity production in the ten biogas plants makes a substantial contribution to save fossil resources ranging from 2.31 to 3.16 $kWh_{fossil} \bullet kWh_{el}^{-1}$ (**table 1, figure 4**). Fossil energy demand is caused primarily by diesel fuel consumption of agricultural machinery, electrical energy supply from the grid to operate the biogas plant and production of mineral fertilizer. Again, the results for the ten plants are quite diverse. For biogas plants, cumulated energy demand

Tab. 1

Greenhouse gas balance and cumulated energy demand (CED) of biogas plants including substitution of grid electricity

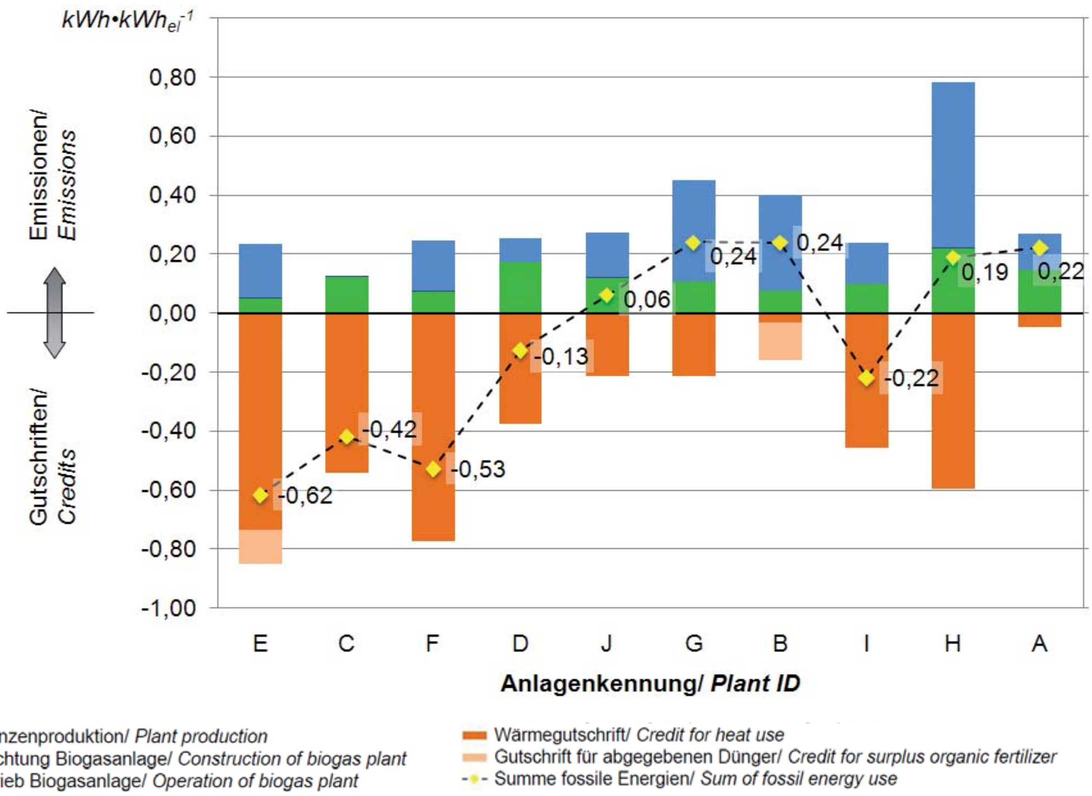
Anlage/*Plant*	A	B	C	D	E	F	G	H	I	J
Treibhausgasbilanz inkl. Gutschrift für Stromeinspeisung *Greenhouse gas balance including substitution of grid electricity* [g $CO_{2\text{-eq}} \bullet kWh_{el}^{-1}$]	-573	-617	-808	-662	-910	-795	-648	-601	-608	-661
KEA inkl. Gutschrift für Stromeinspeisung *CED including substitution of grid electricity* [$kWh_{fossil} \bullet kWh_{el}^{-1}$]	-2.3	-2.3	–2.9	-2.7	-3.2	-3.1	-2.3	-2.3	-2.8	-2.5

Fig. 3



Greenhouse gas balances of the ten biogas plants not including substitution of grid electricity (Baseline scenario)

Fig. 4



Cumulated energy demand of the ten biogas plants not including substitution of grid electricity (Baseline scenario) does not necessarily correlate with greenhouse gas emissions. The reason for this is that emissions of methane and nitrous oxide have a high global warming potential but no influence on energy balance.

Literature

Books are signed with ●

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