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Heat utilization for biogas plants

In biogas plants the use of excess heat from cogeneration increases the energy efficiency substantially and is taking rising prices for energy crops into account. Using model calculations the influence of heat utilization on the economic feasibility of biogas plants is investigated. Heat utilization for the processing of digestion residues and the heating of greenhouses are evaluated. While the use of excess heat for heating greenhouses is economic feasible for all cases considered, the drying of digestion residues requires a profitable use as fertilizer. The larger the biogas plant, the greater economic improvement by heat utilization can be achieved.

Keywords
Biogas, energy efficiency, heat utilization, digestion residues

Abstract
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In biogas plants utilization of heat from the process increases the energy efficiency substantially and, taking rising prices for energy crops into account, is of great economic relevance. Using model calculations the influence of heat utilization on the economic feasibility of biogas plants is investigated. Heat utilization concepts for processing fermentation residues and heating of greenhouses are evaluated. While the use of excess heat for heating greenhouses is economically feasible for all cases considered, the drying of digestion residues requires a profitable use of the products as fertiliser. The larger the biogas plant, the greater is the achievable improvement in economic efficiency through heat utilization.

Influence of heat utilization on economic feasibility of model biogas plants

The effect on profitability by utilisation of heat produced is considered for four model biogas plants in the power range 75-500 kW. Liquid manure proportion in substrate used in plants 1 to 3 exceeds 30 % and therefore earns the manure bonus under the EEG 2009 as well as the renewable primary product (energy crop) bonus. Plant 4 is run only with renewable primary products. In the cost-benefit accounting of the model plants heat utilization of 30 % of total generated heat is already taken into account. The combined heat and power bonus (CHP bonus) is obtained from the corresponding electricity equivalent and additional revenues are generated from the sale of heat (sale price: 3 ct/kWh$_{th}$).

Table 1 shows the influence of heat sales on the economics of the model plants. Depending on the payment structure, the sale of 30 % of produced thermal energy gives increased revenues of 7-8 %. If no extra costs are involved in these increased earnings (e.g. heat consumption at the combined heat and power unit) total earnings will increase by the same amount. Due to the high specific investment cost for smaller plants, plant 1 can only be economically run with heat sales of more than 70 % or a sales price for the heat that is higher than 3 ct/kWh. Utilization of heat produced not only has positive effects on the economic efficiency and overall profitability of the model plants but also improves the energy efficiency of the biogas plants.

Heat utilization with CHP bonus

Following the above assessment of the general effects of heat utilization on the economics of biogas plants, two utilization processes are examined.

Drying of fermentation residues. Applying heat produced in biogas plants for the drying of fermentation residues is especially valuable in larger plants or in areas where overproduction of nutrients often limits field applications of fermentation residues around the respective sites. Separation of solids and liquids can help. One has to be aware that in drying the solids most of the NH_4-N is removed in the exhaust air as NH_3 and this can mean filtering of the exhaust air being necessary. For the 526 kW_{el} biogas plant considered here fermentation residue production is estimated at 30,000 m^3. The investment needed for drying includes the cost of a press auger separator and a dryer (together 245,000 €). In addition there are costs for storing the materials including separate storage of solids and liquids if residues are separated. This increases the investment compared with the simple disposal of untreated fermentation residues. The costs of 101,000 € for a roofed store for the solids slightly exceed storage costs for the liquid proportion.

Additionally there are extra costs totalling 14,500 € for a buffering tank to act as reservoir for residues in an emergency. In comparison to application of untreated residues on fields (478,000 €) there are additional investments of 343,500 € required for the drying of the solid phase and therefore utilising heat from the biogas plant in this way. The most important additional assumptions for calculating the specific costs are:

- Fermentation residue properties: 7.75 % dm, 5.6 kg N/m^3, 2.1 kg P_2O_5/m^3, 6.2 kg K_2O/m^3
- Energy costs of 15 ct/kW_{el} and 3 ct/kWh_{th}
- Application of 50 % of produced N in close proximity of the plant, the rest of the residue to be transported 20 km
- Values for applied nutrients: 0.6 €/kg N, 0.51 €/kg P and 0.26 €/kg K

The heat from the CHP process applied to dry fermentation residues is identified in the EEG 2009 positive list and therefore applicable for the CHP bonus. The result gives specific costs of 1.90 €/m^3 fermentation residues without separation and 5.00 €/m^3 where the separated solids are dried, see **table 2**. Thus additional costs for treatment comprise 3.10 €/m^3. If there are no opportunity costs for the heat, the additional costs are reduced to 0.5 €/m^3 of fermentation residues.

In the model calculation presented here heat required for drying the fermentation residues represents 2500 MWh that is equivalent to 80 % of the heat potential of the biogas plant. Through drying, the separated solids are stabilised but costs for storage and later application are not reduced as there are then two products that have to be applied separately.

The drying of fermentation residues is only economically interesting when the end product can be directed into profitable application. Use of the dried residues as a regular fuel for burning is not permissible under the Federal Immission Protection Ordinance (BImschV) where liquid or solid manure are

Table 1

Model biogas plants with different amounts of utilized excess heat

Kosten-Leistungs-Rechnung[1)] ***Cost/benefit calculation***[1)]		**I 75 kW**	**II 150 kW**	**III 350 kW**	**VI Nawaro 500 kW**
Eingespeiste Strommenge *Amount of electricity fed to the grid*	kWh/a	601,114	1,203,542	2,794,798	4,013,453
Wärmemengenanfall *Generated heat*	kWh	777,045	1,409,480	3,358,553	4,587,428
Leistungen (30 % Wärmenutzung) *Benefit (30 % heat utilized)*	€/a	148,676	296,360	607,665	799,638
Gesamtkosten *Total costs*	€/a	164,130	260,097	502,491	688,937
Gewinn bei.../*Benefit at...*					
0 % Wärmeabsatz/*Heat utilized*	€/a	-27,857	12,746	49,794	33,292
10 % Wärmeabsatz/*Heat utilized*	€/a	-23,723	20,585	68,254	59,095
20 % Wärmeabsatz/*Heat utilized*	€/a	-19,588	28,424	86,714	84,898
30 % Wärmeabsatz/*Heat utilized*	**€/a**	**-15,454**	**36,263**	**105,174**	**110,700**
40 % Wärmeabsatz/*Heat utilized*	€/a	-11,319	44,102	123,634	136,503
50 % Wärmeabsatz/*Heat utilized*	€/a	-7,185	51,942	142,094	162,305
Gewinnveränderung je 10 % Wärmeabsatz *Change of benefit at +/- 10 % heat utilized*	**€/a**	**4,134**	**7,839**	**18,460**	**25,803**

[1)] Für einen Wärme-Abgabepreis von *(assuming a revenue for sold heat of)*: 3 ct/kWh_{th}

Table 2

Specific costs for the recycling of digestate without treatment and drying in a belt dryer

	ohne Aufbereitung *Without treatment*	Bandtrockner *Belt dryer*
Spezifische Kosten ***Specific costs***	**[€/m³ Gärrest]** ***[€/m³ Digestate]***	**[€/m³ Gärrest]** ***[€/m³ Digestate]***
Investition und Instandhaltung *Invest and maintenance*	1.50	2.80
Energiekosten $_{el.}$ *Energy costs* $_{el.}$	0.40	1.80
Energiekosten $_{th.}$ *Energy costs* $_{th.}$		2.60
Personal *Personnel*		0.20
Ausbringung *Application*	2.00	2.10
Transport *Transport*	2.40	2.30
Summe Kosten ***Sum costs***	**6.30**	**11.70**
Einnahmen ***Revenue***		
Nährstoffe *Nutrients*	4.40	4.30
Summe Einnahmen ***Sum revenue***	**4.40**	**4.3**
Gesamt ***Total***	**1.90**	**7.4**
Differenz ***Difference***		**5.5**
Ohne Wärmekosten ***Without heat costs***		**2.9**

part of the co-fermentation. Classification as regular fuel would need a special permit with numerous requirements to be met. The regulation requirements for fermentation residues from pure crop materials are unclear. Should the processed product not be applied as fertiliser it no longer has entitlement to the CHP bonus and the positive effect of the bonus on the economic viability of the plant is thereby lost.

Heating greenhouses. Greenhouses can utilise vast amounts of heat over long periods so that cheaper heat sources can ensure reliable revenues and lower costs. Presented in the following example is the supply of heat for different crops and for two different sizes of greenhouses.

For ornamental plants the differentiation between three plant-related temperature ranges is as follows:

- „Cold" (< 12 °C)
- „Temperate" (12-18 °C)
- „Warm" (>18 °C).

As in the case for drying fermentation residues, the heat comes from a 526 kW_{el} biogas plant. Approximately 70 % of the total amount of heat produced (3,200 MWh/ year) is available for heating. **Table 3** shows the required amount of heat for the different cultures and various greenhouse sizes. In the example calculation, the provision of heat from mineral oil is replaced by heat from the biogas plant for covering the basic heating requirement. The cost for covering peak requirement periods with mineral oil heating is taken into account.

Heating greenhouses is nominated in the positive list of the EEG 2009 but this is coupled to the requirement that a similar amount of heat produced from fossil fuel is replaced and that the extra costs for the heat production comprise at least 100 € per kW thermal energy. These EEG requirements are fulfilled in the following calculation.

Furthermore it is assumed that the operator of the biogas plant is selling produced heat for 3 ct/kWh, earning income over and above the CHP bonus.

For the operator of the greenhouse cultivating ornamental plants under „cold" conditions under the above mentioned heating costs, and despite additional investments for heat pipelines, there is a cost advantage of 10,570 or 78,473 €/year compared with heating with mineral oil only (**table 4**). The calculation is based on an oil price of 0.70 €/l. **Figure 1** shows the potential savings for the „warm" and „temperate" cultivation of ornamental plants which increase through the higher income for the heat with only limited increase in fixed costs. Possible savings against oil use are up to 78 %.

Conclusions

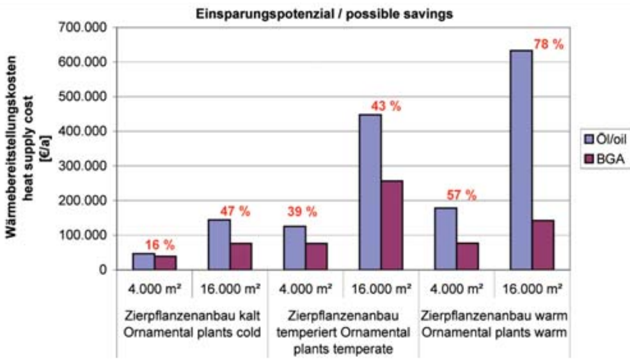
Available nowadays are some heat utilization methods that are already energy efficient and economically viable. The calculations presented here show very clearly that the economics of biogas plants could be greatly improved where a high percentage of heat is utilised. In addition the overall efficiency of the biogas plant can be improved. Where 30 % of the produced heat is utilised, 150 kW capacity biogas plants can achieve a return

Table 3

Annual heat requirement of different greenhouses and amount of excess heat utilization from a 500 kW_{el} biogas plant

Kulturführung ***culture***	**Zierpflanzenanbau** ***Ornamental plants***					
	Kalt ***Cold***		**Temperiert** ***Temperate***		**Warm** ***Warm***	
Unterglasfläche [m²] ***Greenhouse size***	**4,000**	**16,000**	**4,000**	**16,000**	**4,000**	**16,000**
Zur Beheizung notwendige Wärmemenge [MWh/a] *Amout of heat required*	414	1,450	1,320	4,812	1,924	6,975
Genutztes Abwärme-potenzial einer 500 kWel BGA [%] *Utilized heat potential of a 500 kWel biogas plant*	13.3	46.4	42.2	100	61.6	100

Fig. 1



Possible savings for heating various greenhouses of different sizes

on total capital investment of over 12 %. Smaller plants must utilise much greater amounts of produced heat or increase the selling price in order to operate economically. Under the EEG 2009 a CHP bonus is payable for the drying of fermentation residues. This can be a practical use for the heat, especially with larger biogas plants. Large amounts of heat can be used in the drying of fermentation residues and the storability of the solids is increased. The drying of fermentation residues is economically interesting when there is no alternative use for the heat available and where there is a profitable market for the dried material as fertiliser.

Also interesting as an economical use for biogas heat through their year round demand for thermal energy are greenhouses. This application can replace very large amounts of heating oil which, on the one hand, lowers costs for the greenhouse operator and, on the other, improves the energy efficiency and the economic situation of the biogas plant.

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Table 4

Cost of heat supply using mineral oil and biogas for two sizes of greenhouses in cold cultivation

Unterglasfläche ***Greenhouse size***	**m²**	**4,000**		**16,000**	
Wärmebereitstellung durch ***Heat supply by***		**Ölheizung Oil heating**	**BGA Biogas**	**Ölheizung Oil heating**	**BGA Biogas**
Kosten ***Costs***					
Investition *Invest*	€	86,614	141,057	155,539	216,861
Summe veränderliche Kosten (Reparatur und Brennstoffkosten) *Sum of variable cost (maintenance and fuel)*	€/a	37,770	25,282	129,174	55,765
Summe fixe Kosten (Abschreibung, Zinsen, Versicherung) *Sum of fix costs (write-off, interest, insurance)*	€/a	7,940	12,930	14,258	19,879
Summe Arbeit *Sum personnel*	€/a	390	390	390	390
Summe Gemeinkosten *Sum overhead*	€/a	500	500	500	500
Summe Kosten *Sum costs*	€/a	46,625	39,102	144,348	76,534
Differenz Öl-/Biogasheizung *Difference oil/biogas heating*	€/a	7,523		67,813	
Einsparung Biogas- gegenüber Ölheizung *Savings biogas vs oilheating*	%	16.1		47.0	