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Assessing concepts for utilising heat from biogas plants

A large proportion of heat produced from biogas plants continues to be unexploited, even when financial encouragement for increasing total efficiency of biogas plants already exists. To increase the proportion of heat utilised, heat sinks such as heating and warm water supply within buildings, drying systems and heat and cold for industrial processing must be increased through systems coupling heat-cooling-power production. In this respect choice of location is the most important parameter for economic success when planning a biogas plant. The various heat sinks have to be differentiated according to their economic efficiency, required investment, potential heat emission, heat exploitation continuity and potential for fossil fuels substitution.

Keywords

Heat utilisation, heat supply, peak demand, annual duration curve

Abstract

Landtechnik 68(3), 2013, pp. 202–208, 6 figures, 3 tables, 5 references

With a share of around 91 % biomass-based energy is the dominating source of heat in the renewable energy sector. The absolute heat consumption rose by 6 % in 2012 over the previous year [1]. However, the stagnating proportion of renewable energy heat within total heat supply indicates that this increase was mainly weather-induced. Thus with the colder weather compared with 2011 firewood consumption in private households also increased again following a reduction in the previous year. The weather is also one of the influences reflected in the use of coproduced biogas heat in that a large proportion of the biogas heat from combined heat and power systems (KWK) is used as heating for buildings via local pipeline networks. Evaluation of survey results showed that 70 % of biogas plant operators applied their externally available heat for the heating of living and working accommodation or workshops as well as for the production of warm water and that around 14 % offered this heat via local pipeline networks for heating in residential areas and neighbouring domestic housing. Around 30 % of the operators said their available heat was applied for heating livestock housing. [2].

With the introduction of the KWK bonus (for using heat as well as power from renewable energy plants) the amended renewable energy act (EEG) in 2004 created encouragement for the increase of total efficiency from biogas plants. As a result, utilisation of this coproduced heat could be increased although, according to operator information, an average of only around 45 % of the externally available heat is being actually used [2].

Especially in the power output sector between 150 and 500 kW_{el} there remain numerous plants that have not introduced any further utilisation of the externally available heat, or else indicate a low degree of heat utilisation. Thus half of such plants utilise under 40 % of the heat produced [2].

While electricity production from biogas was substantially increased from 8 139 GWh to 20 500 GWh between 2008 to 2012 through expansion of plant numbers, only modest increases in the use of biogas heat could be achieved in the same period: from 8 245 GWh in 2008 to 11 282 GWh in 2012 [1].

Legal aspects of heat utilisation

With the amending of the EEG 2012, the "practical" utilisation of coproduced heat is obligatory in new plants in order to be able to take full advantage of the electricity feed-in remuneration. Following a transitional period during the first operational year of a biogas plant, 60 % of electricity produced must be realised as part of coproduction of power and heat. Hereby, 25 % may be presumed as utilised in heating the fermenter. Plants that on average during a calendar year feed the fermenter with at least 60 % by mass of farmyard manure or 90 % bio waste, or directly market the electricity, are freed from this legal requirement [3].

Accepted as legally recognised heating use are supplies to buildings, heat network feed-ins, process heat supply, the heating of farm buildings including livestock barns and heat for further power production.

Heat production capacities of biogas plants

The relationship of the process heat requirement for a fermenter to the heat output of a power and heat production plant varies greatly according to plant size and conception, substrate used and climatic conditions.

Presented in **Table 1** are results of a survey of biogas plant operators during the years 2011/12 for information on average own-heat requirement according to power classification and installed plant power. In every case the operators reported average annual values or totals only. Statements on the actual power requirement on individual days could not be produced.

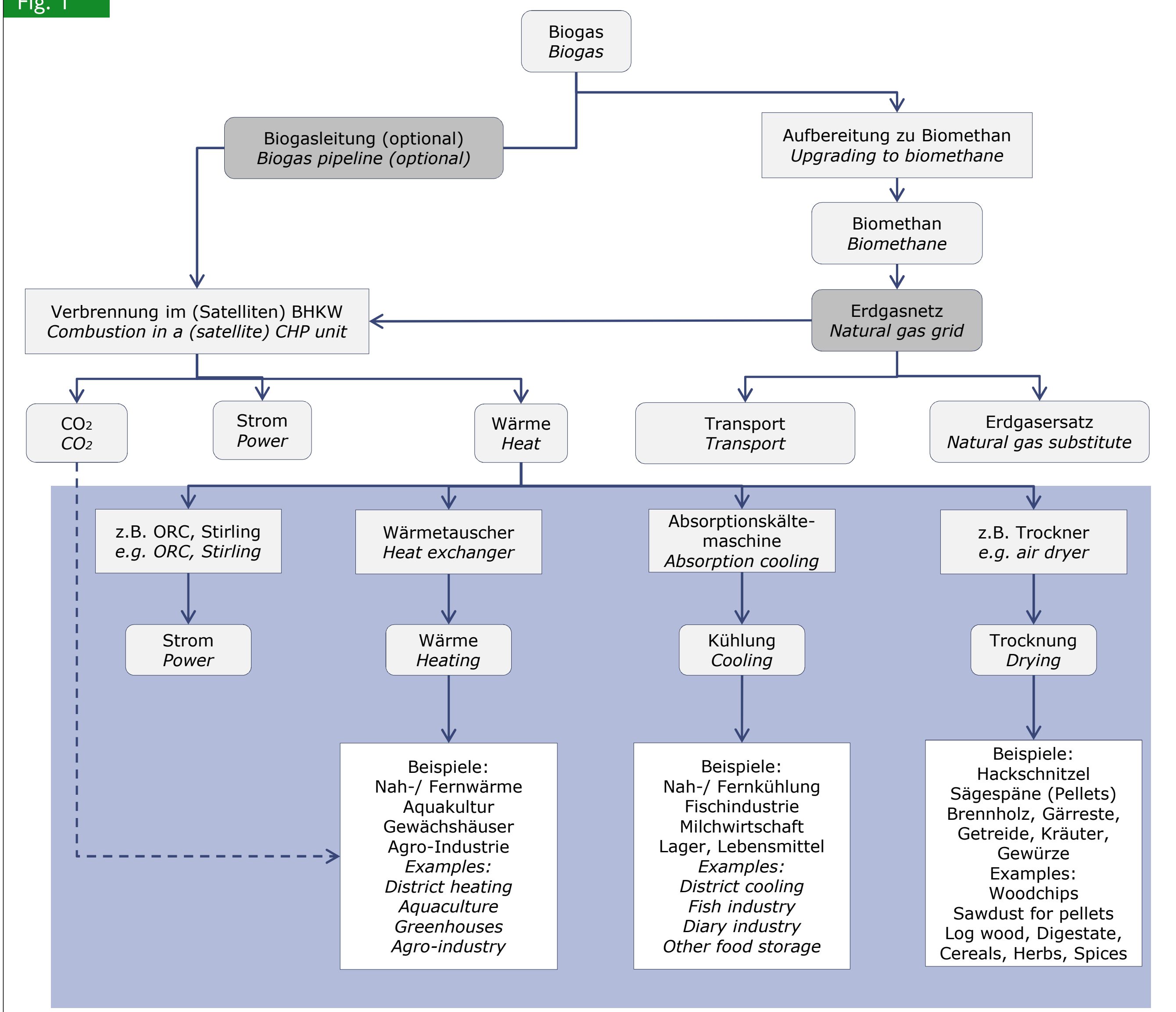
Significant is that biogas plants in the lower power ranges < 70 kW_{el} indicated a heat requirement that was clearly higher

Table 1

Mean inherent heat demand relating to installed plant performance during 2011/12 period

Anlagenleistung (kW_{el}) ***Plant performance***	**Mittlerer Eigenwärmebedarf (%)** ***Mean inherent heat demand***	**Standardabweichung** ***Standard deviation***	**Median** ***Median***	**Anlagen** ***Plants***
bis 70	57.2	31.1	60	23
71–150	39.1	18.2	30	30
151–500	29.9	15.3	25	139
501–1000	26.4	15.0	20	77
> 1000	18.3	6.0	20	26
Gesamt	31.0	19.0	25	295

Fig. 1



Simplified flowchart for the use of biogas [4] than that of the upper class > 500 kW_{el}. This is mainly connected with the fact that in the lower power classes a higher proportion of farmyard manure with high moisture content is used and in the upper classes more energy crop materials (NawaRo) [2]. Additionally, higher transmission heat losses occur in plants with manure substrate because the ratio of fermenter surface area to fermenter size is greater than with plants using energy crops.

Heat utilisation

Fundamentally, heat can be used for heating, drying, for cooling or for additional generating of electricity (**Figure 1**).

Mostly, coproduced heat from biogas plants is used for heating buildings and for hot water production, especially in plants on farms. Hereby the heat available from many plants is considerably more than that required for the buildings on the farm [4]. Therefore to achieve a higher degree of heat utilisation more heat-using possibilities have to be added. Heating of additional buildings can require more investment for redundancies (heat producers) and heat storage facilities. This is especially applicable when the power-heat plant is operated to produce different levels of power during daily operation to match electricity requirement fluctuations.

For optimising a heat calculation for heat utilisation possibilities, either dependent or independent of weather conditions, the example of a biogas plant model was used to vary the amount of heat taken from the plant according to selected heat uses. The results were then recorded. Additionally, the amount of coproduced heat from the power-heat plant and its own heat requirement was presented in graph form as a year's distribution and annual load duration curve so that heat surplus or deficit (power peak coverage) could be localised.

The following assumptions were made for the model calculation:

The process temperature of the energy crop biogas plant model was 40 °C. The plant had an installed electrical power capacity of 500 kW_{el} and scheduled for operation in 2014. 8 000 full-utilisation hours were assumed. The thermic output was 537 kW_{th}, the electrical efficiency 40.1 % and the thermic efficiency 43.2 %. The total heat production of the power-heat plant was 4 295 310 kWh_{th} per year and the heat surplus after subtraction of processing heat (17.5 %) 3 541 773 kWh_{th} per year. The maximum heat load of the biogas plant was 109 kW_{th}.

Local heat systems for heating houses

The amount of heating required by domestic homes differs with the seasons and is climate related and can be covered with the heat requirement of a biogas plant: the heat requirement is high in winter months and less during summer so that in summer other possible uses for the produced heat have to be found. In the heating of homes a large role is played by the achievable price of the heat and the available number of customers. The more households with a high heating requirement within a closely meshed local heating supply network, the lower are the specific costs of heat delivery and the higher are therefore the earning expectations. The heating supply density of a developed local heating pipeline network should, as far as possible, be over 1.5 MWh per meter pipeline length and year.

Additionally, the implementing of a local heating network pipeline is very dependent on the efficiency standard of the building, as well as the heating technology in place in the individual households [5].

Table 2 and **Figures 2** and **3** give an overview of the heating supply from the 500 kW_{el} biogas plant model with a local heating supply network for heating of domestic housing in relationship to number and age of buildings involved.

Heating of glassshouse crops/greenhouses

The heating of glasshouse crops/greenhouses offers the possibility of being able to sell a large amount of heat to single, or just a few, customers. This reduces administration inputs but can also have a negative effect on the achievable price for the supplied heat.[5]. Compared with a local heating network the pipeline involved is mostly shorter and the associated pipeline losses less. The heat sales would be greatly dependent on the crop production and would be mostly low during summer.

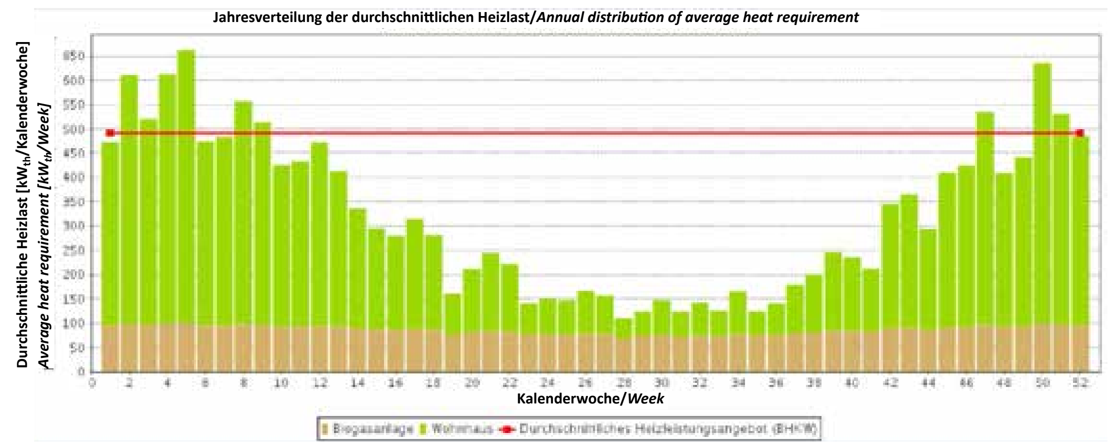
Table 2

Overview of parameters in heat production from a biogas plant with installed electrical performance of 500 kW_{el} relating to number and ages of single-family houses

Anzahl Einfamilienhäuser[1)] (Baujahr. 1978–1993/ 1984–1994) *Number of single-family houses (Built 1978 to 1993/1984 to 1994)*	Maximale Heizlast *Maximum heat requirement* [kW_{th}]	Nutzwärme-bedarf *Useful heat demand*	Wärmebele-gungsdichte *Heat density* [MWh/m · a]	Summe eingesparter Brennstoff (Heizöl)[2)] *Total fuel saved (heating oil)* [l /a]	Genutzte BHKW-Wärme nach EEG 2012 *Heat from power-heating plant actually used, according to [3]* [%]	Wärmenutzungs-kriterium nach EEG 2012 erfüllt? *Thermal extraction criterion according to [3] fulfilled?*
25 (10/15)	223	570 763	0.5	63 418	40.5	nein/*no*
45 (20/25)	383	1 047 552	0.9	116 395	52.7	nein/*no*
80 (35/45) [3)]	659	1 856 709	1.6	206 301	68.7	ja/*yes*

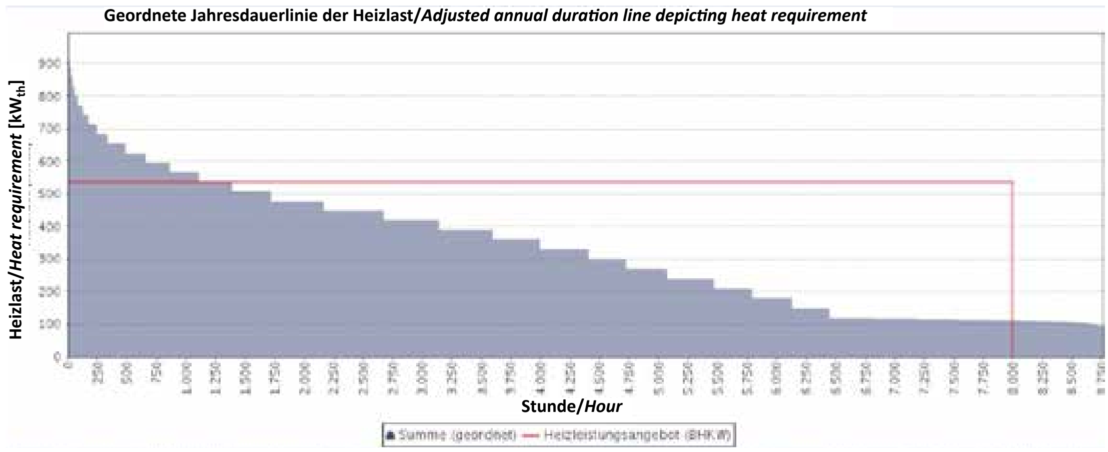
1) Gleichzeitigkeitsfaktor 0,8; Beheizte Nutzfläche pro Haus 120 m²; Trassenlänge 1200 m; Wärmeübertragungsverluste 200 kWh/m /*Simultaneity factor 0.8; heated occupied area per house 120 m^2; supply distance 1 200 m; heat transport losses 200 kWh/m.*
2) Wirkungsgrad Wärmeerzeuger 90 %/*Efficiency of heat producer 90 %.*
3) Spitzenlastanteil 123 042 kWh_{th} pro Jahr/*Peak load proportion 123,042 kWh_{th} per annum.*

Fig. 2



Annual distribution of average heat requirement of 500 kW$_{el}$ biogas plant incl. 80 single-family houses (built 1978 to 1995) and idealised heat supply from a biogas plant (red line)

Fig. 3



Adjusted annual duration line depicting heat requirement of a 500 kW$_{el}$ biogas plant incl. 80 single-family houses (built 1978 to1995) and idealised annual duration line of heat supply of a biogas plant (red line); peak load: heat total 123,042 kWh$_{th}$ per annum.

Table 3 and **Figures 4** and **5** give an overview of the heat supply from the 500 kW$_{el}$ biogas plant model for a greenhouse in relationship to the heated greenhouse area.

Drying of produce

The drying of agricultural products such as cereal grain, maize grain, rapeseed and solid biomass such as firewood logs, woodchips and sawdust are amongst the most important applications. Additionally, sewage solids and fermentation residue can be dried. Depending on the produced material, batch, belt and feed-and-turn driers can be used in combination with biogas plants.

Solid biomass, as with fermentation residue and sewage solids, can be dried throughout the year. The other agricultural products are dried only seasonally during their respective harvest periods. If drying a farm's own production, e. g. cereal or maize grain, represents the only utilisation of the biogas plant heat surpluses then often no great amount of heat is exploited in that, at least in the case of grain and oilseeds, only a portion of the harvested material might require drying. With this, the drying is limited to a few days in the year and means that handling of seasonally available own-farm products tends to be just a supplementary possibility for heat utilisation in summer months.

If in the near vicinity of the biogas plant there are further farms, or industrial facilities, with produce requiring drying the possibility of contract drying can offer an improvement in the exploitation of a drier as well as in the economics and the heat utilisation of the biogas plant. The year-round utilisation of larger amounts of heat is achievable through drying timber for firewood and fermentation residues for fertiliser manufacture. This does not allow any savings in fossil fuels, however, as their application for drying purposes is seldom economically viable.

Combined power, heat and cooling processes

Combined power, heat and cooling processes offer the possibility of heat being used for cooling in the summer months or all year round. Alongside milk cooling or the cooling of livestock

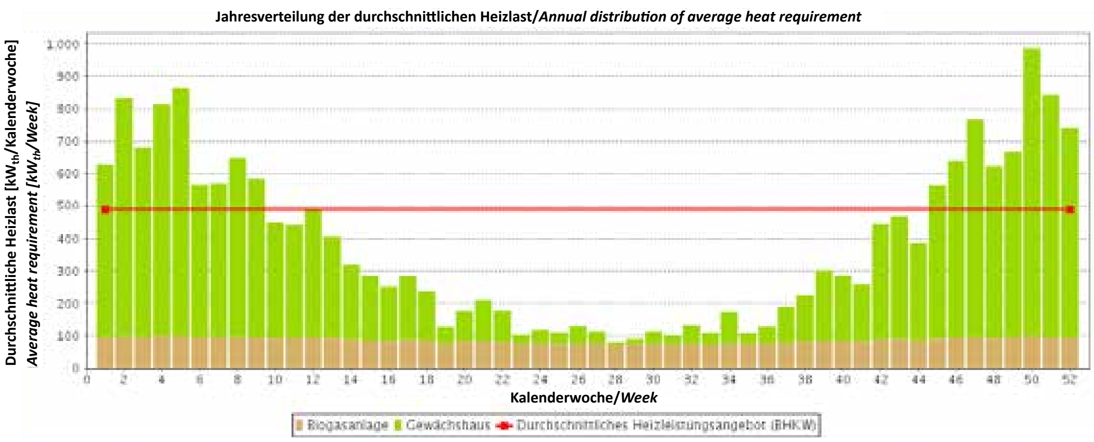
Table 3

Overview of parameters of heat supply from a biogas plant with 500 kW_{el} installed electrical capacity for a greenhouse relating to heated area within the greenhouse.

Gewächshausfläche 1) *Greenhouse area* [m^2]	**Maximale Heizlast** *Maximum heat requirement* [kW_{th}]	**Nutzwärmebedarf** *Useful heat demand* [kWh/a]	**Wärmemenge der Spitzenlast** *Total heat peak load* [kWh_{th}/a]	**Summe eingesparter Brennstoff (Heizöl) 2)** *Total fuel saved (heating oil)* [l/a]	**Genutzte BHKW-Wärme nach EEG 2012** *Heat from power-heating plant actually used, according to [3]* [%]
1 000	308	335 206	-	37 245	34.8
5 000	900	1 347 294	57 211	149 699	57.6
10 000	1 599	2 533 241	745 325	281 471	70.9

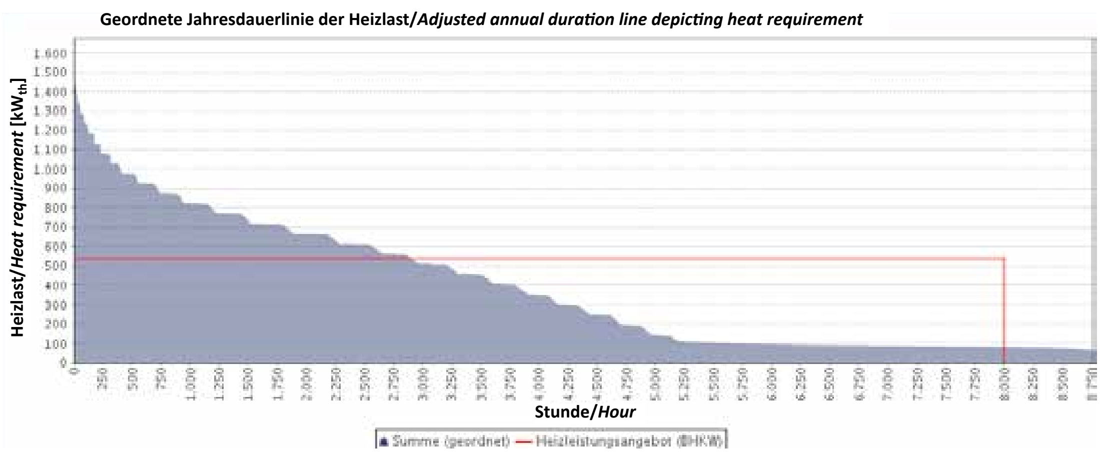
1) Stehwandhöhe 4 m; Eindeckung Kunststoffstegdoppelplatten; Wärmeausbringung Vegetationsheizung; Temperaturführung Zierpflanzenbau temperiert; Trassenlänge 500 m; Wärmeübertragungsverluste 200 kWh/m / *Standing wall height 4 m; roofing double plastic sheeting; heat distribution vegetation heating; controlled temperature ornamentals production tempered; supply distance 500 m; heat delivery losses 200 kWh/m*
2) Wirkungsgrad Wärmeerzeuger 90 %/ *Efficiency of heat producer 90 %.*

Fig. 4



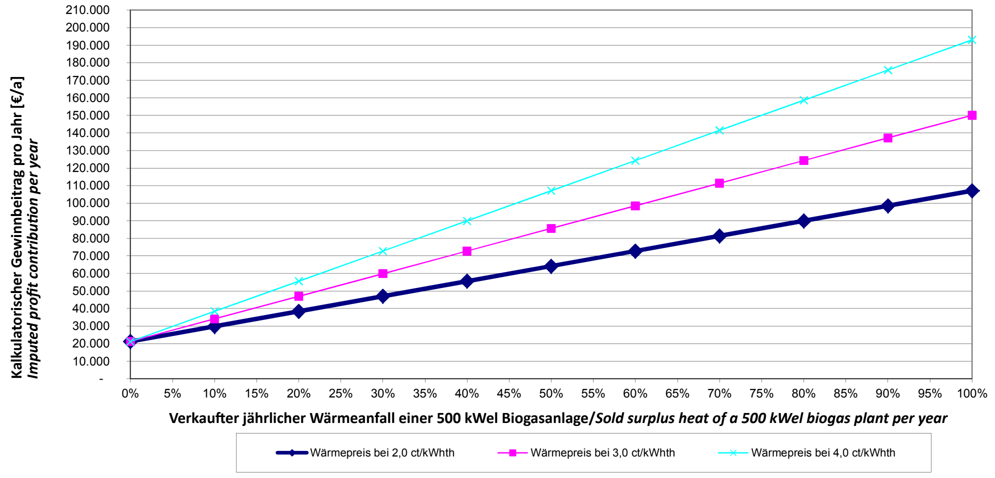
Annual distribution of average heat required from a 500 kW_{el} biogas plant incl. 10,000 m^2 greenhouse and idealised heat production of biogas plant (red line)

Fig. 5



Adjusted annual duration of heat requirement from a 500 kW_{el} biogas plant incl. 10,000 m^2 greenhouse and idealised annual duration line of the heat production of biogas plant (red line); peak load: heating performance 1,062 kW_{th}, heat total 745,325 kWh_{th} per annum.

Fig. 6



Economic efficiency of 500 kW model plant

housing (pig barns) there's the possibility of servicing storage halls or cool houses, e.g. fruit and vegetable storage. For utilising the power plant heat in this way, indirectly heated 1-step, 2-step or 3-step absorption chillers are applied. The higher the chiller tier, the more efficiently it works. The performance number serves as the efficiency criterion (energy efficiency ratio EER). This value describes the relationship of the cooling performance to required heat output and mostly lies under 1 for absorption chillers. Typical EER values for refrigeration machines run from 0.65 to 0.8 for 1-step plants and from 0.9 to 1.2 for 2-step plants [4]. Used as refrigerant is, depending on the required cooling temperature, solutions of lithium-bromide water ($LiBr/H_2O$) for cooling temperatures of up to 6 °C, or ammonia water (NH_3/H_2O) for cooling temperatures of 0 °C to -60 °C [4].

The greater the difference between ambient temperature and the temperature required by heat or cold customers, the higher the potential heat sales of the biogas plant and, with that, substitution of fossil fuels.

Evaluating the economic viability

Figure 6 shows the influence of the price for heat, and the amount of heat sold, on the economy of the previously described 500 kW plant model. Apart from the EEG-determined electricity earnings, the economic viability is largely dependent on the amount of heat sold. For example, if 50 % of the annual heat production of the power heat and cooling plant is sold at a price of 3.0 ct/kWh_{th} the calculated annual contribution to profits would be 85,657 €.

Conclusions

A statement on the advantages of a heat production concept can only be made individually. The establishment of a heat utilisation contract depends mainly on economic aspects. The buyer of heat wants to save money compared with any source that's being substituted. The motivation of the biogas plant operator is based on additional income from the sale of heat and on securing of the minimum degree of heat utilisation required by the EEG.

Achievable price is strongly dependent on the sales structure. Thus the supplier to private households can charge a higher price than the supplier delivering to industry. Further factors of influence include point of delivery (at the power heating cooling plant or at the customer premises), the number of potential heat customers and their heat requirement in the sales area, as well as the maintaining of redundancies.

References

[1] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Hrsg.) (2013): Zeitreihen zur Entwicklung der erneuerbaren Energien in Deutschland unter Verwendung von Daten der Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat), Berlin, Stand: Februar 2013
[2] Deutsches Biomasseforschungszentrum DBFZ (2012): Monitoring zur Wirkung des Erneuerbare-Energien-Gesetz (EEG) auf die Entwicklung der Stromerzeugung aus Biomasse, DBFZ Report 12
[3] Erneuerbare-Energien-Gesetz (EEG) (2012): Gesetz für den Vorrang Erneuerbarer Energien vom 1. Januar 2012
[4] WIP Renewable Energies (Hrsg.) (2012): Nachhaltige Wärmenutzung von Biogasanlagen, München
[5] Below, R. (2012): Optimierung der Wärmenutzung von Biogasanlagen – Fünf Praxisbeispiele und Empfehlungen aus der Region Vorpommern, Bachelorarbeit, Hochschule Neubrandenburg

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