Regional Supply of Energy from Small Scale Biogas Plants - Discovering Alternative Heat Markets in Denmark

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Abstract— *This paper argues, among other things, that local biogas Combined Heat and Power plants (CHP) that distributes district heating should have first priority when selecting a distribution option, if a sufficient winter and summer heat market can be identified. In this way the energy will be produced and consumed locally with high energy efficiency and environmental benefits as a consequence. Due to long heat market distances, or due to an already saturated local heat market, this might not always be an opportunity. In such situations it is beneficial to look at other distribution options. The supply of e.g. non-upgraded city gas to households, and upgraded biogas to the natural gas (Ngas) network, were found to be feasible in such situations. It is further concluded that non-upgraded biogas distributed in separate gas networks is an option, primarily for industry, to cover process heat demands. To support such distribution options new stakeholders like Ngas and energy companies, as well as industry, are needed in the future. As far as governmental support is concerned, it is, for example, important to promote and investigate alternative heat markets to support the development of new gas boosters and to provide funding for initial analysis of the possibilities for implementing biogas facilities within local communities, all of which would support a further development of the biogas sector.*

Keywords— **Biogas, Combined heat and power (CHP), Denmark, district heating, heat markets, renewable energy.**

1. INTRODUCTION

There are currently 21 centralized biogas CHP plans in Denmark that receive livestock manure from several connected farms, primarily from pig and dairy cow farmers, as well as organic waste from industry and households to increase the gas production. Denmark also host approximately 45 farm biogas plants, which are located at a single farm and most often based on manure from a large stock of slaughtered pigs. Apart from this several biogas plants are operated on wastewater treatment plants, digesting sludge from the cleaning process. Hence, 58 biogas plants are connected to water treatment, 26 to utilization of landfill gas, and finally six industrial plants digesting sludge from, for example, medical and food manufacturing industries [1] & [2].

The gas is primarily used for CHP production, providing electricity to the grid and district heating to local communities. Biogas distributed on the natural gas (Ngas) network, by means of upgraded biogas, is still in its infancy in Denmark. Only one plant injects small amounts of upgraded biogas from a wastewater treatment facility, and another is operated as a pilot plant on a centralized biogas plant. The total production of biogas, mainly from centralized biogas plants, equals four PJ, or around 0.5 % of the total national energy consumption [1].

The annual production of livestock manure in Denmark accounts for 30 m. tons, but only six per cent of this amount is digested. The political focus on the biogas technology has been strengthened in recent years, and the government's targets for biogas have increased.

Today, the political target is to digest 50 % of the manure before 2020, which will contribute to an energy production of approximately 20 PJ [3]. This will provide a reduction in CO_2 emissions corresponding to approximately 580,000 tonnes annually [1].

Apart from the CO_2 emission reductions there are several other important environmental benefits associated with biogas, which emphasize the relevance of biogas as a valuable technology in a forthcoming transition of the energy supply. Production of biogas has, for instance, the ability to transform organic waste materials into valuable resources for society, by utilizing waste from animal livestock or organic waste from household, industry etc. The generation of waste is a large problem globally, and challenges with overproduction of organic wastes from industry, agriculture and household, are commonly observed [4].

Centralized biogas plants digest agricultural such as: Rape oil and seed, soybean, corn residues, fruit and vegetables residues this emphasizes the plants capability to re-circulate nutrients. Furthermore, the following industrial waste products are often applied to the plants: Fish residues, different waste from food industries, flotation grease, and intestinal contents from slaughterhouses. Again, other plants also digest organic source separated food waste from kitchens and canteens, from e.g. Copenhagen. The organic waste is hence re-cycled in the biogas plant together with manure etc. The biogas technology can thus assist in re-circulate nutrients from organic waste back to the soil, instead of being - in a Danish context - mainly incinerated, or dumped in landfills which are commonly applied in several

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European countries and elsewhere. Thus, the volume of the total waste will decrease, just like nutrients will be re-cycled, which can increase the fertility of the soil [2].

Nutrients in the fertilizer will also be more directly assessable for the farm crops, as the chemical form shifts to ammonium when the manure has been digested. An 80 % uptake of nitrogen is observed for digested manure, as opposed to 70 % for untreated manure. This means that the risk of nutrient pollution to rivers, lakes and ground water reservoirs are reduced. Also, unpleasant odors connected with distribution of manure on the fields decrease by as much as 30 %. As the digested manure receives a declaration of its content of nitrogen, phosphorous and potassium, it enhances the options for controlling and regulating the distribution of nutrients on farmland even further [5].

The manure also undergoes a sanitation process in the reactor tank meaning that pathogen organisms, germ and seeds are eliminated, which reduces the risk of spreading diseases between farms. The degradation of hazardous substances like for instance PAH (polyaromatic hydrocarbons) - which increase the risk of cancer, is genotoxic, and can damage fetuses and the ability to have children - can also be significant reduced by the biogas process [6]. Almost 100 % degradation of such substances was found through experiments made on centralized biogas plants in Denmark [5].

2. PROBLEM AREA & RESEARCH QUESTION

In order to harvest the many benefits associate with biogas, as described above, it is important that the technology is disseminated throughout Denmark; and more extensively on Zealand. This paper therefore presents and discusses how the utilization of biogas can be enhanced within municipalities on Zealand, which lack manure potentials compared to mainland Jutland. The quantity of manure is thus lower and the catchment area larger, due to longer distance between farms of relevant size. The existing distribution options for biogas have so far been to establish 1) co-owned centralized biogas plants for supplying electricity to the grid and district heating to a local heat market (households), as well as 2) smaller farm biogas plants supplying electricity to the grid and heat to farmhouse and stables.

The main stakeholders in the biogas development have primarily been farmers wanting to treat their livestock manure in biogas plants, to receive back a more valuable fertilizer for their crops. The biogas sector has, however, not evolved for several years and barriers like lack of financial loan opportunities, low profitability, difficulties in locating large centralized biogas plants, and lack of gas boosters (organic waste) enhancing the gas yield, has hampered a further development.

Thus, alternative distribution options and inclusion of new stakeholders in the biogas development could be beneficial. This, in combination with enhanced governmental framework conditions, could push the biogas sector forward. But which new distribution options can be identifies for biogas and which new stakeholders could be included in the biogas development? And how can the Danish government enhance the framework conditions for biogas to support such new distribution options? Thus, the following research question is posed:

How can dissemination of the biogas technology be enhanced on Zealand, and how can new stakeholders and governmental support move the biogas sector forward?

3. METHODOLOGY

First we provide an overview of the biogas distribution options by looking at alternative ways of using the biogas produced; e.g. for distribution of high and low temperature process heat to industry, or for the upgrade to Ngas standard to be supplied on the gas network or used for transportation purposes. An option could, for example, be to distribute the energy as non-upgraded city gas to households, or distribute it in separate pipes by means of a locally established gas network to e.g. industry. Distribution of traditional district heating to new heat markets, identified within local communities, could also be an opportunity.

Second, we present the case studies conducted on Zealand to illustrate new distribution options. We will exemplify these distribution options taking our point of departure in three case studies. Each case will thus be utilized to examine several different distribution options, followed by a specific choice in the context examined, and an outline of the selected plant concept including its benefits, etc. Third, the emphasis is put on new stakeholders and their future role in the biogas sector. Finally, we suggest how to enhance the governmental framework conditions for biogas to promote the dissemination of the new distribution options proposed.

4. BIOGAS DISTRIBUTION OPTIONS

Figure 1 below depicts the distribution options for biogas emphasized during this research. In the section to follow we will provide examples of some of the distribution options provided in the figure.

Heat & gas supply

Local district heating network:

Existing centralized biogas CHP plants typically distribute heat to a local market of heat consumers by means of district heating. The size of the market can vary greatly from a few hundred customers to several thousand dependent on whether the district heating network is a smaller local network, or connected to a larger conventional network in the region. The plants are often established with municipal loan guaranties, due to their contribution to the municipal heat supply. All centralized biogas CHP plants in Denmark are established as conventional plants, and thus not as organic plants. In some areas the concentration of organic farms are relatively high, among others on Zealand, and it is therefore interesting to focus on the options for implementing an organic centralized plant to provide organic crop farmers with fertilizer.

Another challenge is that existing biogas CHP plants cannot allocate all heat produced during summer periods, as the demand for primarily space-heating decreases.

Newer the less, analysis show, that it is economically feasible to utilize biogas for supply of CHP in local communities if the demand for heat is high. By contrast, it is economically feasible to utilize the share of biogas - not being supplied as CHP locally - for upgrading to Ngas if the local heat demand is limited [7]. Thus, if alternative summer and winter markets for distribution of heat could be identified, it would be beneficial for the economy of the plants, and would increase the overall resource efficiency. If not, upgrading to Ngas networks could be an opportunity.

Local biogas network:

Direct supply of non-upgraded biogas e.g. to industrial and residential areas by means of local biogas networks is an option for expanding the distribution of biogas in the future. The location of especially industrial areas - due to the likeliness of a stable annual heat demand as oppose to households - can be coordinated with the location of existing biogas plants or the location of new plants. Thus, biogas can supply energy to such areas through a local biogas network, where opportunities for extending the conventional district heating network, or the implementation of individual renewable energy solutions, is not an option.

Such a network of non-upgraded biogas to local heat consumers is not yet applied in Denmark. But currently, a network of gas pipes for non-upgraded biogas for CHP production is being established in Ringkøbing-Skjern Municipality. From several smaller livestock farms the gas will be piped to a larger Ngas CHP plant in the area, distributing CHP to the local community (see more on alternative biogas designs etc. in [2]). Moreover, a gas pipe for non-upgraded biogas will be established to Arla (diary company), which uses large quantities of Ngas in their production of milk powder, which will be converted to biogas [8].

Ngas CHP Plant

Existing Ngas CHP Plant:

Biogas is also supplied to (motor-engine) Ngas CHP plants in which the gas is combusted for electricity and heat production. The heat is thus distributed by means of a larger conventional district heating network, supplying a greater area or region with heat. In coming years many Ngas CHP plants will convert to solar energy or biomass such as wood pellets etc., as the cost of Ngas will increase, due to changes in taxes put on fossil fuel utilization. It is therefore possible to substitute the use of Ngas with biogas within existing Ngas CHP plants.

The total efficiency of Ngas CHP plants and biogas CHP plants are highest on the first, as they can adjust the heat production to the heat demand and vary the electricity production, due to the flexibility of the Ngas system. On centralized biogas CHP plants the efficiency are hence lower, due to heat losses during summer periods where the local heat market is limited. Due to a constant supply of manure from livestock farms, which are only reduced by 15-20 % during summer periods, the flexibility on biogas CHP plants are lower thus and surplus energy (heat) is therefore produced [7].

New Ngas CHP Plant:

In areas where the utilization of Ngas and an extension of the conventional district heating network is not an option, new biomass fuelled CHP plants could be implemented, receiving gas from nearby biogas facilities. New biomass fuelled CHP plants will face the same problems with lack of heat markets, as described above, unless they supply energy to the Ngas network. If syngas from gasification of biomass and upgraded biogas are combusted on the plant, they will be capable of achieving the same flexibility as fuelled by Ngas only.

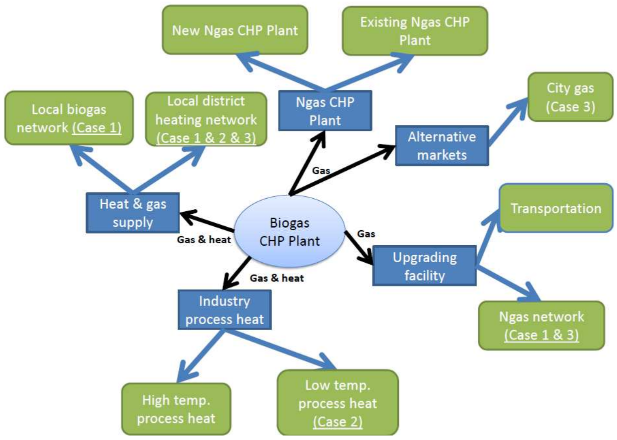

Fig.1. Biogas distribution options and case focuses.

Alternative markets

City gas:

The utilization of biogas from animal manure etc. for distribution as city gas is not yet applied within Danish municipalities, but could be a future supplement to city gas coming from Ngas. Supplied as city gas, there is no need to upgrade the biogas to Ngas standards, as the city gas is thin (49 % Ngas and 51 % atmospheric air). Up to 30 % biogas can be added without technical problems in the households, like the flame stopping, which is caused by a high content of CO_2 in the biogas.

The gas quality is, however, not only determined by the content of methane, as the biogas will have to be cleaned for hydrogen sulfide and ammonia before mixing with Ngas [9]. The distribution of biogas supplied as city gas in Denmark is limited and only municipalities in Aalborg and Copenhagen offer this opportunity to gas costumers'. Here, the biogas is produced on wastewater treatment plants digesting sludge. There is hence a potential market for distributing biogas to the city gas distribution networks within municipalities on Zealand utilizing the already established network.

Upgrading facility

Transport:

Biogas for transportation is still in its infancy in Denmark compared to for example Sweden and currently there are only three Ngas stations for vehicles to fill their tanks with conventional gas. A large municipal or company vehicle fleet could however motivate private stakeholders to become interested in providing upgraded and pressurized biogas for transportation purposes; e.g. the municipality of Copenhagen or a large private taxi company. This could potentially create a market for biogas or a mix of Ngas and biogas, as opposed to conventional gas.

The well-distributed gas network in Denmark (see below) can thus provide the basis for an infrastructure of gas stations throughout the country [10] & [11]. Currently, however, there are no gas stations that provide biogas in Denmark, but only three Ngas stations recently established. However, within the next year or so a few biogas stations, will eventually be introduced by private stakeholders like energy companies [11].

Ngas network:

As seen, biogas can also be upgraded and cleaned to Ngas standards for distribution on the widespread Ngas network, distributing energy to household and industry, etc. To achieve Ngas standards biogas has to be cleaned for CO_2 and pressurized, etc. Today, biogas can be certified by the governmental organization in Denmark named 'Energinet.dk', who guaranties that the gas substitutes fossil fuel like Ngas and thus result in supply of CO_2 neutral energy. The certification makes it possible for the energy consumers to track down the origin of the biogas all along the supply chain. So far only one Danish energy company, DONG energy, produces and distributes upgraded biogas to the Ngas network [11].

The challenge regarding upgrading for transportation and distribution on the Ngas network is however the price, which ad up to 0.5-1.00 DKK (0.067-0.13 €) to the total production price. Thus, only where local markets for biogas CHP cannot be identified - or surplus energy is produced - it would be favorable to upgrade the biogas for distribution to a larger market.

Industry process heat

High and low temperature process heat:

Another future opportunity for utilizing biogas within municipalities on Zealand is to substitute the use of fossil fuels like Ngas or coal etc. in industrial manufacturing. Thus, a large industrial application using e.g. Ngas for high temperature process heat, could thus convert to the use of non-upgraded biogas substituting Ngas. The energy produced on biogas CHP plants could also be supplied as district heating to cover lower temperature process heat demands, also here substituting the use of fossil fuel for process heat generation.

It would be beneficial to identify local industrial heat markets as future distribution option for biogas. This could be the industry that uses heat, primarily during summer periods, like in some agricultural or horticultural businesses. It could also be industries with steadier annual heat consumption, complying better with the production of gas on biogas CHP plants. In this way larger markets for heat will be available all year round and also during summer periods.

5. BIOGAS STAKEHOLDERS

So far the Danish biogas development has been centered around farmers, who has been the main drivers in implementing the technology, supported economically by municipalities through cheap public loans (municipal loan guarantees with an interest rate of four per cent p.a.). Some municipalities are however reluctant to provide such loans, due to bad experiences with failed biogas projects, e.g. Nysted biogas plant. It is, however, important that this 'Danish-model' of implementing biogas plants, which distributes heat in local communities, supported by the municipal heat planning, is continued.

If the dissemination of the biogas technology and the use of biogas in the energy system should expand further, new stakeholders are however needed in the future. Private companies, e.g. Ngas companies, should be active in upgrading biogas for distribution of gas in the Ngas network, and to provide biogas for transportation purposes. Ngas companies are therefore also likely to actually establish biogas plants to enable ownership of the entire production chain. This development is in it infancy, but already seen on Funen, where an Ngas company has engaged in the implementation of a biogas plant in Jutland.

Manufacturing industries too should look for opportunities for converting fossil fuel fed boilers with biogas for process heat generation as seen in the case of Arla producing milk-powder in Ringkøbing-Skjern. This could be through the supply of biogas from a nearby biogas plant, or by implementing a biogas plant at the company itself digesting organic waste, e.g. from slaughterhouses, sugar factories, breweries and other types of beverage and food manufacturing industries.

The existing pattern of ownership within the Danish biogas sector - with privately co-owned centralized as well as farm biogas plants - will thus be challenged in the future, if a larger market for and distribution of biogas should be achieved. This also includes the public sector (municipalities), where alternative ways of distributing biogas should be provided in the future. The use of biogas as city gas is an example for the future, as well as distribution of public supported non-upgraded biogas in separate biogas networks for heat purposes. In the following section we will exemplify some of these distribution options previous outlined, by means of three case studies conducted on Zealand.

6. BRIEF PRESENTATION OF CASES

Data used in the following section are from the 2014 research report conducted by the authors titled: "Opportunity analysis of biogas distribution options on Zealand & The future role of municipalities in promoting biogas" (see ref. [12]).

Case 1: Organic biogas plant in Lejre municipality

Distribution options:

As indicated in Figure 1 there are three distribution options for Case 1. The options are as follows: 1) the use of non-upgraded biogas in a local gas network supplying households with biogas for heating purposes, and 2) the production of CHP in a gas engine for distribution of electricity and district heating, or heat only by means of a heat boiler, and 3) supply of biogas to an upgrading facility that upgrades it to Ngas standards, and thus supply the biogas to the existing Ngas network.

Choice of energy supply:

A minimum of 5 m. m³ biogas should be produced on an annual basis to deal with the investments in an upgrading facility. As the suggested plant only produces 3.7 m. m³ biogas annually, it is not considered a feasible solution in this case. Distribution of non-upgraded biogas to households through a local biogas networks requires a steady heat market all year round, as it is problematic - both technically and economically - to store the biogas over longer periods.

The supply of non-upgraded biogas directly through a local biogas network is however hampered by lack of a *sufficient* heat market in the case area. The actual heat demand in Kirke Hyllinge is 9,500 MWh of Ngas, but the generated biogas will provide 22,900 MWh heat only. Thus, there is a surplus of biogas for the heat market in Kirke Hyllinge. A traditional plant concept where the biogas is converted to heat *and* power by means of a gas engine is therefore selected in this specific case, leading to a heat production of 11,600 MWh and a power output of 8,800 MWh annually. The proposed supply of energy is illustrated in Figure 2 below.

Plant concept & benefits:

- The plant concept is a traditional CHP plant with supply of electricity and heat, and
- Is operated as base-load for a more favorable plant profitability, thus
- The energy needs of the local community is matched with the capacity of the technology
- The biogas plant substitutes the use of Ngas in the local community
- The plant facilitates an increase in organic farming in the local community on Zealand
- The use of ray-grass are suggested, but several other types of local gas boosters are identified like industrial waste and agricultural residues
- The fertilizer (digestate) has high value for farmers due to nitrogen content and is easy distributed on farmland.

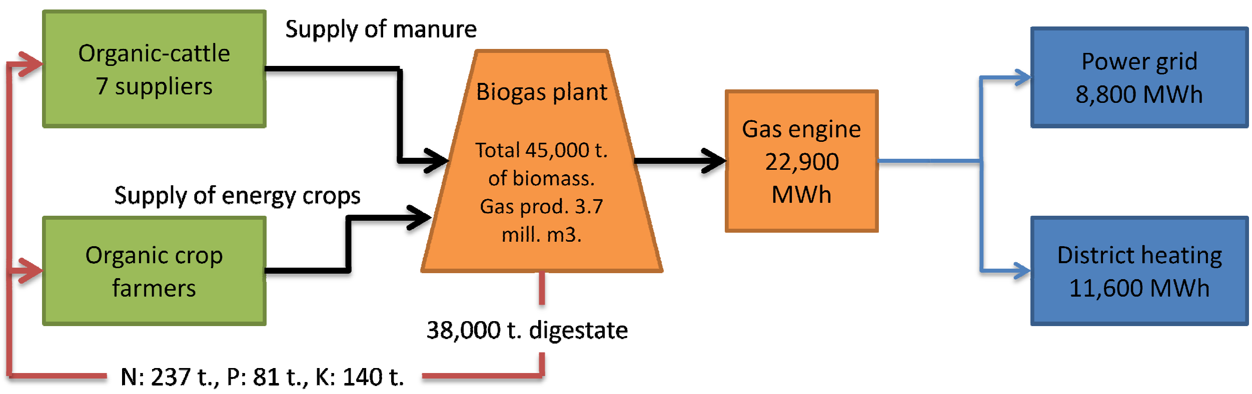

Fig.2. Biogas plant in Kirke Hyllinge.

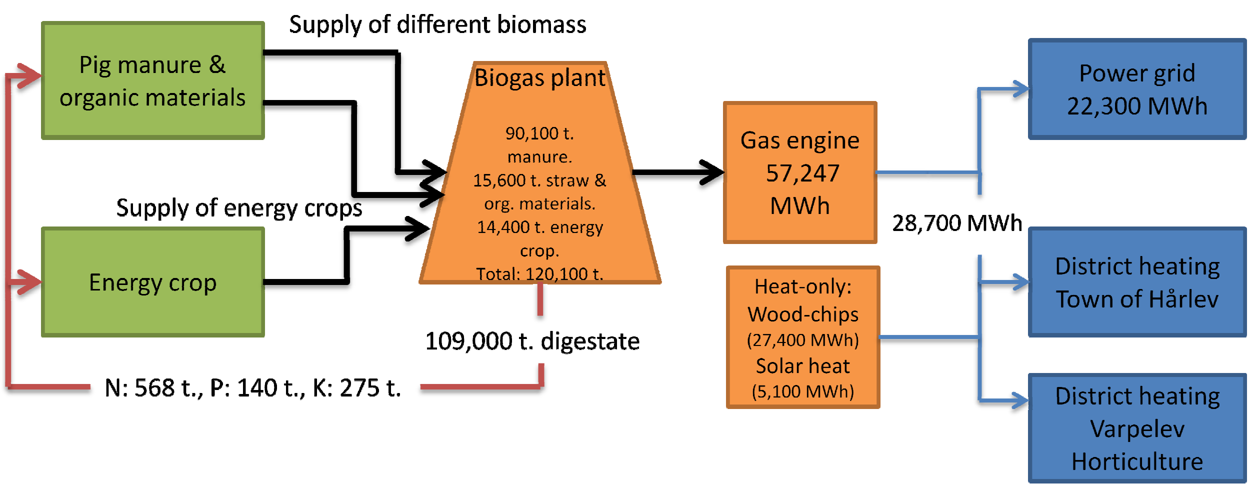

Fig.3. Biogas plant in Hårlev / Varpelev-horticulture.

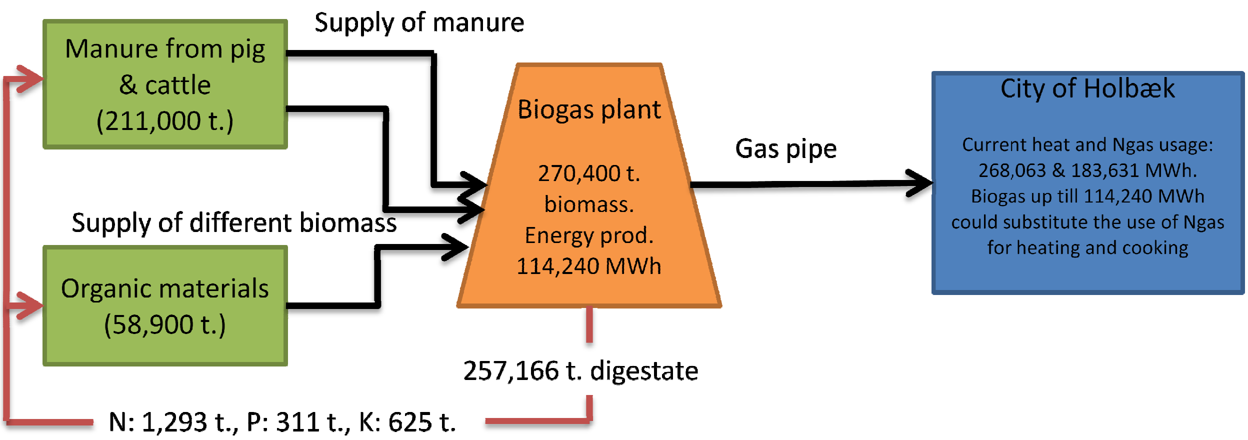

Fig.4. Biogas plant in Tuse.

Case 2: Biogas plant in the towns of Varpelev - Hårlev

Distribution options:

There are two distribution options for Case 2. The options are as follows: 1) production of CHP by means of a gas engine distributing power to the grid and district heating through an existing or new district heating network, or 2) supply of energy to a local industry substituting on-site consumption of fossil fuels for low temperature process heat.

Choice of energy supply:

The energy production is estimated as being sufficient to provide energy to both cases examined; to a district heating network supplying heat to citizens of Hårlev *and* to substitute the use of a coal fired boiler for heat production at Varpelev horticulture. The biogas plant will produce 22,300 MWh electricity distributed on the power grid and 28,700 MWh heat, which partly will be used for district heating supplied to the town of Hårlev (primarily during winter), and partly for low temperature process heat to Varpelev horticulture (during summer). They produce tomatoes and cucumbers in greenhouses. The company will additionally produce heat from solar heat collectors and from combustion of wood chips, of which some of this heat also will be supplied to Hårlev, by means of district heating network from the company, when surplus occur. The energy system is depicted in Figure 3.

Plant concept & benefits:

- The plant is a traditional CHP plant with supply of electricity and heat, where
- The heat market is matched to the local context, and
- Alternative heat markets provided by a horticulture requiring heat in summer periods, thus via
- Supply of low temperature process heat to industry
- The biogas plant is operated as base-load, and
- Substitute the use of Ngas and coal in the local community and industry
- Straw and grass from grass seeds are identified in the local community and could be supplied as gas boosters
- A valuable fertilizer is produced like in the previously case.

Case 3: Biogas plant in the town of Tuse

Distribution options:

There are three distribution options for Case 3. The options are as follows: 1) the use of biogas for CHP production with supply of electricity to the grid and heat by means of district heating, or 2) distribution of biogas as city gas substituting Ngas, or 3) upgrade biogas to Ngas standards for supply in the gas network substituting Ngas.

Choice of energy supply:

The large city near Tuse - named Holbæk - is currently supplied by Ngas, which is used for heating up households in individual installations (heat boilers). The high production of biogas from the suggested plant, which totals 17.7 m. m³, makes it economic feasible to upgrade it and distribute the gas - through a gas pipe - to the city of Holbæk, where the energy will cover half of the existing heat demand based on Ngas. Alternatively, and less cost full, the biogas can simply be cleaned for hydrogen sulfide and ammonia before mixed with Ngas, and then distributed as city gas for cooking in Holbæk. Both options are therefore viable in the case of Holbæk, and they provide opportunities for achieving high CO_2 emission reductions.

Even though a part of the biogas - with a future expansion of the supply of district heating - could be utilized for district heating purposes also, the immediate selected distribution options are here to upgrade the biogas to Ngas standards for heating purposes, and to clean and distribute the biogas as city gas. When the district heating network is expanded furthermore, energy from biogas can be supplied this way. Figure 4 above illustrates the proposed energy supply system.

Plant concept & benefits:

- Production of city gas or/and upgraded gas to the Ngas system is proposed in this case, due to lack of local heat markets, but
- Due to an expansion of the district heating system in the future, it will be possible to
- Supply district heating to households in winter, and
- Upgrade biogas to the Ngas network during summer

periods

- The flexibility of biogas as energy carrier is thus used to facilitate a transition period from Ngas to district heating in the local community
- Biomass boosters like deep litter, straw and grasses are identified in the local community, and if especially the latter are applied,
- A valuable fertilizer is produced due to the high content of nitrogen.

Case discussion and highlights

Besides the production of energy on biogas CHP's plants - supplying energy to local communities as electricity to the grid and district heating to local communities, substituting the use of Ngas etc. - the cases also highlights the opportunity of identifying new types of heat markets. The cases show that it *is* possible to identify alternative heat markets that are vital for the plant profitability. This was shown by the distribution of district heating to a horticulture company requiring heat during summer periods, where supply of low temperature process heat (district heating) was suggested. Such markets are hence assessable and should be identified more thoroughly in the future. In situations where alternative summer heat markets are not available - and surplus energy occur - it would be possible to upgrade the biogas to the Ngas network, and hence supply the energy to the national network.

In addition to the heat markets identified above, we suggest the following alternative heat markets being supplied by heat from biogas plants during summer periods: Other types of agricultural business, like sugar industries using large amounts of heat during summer periods when processing sugar beet. The heat could also be used during summer periods for drying fractions of municipal waste. Thus, fractions for incineration - not being digestible - could be dried during summer months and incinerated during winter periods, and the wet fractions however immediately supplied to biogas plants.

Alternatively, the heat could be supplied to an outside swimming pools requiring heat to provide a comfortable water temperature. On an annual basis, but to a minor extent, the heat could also be supplied as hot water to washing machines and dishwashers in households that all rely on electricity to produce hot water. This could instead be supplied by means of district heating. In this way the energy efficiency will increase, and the machines will avoid heating elements that are attacked by calcification.

The cases also illustrated that it is possible to match the local energy demand with the plant capacity, and that the biogas plant should be operated as base-load in order to achieve a favorable plant profitability. If peak heat demand is required, it should be covered by an alternative energy source, for example a small wood fuelled boiler or solar energy. All cases show that grasses can be applied to the biogas plant, hence avoiding the use of food products (maize and beet which are traditional gas boosters) to boost the gas production.

Emphasis was put on ray-grass, but clover grass and lucerne could also be an option. These grasses provide a high gas yield, and at the same time they contain large amounts of nitrogen, which is favorable when applying it on farmland later on as digested fertilizer. Due to the dry matter content obtained (below 10-12 % TS), the actual distribution of the fertilizer is easy. Besides the option and benefits of using grasses, the cases also show that manure from mink and deep litter can be utilized, and that waste from agriculture, like straw, as well as industrial waste are assessable; the latter however in limited amounts.

All cases showed environmental benefits as far as CO_2 emission reductions and the production of valuable fertilizer. The case of Tuse however also prove that a centralized biogas plant based on organic farming can support the development of organic farms on Zealand even more, and thus assist in limiting the overall amount of pesticides, fungicides etc. used in Lejre municipality. Currently, there is lack of organic manure that hampers a further development of organic farming on Zealand.

The cases further proved that new stakeholders should engage in biogas development, as the need to upgrade biogas will occur in the future as distribution option. Where the local heat market is too small or already saturated, etc., it is important to be able to upgrade to the Ngas system. The supply of non-upgraded biogas as city gas was also identified as a distribution option, requiring new stakeholders to engage. Thus, Ngas companies and other energy companies could play a role in providing such upgrading services.

7. FRAMEWORK CONDITIONS

The newly increased construction grant is most beneficial for the biogas sector that faces very high construction costs, hampering favourable plant profitability. We, however, suggest that the construction grant - when not fully utilized, as is currently happening - should be used to provide cheap municipal loan guarantees. The expected support to biogas used within industry and for transportation purposes is also very beneficial. Support for biogas used in industry is highly relevant, as it facilitates the development of local heat markets. Thus, these framework conditions support the new distribution options outlined.

We further propose that the 10 and 26 DKK/GJ (1.33 and 3.46 €) become index-regulated, and thus follow the general economic trend. Otherwise, the operating support will not be worth much due to the relatively high inflation currently seen. The electricity price should also follow the Ngas price, as the increasing gas prices eventually will de-value the price of electricity achieved at the plants. In addition to the suggestion above, the following initiatives could be provided by the government to support the biogas sector:

The government could also provide financial support for initial surveys and analysis of possibilities for implementing biogas plants in local communities. This type of support is for instance provided for windmills and has proved beneficial. In addition to this, financial support for implementing local biogas networks for non-upgraded biogas could be very useful. The biogas can thus supply energy to industry and households phasing out Ngas or other types of individual solutions based on fossil fuels. This will support new heat markets for biogas within local communities, and thus enhance the profitability of the biogas plants implemented. We further suggest that the government support a mapping of alternative heat markets within the Danish communities, which could be conducted by municipalities, and result in a more local and non-upgraded distribution and consumption of the energy where possible.

Where this is not possible, the Danish government should require decentralized Ngas CHP plants to be obliged to use and thus purchase biogas from a nearby biogas plant. This would create a larger market for biogas, but still, however, be connected to a seasonal need (reduced demand during summer periods). Thus, the expected governmental support related to upgrading of biogas to Ngas standard - to be utilized within industry and for transportation purposes etc. - is therefore also important for creating additional markets.

Besides carrots and sticks, the government may also engage municipalities on a voluntary basis in the dissemination of the biogas technology, by elaborating on its benefits. Much more must be done in order to provide and distribute knowledge of the effects of biogas within local communities. Thus, the biogas sector should not only be promoted by rules, regulation and economic support etc., but definitely also by the many benefits associated with the technology such as how it benefits the climate, water resources, and the benefits obtained by farmers through better crop nutrients etc. Local short and long term jobs are also created and new taxpayers provided.

We suggest that governmental officials and green organisations, together with the biogas branch organisation, including farmers etc., provide seminars and conferences conducted in each region or within specific municipalities where the potential for biogas is very high. Courses should be provided to local politicians and planners within municipalities and biogas networks across municipal boarders should be established. Visits to biogas plants and study materials can be disseminated, and people in the branch can tell the ‘good story’.

8. CONCLUSION

The Danish biogas sector is currently hampered by a technology track focuses on large scale biogas CHP plants distributing electricity and heat to local markets, and the fact that municipalities are reluctant to provide municipal loan guaranties, which limits new plants being implemented. The main purpose of implementing biogas plants has also shifted, challenging the technology track. Previously, the importance for farmers engaging in biogas was primarily to receive back digested manure providing a good quality fertilizer [13]. Today, however, new priorities have emerged where farmers and other potential investors would like to gain a profit from their investments in biogas. In order for this sector to move forward new stakeholders should therefore be included and new ways of using and distributing biogas should be emphasised. New framework conditions provided by e.g. government should further support the dissemination of the biogas technology.

Departing from the case studies conducted, we argue that local biogas CHP plants should have first priority when selecting distribution options if a sufficient (summer and winter) market for heat can be identified, as the energy will be produced and consumed locally, followed by high energy efficiency and environmental benefits. It is, however, not obvious that all the energy can be distributed locally by means of CHP, due to long heat market distances or due to a saturated heat market. In such situations it is beneficial to look at other distribution options, as mentioned above. Distribution of non-upgraded biogas in separate gas networks could be an option to e.g. households, but most beneficially to industry for process heat purposes.

The cases highlight that upgrading of biogas to the Ngas network during summer periods could be a new distribution option if local heat markets cannot be found. Greenhouses requiring heat during summer periods and sugar factories processing beet during the warm summer, etc., can for instance provide alternative heat markets. There are, however, no unified solutions and each context will have to be exanimated separately in collaboration with e.g. neighbor municipalities to find the optimal solution.

The government has enhanced the economic support to biogas compared to previously, but there is still a need to enhance the framework conditions for biogas in various ways, e.g. index-regulate the economic support (the 1.33 and 3.46 €/GJ), and have the electricity price follow the Ngas price. The support to biogas within industry and for transportation purposes is highly relevant for disseminating the new distribution options proposed in this research. The government should also, very importantly, assist in providing alternative gas boosters, preferably grasses with multiple benefits for the natural environment, which can also support the foundation for organic farming. The government could assist in planning how such resources should be harvested and shared between the regions in Denmark to avoid unfavourable competition. To oblige CHP plants to utilize biogas from nearby biogas plants in their fuel mix, can also support the biogas sector.

We further suggest that the government fund initial analysis of opportunities for implementing biogas within municipalities - equal to the fund provided for wind energy - and support the implementation of local gas networks for non-upgraded biogas, as well as mapping of alternative heat markets within Danish municipalities. Pivotal is also that the government provide knowledge to municipalities about the benefits of biogas, focusing on climate, nutrients, water resources and job creation, etc. New stakeholders in the biogas sector could be industry, Ngas companies and other energy companies providing upgrading facilities for supply of biogas on the Ngas network, or for use within the transportation sector.

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