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DEVELOPMENT OF A BIOGAS PLANNING TOOL FOR PROJECT OWNERS

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SUMMARY: A spreadsheet model was developed, which can be used as a tool in the initial phases of planning a centralized biogas plant in Denmark. The model assesses energy production, total plant costs, operational costs and revenues and effect on greenhouse gas emissions. Two energy utilization alternatives are considered: Combined heat and power and natural gas grid injection. The main input to the model is the amount and types of substrates available for anaerobic digestion. By substituting the models' default values with more project specific information, the model can be used in a biogas projects later phases to provide data for other documents needed such as economic and environmental assessments.

1. INTRODUCTION

Anaerobic digestion of manure and organic wastes has come into focus as a key part of a transition of the Danish energy supply towards independence on fossil fuels in the year 2050. In 2011 the Danish government published a “roadmap” to achieve fossil fuel independence, where key elements to reach the overall objective included improving energy efficiency, electrification of heating, industry and transport, expansion on wind power production, intelligent energy system (allowing more adjustments of demand according to supply) and expansion of biogas production. The existing natural gas grid in Denmark and its associated gas storage facilities provides the possibility of renewable energy gas storage, whereby biogas can help balance the fluctuating energy production from wind turbines (The Danish Government, 2011).

To increase biogas production in Denmark, incentives were implemented in 2012 in the form of increased state subsidies on biogas energy (electricity production, natural gas grid injection, biogas for transportation, process energy for industrial purposes), as well as allocating funds for financial support towards biogas plant construction costs. With regards to biogas energy subsidies, the following conditions were implemented (Folketinget, 2012):

- Electricity produced from facilities, where biogas is the only fuel used receives a subsidy, so that the facility's income is 1.15 DKK/KWh electricity sold to the grid. (1 DKK is approximately equal to 0.13 €)
- Biogas upgraded and injected to the natural gas distribution grid receives a subsidy of 115 DKK/GJ.
- Biogas for transportation uses and process energy in industry receive a subsidy of 75 DKK/GJ. Process energy includes use at the biogas plant itself – for example to heat reactors. The subsidies are partially adjusted according to the market price of natural gas recorded by

the gas exchange Nord Pool Gas, which means that if the price of natural gas goes up, the subsidies will decrease and the other way around. A smaller part of the subsidies will be phased out starting in 2016.

These increases in subsidies may cause a “second wave” of Danish centralized mixed substrate biogas plants. Digestion of manure and organic wastes in centralized biogas plants is a well-established practice in Denmark since the experimental introduction in the 1970s. However, a shift in energy and environmental policies and limited availability of suitable organic wastes caused a pause in the construction of new centralized biogas plants from the late 1990s until very recently (Raven and Gregersen, 2007). Due to this pause, recent experience among consultants and local authorities in Denmark regarding planning of centralized biogas plants in a Danish context is sparse.

Region Zealand, Denmark is leading an initiative in cooperation with Roskilde University and others to promote and coordinate the expansion of biogas production in the Region. Most of the Regions’ municipalities have signed on to the European Union “Covenant of Mayors” Programme, requiring them to set greenhouse gas reduction targets in their respective geographic areas, as well as developing strategies to meet those targets – so-called “Strategic Energy Action Plans”. Re-use of gained experiences regarding realization of individual biogas plants is an expected benefit of the cooperation within the Region, as well as minimization of repeating mistakes.

The first biogas plant to be constructed in this framework will be Solrød Biogas. Results of a preliminary study on environmental consequences of realizing this plant were presented at Sardinia Symposium 2011. This plant will receive app. 150.000 tons/year of substrates of which app. half of that will be residues from pectin production, whereas manure and beach cleaning waste are other significant substrates. The biogas plant is scheduled for completion in 2015. Its’ implementation is financially supported by the European Union through the Intelligent Energy Europe program, and the company responsible for the facility’s construction and operation will be owned by the Municipality of Solrød, VEKS (district heating company, which will own and operate the biogas engine facility where the biogas will be utilized) and CPKelco (supplier of pectin and carrageenan production waste to the biogas plant).

In this context, a spreadsheet model was developed to assess energy production, environmental effects (with emphasis on green house gasses) and economy for biogas projects. Biogas can be utilized for many energy purposes: combined heat and power (CHP), vehicle fuel, upgrade and injection in a natural gas distribution network, process energy in industry and more. The spreadsheet model described in this paper considers two centralized biogas plant concepts, which differs in type of energy utilization: CHP and injection upgrade and injection in a natural gas distribution network. CHP is by far the most common usage of biogas in Denmark today, but we estimate that biogas upgrade will be more common due to changes in biogas energy subsidies, which will make it an interesting option in areas with limited possibilities for utilization of heat in district heating networks.

2. MODEL DESCRIPTION

2.1 Aim of the model

The aim of the spreadsheet model and the manual written for its potential users is to function as a planning tool to evaluate important parameters in a concrete biogas project such as gas production, energy use, construction costs, running costs and environmental performance. It is intended to function as a tool in the early stages of the project (e.g. feasibility studies) as well as in further development of the biogas project, where the models’ default values regarding, for

example, methane potentials of various substrates, construction costs, energy prices etc. are substituted with more project specific information, as these become known.

The model is not designed to provide all data necessary in the planning of a biogas project. For example, a comprehensive analysis of the environmental effects of realizing a biogas plant will under certain circumstances be required. Although the model quantifies some relevant environmental effects such as greenhouse gas reductions and emissions, transportation of substrates and degassed biomass, it will likely not be sufficient for such an analysis. Likewise, a separate economical assessment/business case will be necessary prior to realizing the project, wherein models of financing the project are investigated. This model considers construction costs, other costs related to realizing a biogas project, running costs, reinvestments and incomes but does not take financing costs into account. In contrast, the model described in Karellas et al., 2010 includes financing costs. By including those, some basic assumptions regarding type of financing had to be made such as amount of own equity, grants, loan, interest rate and loan payback period, which may vary depending on who is going to make the investment.

Many model parameters listed in this paper are specific to Danish conditions. These include salaries; taxes; energy subsidies and CO₂ emission factor in the electricity grid.

2.2 Energy utilization alternatives

The model considers two energy utilization alternatives: Combined heat and power (CHP) and Natural gas grid injection (NGGI). CHP is the most common energy utilization alternative in Denmark, but NGGI may become more used due to the described recent change in biogas energy subsidies, and may be a favorable alternative in areas where the Danish natural gas grid is present, but the possibility of heat utilization, such as in a district heating network, is not.

Figure 1 show a simplified flow diagram of a generic mixed substrate biogas plant where CHP is used. Note here that the model assumes that the CHP unit supplies the heat required for the digestion process. For NGGI it is assumed that heat is recovered from the biogas upgrade process (see Figure 2). According to Jensen, 2009, 40 % of the energy used for biogas upgrade can be recovered for heating purposes, which is the models' default parameter.

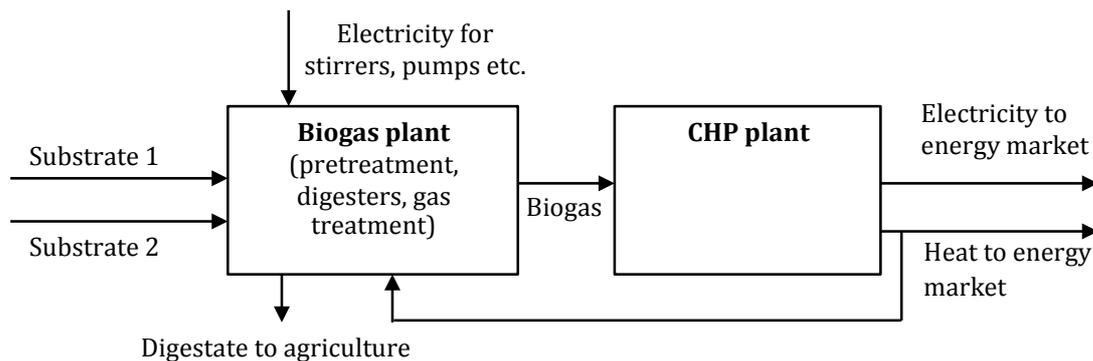


Figure 1. Simplified flow diagram of a generic mixed substrate biogas plant, where CHP is chosen as energy utilization alternative.

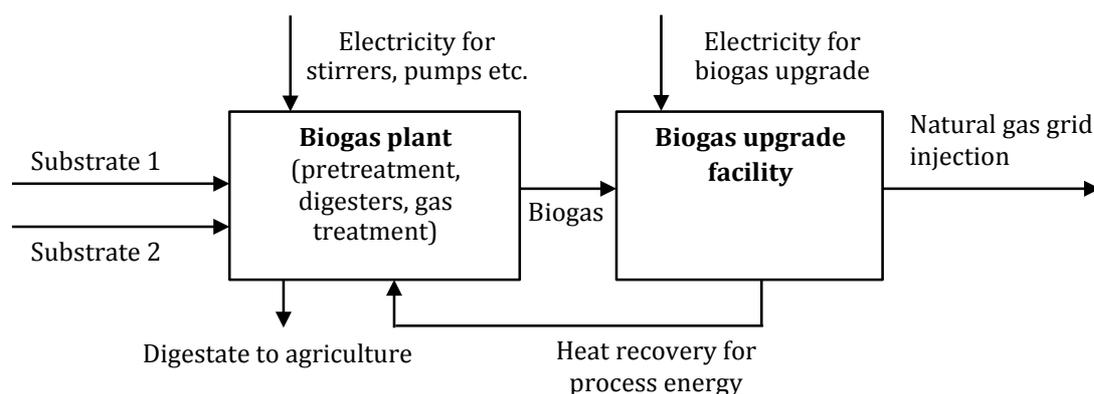


Figure 2. Simplified flow diagram of a generic, mixed substrate biogas plant, where NGGI is chosen as energy utilization alternative.

2.3 Input parameters – substrates

The following values have to be typed in for each substrate:

- Amount supplied (ton/year)
- Total solids (%)
- Volatile solids (%)
- Biogas yield ($\text{m}^3 \text{CH}_4/\text{ton VS}$)
- Distance to supplier (km)
- Nitrogen content (kg N/ton)
- Phosphorous content (kg P/ton)
- Gate fee (DKK/ton)
- Price (DKK/ton)

Typical values are suggested for common substrates such as different types of manure, waste types typically utilized for biogas production and energy crops, including maize. Methane potentials are commonly reported values of gas production for various substrates. These can be measured in batch experiments as described in Hansen et al., 2004, where gas production of a mixture of inoculum and substrate is measured over a period of, for example, 50 days. In a biogas plant, this maximum gas production is often not achieved, since this would require very long residence times in the reactors, and thereby increased costs. Deublein and Steinhauser, 2008 reports that the economical optimum is typically 75 %. To convert methane potential to biogas yield, as it is defined in the model, it is therefore suggested to multiply the methane potential by a factor of 0.75.

2.4 Calculations

2.4.1 Biogas production and energy use

Biogas production is calculated for each substrate separately. This is done by multiplying the input parameters: amount supplied, total solids, volatile solids and methane yield. Adding biogas production from each substrate yields the total gas production at the biogas plant.

Biogas plants and biogas upgrade facilities require a substantial amount of process energy. The basis for estimating energy usage is information from the Danish Energy Agency, who regularly publishes a catalogue of energy producing technologies (Danish Energy Agency and

Energinet.dk, 2010). Here, the electricity consumption of the biogas plant is estimated at 4, 5 or 6 kWh/ton of substrate treated, where 4 kWh/ton applies to larger centralized biogas plants (800 tons substrate received pr. day), 5 kWh applies to medium size plants (550 tons/day) and 6 kWh applies to relatively small centralized biogas plants (300 tons/day). This effect of scale is included in the model, where the total electricity consumption is calculated as 4, 5 or 6 kWh/ton of substrate, varying in steps according to the total amount supplied. For all biogas plant sizes, heat consumption is set at 34 kWh/ton of substrate, which is in-line with Danish Energy Agency and Energinet.dk, 2010.

Electricity use for biogas upgrade was set as 0.25 kWh/m³ biogas (Jensen, 2009), while energy recycling (heat recovery) from the upgrade process is set at 40 % as mentioned in section 2.2.

2.4.2 Energy production

Energy production is calculated for each of the two energy utilization alternatives – CHP and NGGI.

In the case of CHP, a central parameter is the electricity and heat efficiencies of the gas engine. These are set as 42.5 % and 50.5 % of the lower heating value respectively (Danish Energy Agency and Energinet.dk, 2010 – 1-10 MW Gas engines). As illustrated in Figure 1, the model assumes by default that required heat for the digesters is supplied from the CHP unit. Since biogas use for process energy is subsidized as mentioned in the introduction, we consider it likely that the CHP unit will provide process energy in many cases. Therefore, the estimated heat energy demand calculated as described in section 2.4.1 is subtracted from the calculated production to provide an estimate of the heat energy available for district heating. Also, the model assumes that 100 % of produced biogas is fed to the CHP unit. This assumption implies among, other factors that the biogas plant has sufficient gas storage in case of maintenance of the CHP unit.

In the case of NGGI, methane loss from the upgrade process is set at 1.5 % (Dansk Gasteknisk Center, 2009). This methane loss, as well as gas required for heating the digesters at the biogas plant is subtracted from the total gas production, whereby amount of gas for NGGI is estimated.

2.4.3 Transportation

The total transportation in tonkm is calculated for each substrate as well as digestate. By default the model assume that the distance to farmers receiving digestate for fertilizer use is equal to the average distance to suppliers of substrates, which the user of the model has to type in (see section 2.3). This may not be the case in all biogas projects, but can be seen as a reasonable assumption in the early phases of planning a biogas plant.

Costs of transportation, as well as greenhouse gas emissions resulting from transportation are calculated. Default values are 2.66 DKK/tonkm (Danish Energy Agency and Energinet.dk, 2010) and 0.35 kg CO₂ eq./tonkm (Danish Ministry of Transport, 2010) for costs and green house gas emissions respectively.

2.4.4 Costs and incomes

The model estimates total plant costs and running costs. Total plant costs are here defined as cost related to realizing the biogas plant, including reactors, tanks, pumps etc., but also land purchase, project development and typical investment needed at farms involved in the project. The source of information on total plant costs is the “technology catalogue” mentioned in section 2.4.1, which in this case refers to a study published in 2002, where total plant costs are calculated for three size categories of Danish centralized biogas plants, based on experience from experiences

in the Danish biogas sector (Danish Energy Agency and Energinet.dk, 2010, Nielsen et al., 2002). Total plant costs are here reported to be 5.7, 8.0, 9.7 million € for the three sizes of biogas plants defined by the input of substrates (300 tons/day, 550 tons/day and 800 tons/day). The model calculates total plant costs as a function of amount of substrates supplied derived the data on these three biogas plant sizes.

Costs for the CHP unit or NGGI unit are estimated based on information from Danish Energy Agency and Energinet.dk, 2010.

Operating cost items include operation and maintenance, labor costs, transportation of substrates and digestate, consumables, taxes and feedstock costs. Also, typical reinvestments are considered. Operating costs and reinvestments are derived from the study described in Nielsen et al., 2002, and vary between 15 DKK/ton of substrate received for relatively large biogas plants (300.000 tons/year) up to 22 DKK/ton of substrate received for smaller, centralized biogas plants (100.000 tons/year). This effect of scale is mostly due to reduced labor costs per ton of substrate received for the larger biogas plants (Nielsen et al., 2002).

Revenues comprise sales of electricity (CHP), heat (CHP), upgraded biogas (NGGI), gate fees, and subsidy for use of biogas for process energy. By default, the model assumes that 100 % of heat available for sale from the CHP unit can be sold. This assumes availability of a district heating network, or other large potential customer nearby, where demand for the energy exists.

2.4.5 Greenhouse gasses

The model estimates net reduction in greenhouse gas emissions, by taking into account the following:

- Substitution of fossil fuels (energy production)
- Reduction in methane and nitrous oxide emissions through change in manure management
- Reduced use of chemical fertilizers
- Emissions due to energy use
- Emissions from transportation of substrates and digestate

With regards to fossil fuel substitution, two calculation methods are used to calculate greenhouse gas reduction caused by electricity production. In the first case it is assumed that produced electricity substitutes production with the average associated greenhouse gas emission as it is today (average mix of electricity production facilities). Secondly it is assumed that production substitutes coal powered production, which will correspond to the Danish Energy Strategy mentioned in the introduction, where fossil fuel based energy sources are phased out, and supply of renewable energy (such as biogas) is increased.

Three scenarios are considered with regards to heat energy substitution: Expansion of district heating, where individual fossil fuel (mix of oil and natural gas) based heating is reduced, injection into existing district heating network with an average mix of energy sources and substitution of another renewable energy source, such as wood pellets. In the last case, the substitution factor is zero.

Reduced methane and nitrous oxide emissions from change in manure management are calculated using average values reported in the Danish National Inventory Report (Nielsen et al., 2011): 15.1 kg CO₂ eq./ton cow manure and 22.4 kg CO₂ eq./ton pig manure.

3. APPLICATION – EXAMPLE AND DISCUSSION

In the framework of the effort by Region Zealand to expand production of biogas in the Regions' municipalities mentioned in the introduction, a study using the model was done for Vordingborg Municipality. Vordingborg Municipality is situated in the southern most part of the island

Zealand and also comprises the island of Møn and several smaller islands. It is mostly rural. In the study local potential substrates were mapped focusing on agriculture and the food industry. The study suggested feasibility of constructing three smaller centralized biogas plants (see Figure 3). Locations of these three biogas plants were discussed with the municipality. Distance to suppliers and possibilities of energy distribution were factors considered before the municipality held a public hearing in 2012 to discuss expansion of biogas production for the three suggested locations. Table 1 show key figures estimated from one of the three biogas plants suggested for Vordingborg Municipality. For this biogas plant, a mix of manure from local livestock farms, organic waste from a local malting facility and energy crops were suggested as substrates.

Data regarding total plant costs and operational costs are mostly based on the technology catalogue - Danish Energy Agency and Energinet.dk, 2010, which in turn is based on experience on constructing and operating biogas plants in Denmark. As mentioned in the introduction, a pause in construction of centralized biogas plants in Denmark lasted from the late 1990's until recent years. This may cause estimations on construction costs used in this study to be out of date. Default values of costs are set for a "typical" biogas facility. Additional costs are likely in many cases. Examples of causes for additional costs could be extended distances to gas, electricity or heat distribution networks, need for pretreatment of certain substrates, one or more substrates are "seasonal" such as energy crops (increase in storage related costs) and increase in costs of substrate purchase.

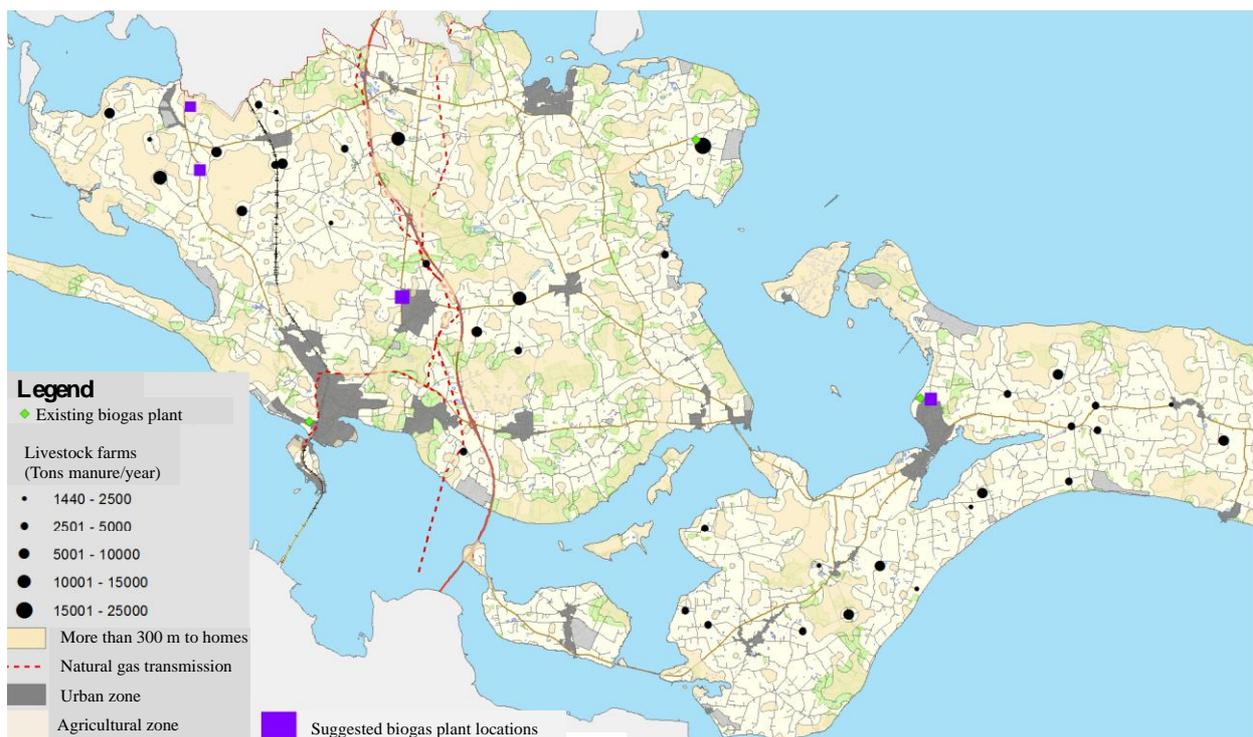


Figure 3. Suggested biogas plant locations in Vordingborg Municipality presented at a public hearing in 2012.

Table 1. Key figures estimated for a biogas feasibility study using the model described in this paper. Key figures are listed for the two energy utilization alternatives: CHP and NGGI.

<i>Key figures</i>	<i>Values (CHP)</i>	<i>Values (NGGI)</i>	<i>Units</i>
Substrate amount	63,400	63,400	tons/year
Average substrate dry matter content	11.9	11.9	%
Biogas production	28.5	28.5	m ³ CH ₄ /ton substrate
	1,806,470	1,806,470	m ³ CH ₄ /year
	2,779,185	2,779,185	m ³ biogas/year
Electricity sales	7,656	0	MWh/year
Heat energy sales	6,762	0	MWh/year
Upgraded gas sales	0	1,621,358	m ³ CH ₄ /year
Total plant costs	49,915	49,742	1000 DKK
Operational costs	4,953	5,714	1000 DKK/year
Revenues	10,833	11,406	1000 DKK/year
Net greenhouse gas reduction (min.)	4,227	3,200	tons CO ₂ eq./year
Net greenhouse gas reduction (max.)	8,348	-	tons CO ₂ eq./year
Increase of nutrient recycling	12,240	12,240	kg N/year
	2,040	2,040	kg P/year

Typical values of composition and methane formation of different substrates are used in the model. Some variability has to be expected. It is therefore recommended that the composition of the substrates intended for use are analyzed with regards to dry matter content, volatile solids and nutrients, and that methane formation is measured of the substrate or mix of substrates.

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