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Economies of scale in biogas production and the significance of flexible regulation

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ABSTRACT

Biogas production is characterised by economies of scale in capital and operational costs of the plant and diseconomies of scale from transport of input materials. We analyse biogas in a Danish setting where most biogas is based on manure, we use a case study with actual distances, and find that the benefits of scale in capital and operational costs dominate the diseconomies of increasing transport distances to collect manure. To boost the yield it is common to use co-substrates in the biogas production. We investigate how costs and income changes, when sugar beet is added in this case study, and demonstrate that transport cost can be critical in relation to co-substrates. Further we compare the new Danish support for upgraded biogas with the traditional support for biogas being used in Combined Heat and Power production in relation to scale economies. We argue that economies of scale is facilitated by the new regulation providing similar support to upgraded biogas fed into the natural gas grid, however in order to keep transport costs low, we suggest that the biogas plants should be allowed to use and combine as many co-substrates as possible, respecting the sustainability criteria regarding energy crops in Danish legislation.

1. Introduction

Denmark has a long tradition for biogas production; and since the Energy crisis in 1973 initiated the building of the first biogas test plants, biogas production have increased in Denmark in varies tempi (Raven and Gregersen, 2007). Biogas production is focused on using domestic resources to generate renewable energy along with reducing environmental damage from waste products in agriculture, industry and households. In Denmark the primary input is manure with various co-substrates added to boost the yield, the development in biogas production have been supported through R & D projects, temporary investment grants and support connected to the biogas output. The scale of plants have varied from decade to decade with focus on farm scale plants, then centralised plants and afterwards a revival of farm scale plants (Geels and Raven, 2007). Focus in biogas production has also changed through time from energy production to waste management, nutrients distribution, and green-house-gas reduction and lately back to energy production, where the newest development is towards centralised plants. Traditionally co-substrates have been waste products from the agricultural sector such as e.g. slaughterhouse waste, which the biogas plants were paid to receive. Today these recourses are already in high demand with rising prices and new biogas plants will have to find other resources. (Geels and Raven, 2007).

Earlier studies have already found economies of scale in biogas production e.g. (Jacobsen et al., 2013; Nielsen and Hjort-Gregersen, 2002; Raven and Gregersen, 2007), and while the collection of resources requires transport over longer distances, driving up unit costs of inputs (Mafakheri and Nasiri, 2014), economies of scale for capital expenditures (capex) drives unit costs down. Walla and Schneeberger, (2008) look into the optimal size of a biogas plant supplying a combined heat and power plant (CHP) and find that the increased costs of transporting silage maize is offset by the benefits of scale in terms of capital costs and generation efficiency. We extend this analysis to larger plant size and examine a similar co-substrate (sugar beet) for which there is a specific resource mapping in relation to our case location, distances are however long illustrating the consequences of high transport distances.

Support for biogas in Denmark does not vary with scale in contrast to e.g. in Austria and Germany (Brudermann et al., 2015; Lantz et al., 2007). However, until recently support was only provided to biogas used in local CHPs limiting the biogas production to fit the heat demand for the connected CHP. Since 2014 it has been possible to upgrade the biogas to biomethane for the extensive natural gas net and receive a similar support as for the CHPs. The specific aim of this paper is to determine whether the new Danish support for upgraded biogas allows the scale effects to be realised, compared to the traditional

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support for biogas being used in Combined Heat and Power production.

We therefore consider larger scales compared to earlier studies (Walla and Schneeberger, (2008) and a situation with manure as the primary input resource and allow the choice of upgrading biogas to the natural gas grid. Scale effects for Denmark reported in (Jacobsen et al., 2013) and (Skovsgaard and Klinge Jacobsen, 2015) indicated that economies of scale could be identified in some cases for biogas plants, but adding sugar beet did not provide clear results with respect to scale. We investigate this further and consider whether the current Danish regulation provides the incentives to exploit the economies of scale, and which policy changes that can be affecting this.

Section 2 documents the methodological modelling approach. In Section 3, the results are presented starting with scale effects in the 100% manure case and proceeding with the addition of sugar beet as a co-substrate which facilitates a higher yield, but also adds costs.

Section 4 performs a sensitivity analysis of the key parameters such as yield, sugar-beet prices and transport distances. Section 5 discusses the risk elements that are revealed by the sensitivity analysis and identified due to the regulatory risks. In Section 6, the results for economies of scale, earnings with co-substrates and risk elements are combined for their regulatory implications and policy advice. Finally, Section 7 draws the main conclusions.

2. Methodology and model

Based on a case study of an area in Denmark, we compare the two opposing scale effects for three specific sizes of a biogas plant. Like (Delzeit and Kellner, 2013), we include transport costs for manure, co-substrate (sugar beet) and the output (digestate). We extend our analysis to larger scale and include the option of upgrading to the gas grid, economies of scale is also included in the investment costs for upgrading. We use an excel model to calculate the costs of input collection, biogas production and cleaning or upgrading for further use. Revenues from the operation are based on the gas prices plus subsidies that can be obtained depending on various choices for supplying the biogas output to a local combined heat and power unit (CHP) or to the natural gas grid. The approach is to focus on private profitability regarding the choice of scale and input composition.

Cost data are estimated from Danish historical data, and transport costs are calculated on the basis of an actual location in Northern Jutland in an area, where manure is found in large amounts so it is suitable for large-scale biogas plants. The applied biogas yields are the results of actual experiments on co-digestion conducted as a part of the Biochain project (see Acknowledgements), the choice of co-substrate (sugar beet) is therefore dependent on the availability of consistent data within the project. In order to comply with the issue of case specificity we conduct a sensitivity analysis, and this confirms the importance of specific co-substrate availability (transport cost), price and yield assumptions, which is supporting our conclusions on the importance of regulatory flexibility with regard to co-substrate choice.

2.1. The model set-up

The model is used to calculate total costs for the biogas production based on required input amounts for each scale of operation. We examine scale effects on total costs and income both with a production entirely based on (pig) manure as input as well as the cost and income effects of adding a co-substrate (sugar-beet) to boost the biogas yield.

The value chain is depicted in Fig. 2.1, where the dotted parallelogram encases the economic work space for the biogas plant, and thereby the costs and income which is included in the calculations. Manure and sugar beet is bought from the farmers at a given price and then transported to the plant. Here the input is mixed and digested resulting in two products; the digestate, which is returned to the farmer, and biogas, which is either upgraded for the gas market or cleaned and sold to the local CHP.

Three different plant sizes are investigated. Small (110) with a capacity of 110,000 t of biomass input p.a., Medium (320) with a capacity of 320,000 t and Large (500) with a capacity of 500,000 t. Arguments for this choice of size can be found in the Appendix in the section on key data.

Three different cases of input mix of pig sludge (PS) and sugar beet (SB) in the feedstock are analysed for all scales: A case with manure only, PSSB-0: 100% PS, 0% SB and two cases where sugar beet is added: PSSB-12.5: 87.5% PS, 12.5% SB and PSSB-25:75% PS, 25% SB. The cases were selected on the basis of current and future Danish regulation (to achieve biogas support, the permitted maximum percentage of energy crops is 25% until 2017 and 12% subsequently[1] (Danish Energy Agency, 2012). This gives nine different results to analyse and compare.

To compare the scenarios, the total net income, $TNI\,(p_k, M_j, M_k, r_j, j, k)$ for the different scenarios has to be found.

$$TNI\,(p_j, p_k, M_j, M_k) = TI\,(p_k, p_{manure}, M_k, M_{manure}) - TC\,(M_j, M_k)$$

Where $TI\,(p_k, p_{manure}, M_k, M_{manure})$ is the total income for the plant as a function of the price of output k, p_k, the mass of output k, M_k and the price and mass of the input manure. $TC\,(M_j, M_k)$ represent the total costs as a function of the mass of biomass input, j, and the mass of output k. The sets J and K represent the set of input biomass (manure and sugar beet) and the set of output (gas and digestate).

2.2. Total costs

Total costs are expressed as:

$$TC\,(M_j, M_k) = C_{input}\,(M_{SugarBeet}) + C_{trans}\,(M_j, M_{digestate}) + C_{opex}\,(M_j) + C_{capex}\,(M_j) + C_{outputrelated}\,(M_k)$$

Where $C_{input}\,(M_{Sugar\ Beet}) = p_{sugar\ beet} \times M_{Sugar\ Beet}$, input- and output products are marked in green rectangles in Fig. 2.1. The pricing of manure is, however, closely linked to the output price of digestate and, therefore, input costs for manure are integrated in the income equation, this is further explained in Appendix A.

All capital expenditures are annuitized at a 5% discount rate with a depreciation period of 20 years.

2.2.1. Capital expenditures (Capex) and operational costs (Opex)

$C_{opex}\,(M_j)$ and $C_{capex}\,(M_j)$ are the investment and operational costs related to the actual production of biogas. In Fig. 2.1, this is depicted as the costs related to pre-storage, digestion and post digestion i.e. $C_{capex}\,(M_j)$ includes all necessary plant specific investment costs in storage tanks, digesters, buildings, land, process heaters, control systems, advisory services and so on. $C_{opex}\,(M_j)$, on the other hand, encompasses all operational costs directly related to the plant, i.e. manpower, fuel costs for process heating, maintenance and running costs (Ea Energianalyse, 2014).

Capex and Opex are estimated from data on the estimated costs for projected plants applying for investment support in 2012 in Denmark combined with model plants from the same period in time. The data estimations have been calculated from the equation of the best-fitting estimated trend line on these data, and are implemented in the model as the primary cost for Capex and Opex respectively (Table 2.1).

In the cases where sugar beet is added to the process additional Capex and Opex related to sugar beet are included.

To calculate the input cost for sugar beet pulp, a price of 27.46 Euro/tonne is used. The price is given by SEGES[2] (Abildgaard, 2015)

[1] In the experimental study it was decided to use 12,5% and not the regulated 12%, (Boldrin et al., 2016).

[2] SEGES is an independent consultant firm with focus on agriculture located in Denmark