Economies of Scale in Biogas Production

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Biogas production is focused on using domestic resources to generate CO_2 neutral energy production along with reducing environmental damage from waste products in agriculture, industry and households.

The technology is relatively expensive as an energy producer and therefore economies of scale is a way to improve the competitiveness.

The biogas production chain from the farmer, to the biogas plant and through to the use in a combined heat and power plant or alternatively as upgraded biogas supplied to a natural gas grid involve cost drivers that may exhibit different properties with regard to scale. Supply of the feedstock and the capital costs of the biogas plant are elements that may have opposing scale effects for the economic profitability. Collection of resources requires transport over longer and longer distances depending on the scale of operation. This drives up unit costs of inputs. Unit costs on the other hand declines as economies of scale for capital expenditures are realised. Walla and Schneeberger (2008) looks into the optimal size of a biogas plant supplying a combined heat and power plant. They find that transport costs of silage maize increase with scale, but the benefits of scale in terms of capital costs and generation efficiency more than offsets this. We consider larger scales and a situation with manure as primary input and allowing the choice of upgrading biogas to the natural gas grid.

Methods

Based on a case study for an area in Denmark we compare the two opposing effects for three specific sizes of a biogas plant. Like Delzeit and and Kellner (2013) we include transport costs for manure, co-substrate sugar beet and the output digestate. In the considered area manure is found in large amounts allowing large scale biogas plants. We use a small model to calculate costs of input collection, biogas production and upgrade to natural gas grid. Revenues from the operation is based on the various choices for supplying the biogas output to a local combined heat and power unit (CHP) or to the natural gas grid based on the gas prices + subsidies that can be obtained. The approach is focusing on the private profitability of operation as we examine private incentives for choice of scale and input composition.

The model first calculates input costs based on required input amounts for each scale of operation. First we examine scale effects with a technology entirely based on manure as input. Secondly, we examine the effect of a co-substrate (sugar-beet) on the total cost and scale effects.

For the case with the input mix of manure and sugar-beet we use the local resource constraints for existing sugar-beet output, not considering change in cultivated crops. Transport distances, type of vehicles, loading costs etc are taken into account like in Walla and Schneeberger (2008). Increasing the scale of operation results in longer distances driven to collect, but it varies substantially between the manure and the sugar-beet. All operational and capital expenditures of the biogas plant itself is added dependend on the three different scales. For scale effects there is a choice between using the output from the biogas plant directly in a combined heat and power plant or upgrading the biogas to natural gas standard and connecting to this grid. The larger the scale, the more necessary the final upgrade of biogas become, due to limited demand for the heat output from the CHP. This upgrade involves additional capital and operational expenditures.

Findings

Three scales of operation are compared: Small(110) 110,000 tonnes of input p.a.; Medium(320) 320,000 tonnes of input p.a; Large(500) 500,000 tonnes of input p.a. We use the farms specific locations and calculate the necessary travel distance to collect the manure under some simplified assumptions on actual travel distance while assuming that these transports also return to the same farms with the treated manure/digestate. The travel distance determines the variable part of the transport costs whereas the fixed part per load concists of both loading and unloading time. Scaling up the plant to the largest size will increase the total transport costs per unit with around 50%, in which case the fixed transport costs constitute only 25% of total transport costs. Yabe (2013) using GIS also examines manure treatment in biogas plants and finds finds even higher transport costs (56% of running costs, compared to our 26%).

This rise in unit cost must be compared to the benefits of scale in other cost components. In Figure 1 all unit cost components for the case with only manure is compared. Transport costs are rising as well as operational costs at the biogas plant. For capex there is considerable benefit of scale, that dominates the diseconomies of scale from the transport and opex costs. Even for the very large

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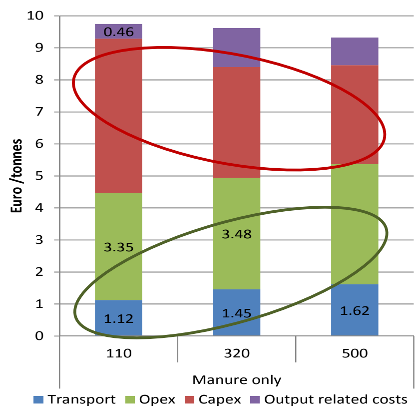
scale of operation Large(500), where biogas production considerably exceeds local CHP demand for biogas, there are substantial benefits to scale.

Biogas production based on manure and no co-substrate is not yielding a high biogas output per input volume. Therefore, we also examine two cases with addition of 12½% and 25% of suger beet as co-substrate. This provide higher yields, but also higher costs. Focusing first on the transport costs we find that sugar beet availability in the local area is dispersed and requires longer transport distances than the manure. Hereby, the total transport costs per unit increase by around 140% when moving from zero to 25% sugarbeet (represented by vertical arrow). For the sugar beet cases the unit cost also rise with scale, and as the level of transport cost is higher the absolute increase in transport cost from 110-500,000 tonnes result in a larger contribution to diseconomies of scale than for the zero sugar beet case. In Figure 3 this larger effect is also observed when all cost components are compared between the three different input cases.



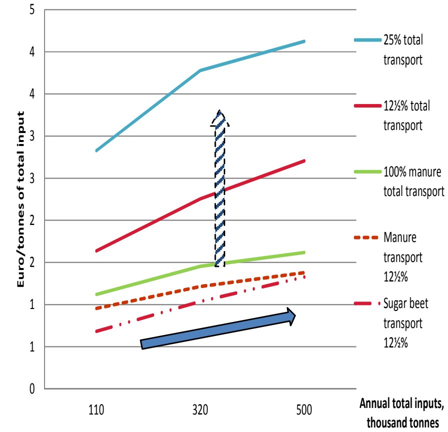


Figure 1: Trade off between rising transport and operational costs against reduced capital costs in a manure case for three different scales of operation (left)
Figure 2: Transport costs per total input 110-500 000 tonnes (right)

In Figure 3 it is shown that total cost per unit of total input more than doubles when 25% of sugar beet is added. The main contributer to this is the purchasing cost of sugar beet (top arrow), but also the rising transport costs (bottom arrow), and output related costs are important. Both elements reveal the importance of securing low cost co-substrates and collecting the resources available close to the plant. For scale effects in sugar beet cases the pattern is almost stable unit cost when increasing from 110-500,000 tonnes of input. Thus, we do not find the same economies of scale as found for the pure manure case.

The explanation is the larger increase in transport costs for sugar beet and digestate and larger increase in output related unit costs. Overall, the economies of scale and the constant unit cost in sugar beet cases both suggest that the largest scale plant is the most attractive provided that operation is profitable and feasible feasible.

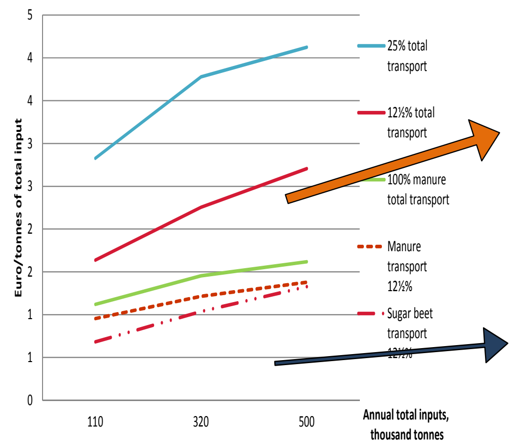


Figure 3: Costs per input unit when adding sugar beet to the input in three different scales (110-500000 tonnes)

Conclusions

In a Danish case study we find that per unit transport costs for biogas plants are rising with scale, partly offsetting the economies of scale found for capital expenditures. A detailed modelling of manure resources available, the fixed and variable transport costs and digestate transport costs suggest that in certain areas in Denmark centralised large scale biogas plants are the most economical provided that all biogas production can be upgraded to natural gas grid and receive the existing support.

When the biogas plant size is scaled up from 110,000 tonnes of annual inputs to 500,000 tonnes, the opposing contributors to scale effects and the net result found are:

- A unit cost reducing effect in capex, where unit costs are reduced by 35%
- A *unit cost increasing* effect from transport, with an increase of 45% for manure input and 96% for sugarbeet input
- For the only manure case the net effect (trade-off) is a total unit cost reduction of 4½ %
- For the two cases with sugar beet the net effect is a slight increase in unit cost, where the economies of scale disappear due to faster rising sugar beettransport cost and output related cost.

We can conclude that there is a case for larger scale biogas plants in Denmark based on economies of scale in costs, but that the effect with co-substrates such as sugar beet requires availability relatively close to the plant.

(see references on page 38)