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The economics of sugar beets in biogas production

The economics of employing sugar beets for biogas production were investigated using a calculation model based on the currently available data. Taken into account were all steps of the chain from cultivation, conditioning and conservation to the influences in the biogas plant. Only by calculating with very good assumptions for the fermentation of sugar beets, they can constitute an economical alternative to the use of silo maize as a fermentation substrate.

Keywords
Biogas, sugar beets, economic efficiency

Abstract
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Sugar beet is becoming increasing popular as substrate for biogas plants. Plant managers are now attempting to integrate beet more and more in their plant concept and are collecting information on its conservation and fermentation. Whether sugar beet is a profitable alternative to forage maize in the biogas plant is currently controversial. There are several arguments for sugar beet in this context: yield of methane per hectare (without foliage) for sugar beet equals that of forage maize; growing beet lengthens the rotation on the farm. It also allows the continuation of beet growing where it would normally have been dropped because of the developments in the sugar market, with associated continued exploitation of infrastructure, management know-how and specialised machinery. In the following paper the production costs of the substrates sugar beet and maize silage are compared and the influence of the respective preparation and conservation procedures on the economics of a 500 kW biogas plant calculated.

Crop production

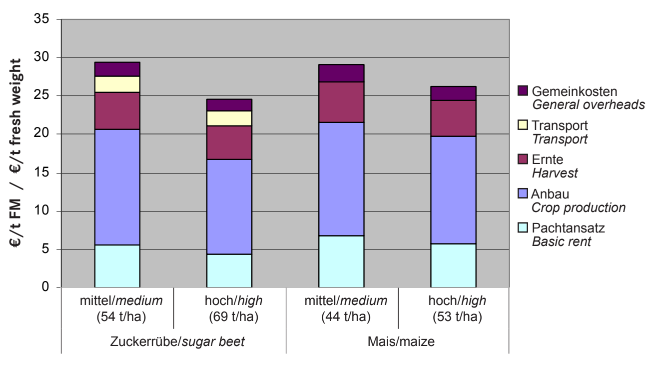
First calculated in this comparison are respective cultivation costs up to delivery at the biogas plant. Standard mechanisation is assumed entailing a guide tractor size of 120 kW taken from the KTBL databank, and a distance between field and biogas plant of 4 km. Fermentation residue is applied as fertiliser and not costed in the calculations. Nitrogen losses during its storage and field application require a balance fertiliser application equal to 40% of nitrogen withdrawal. Rental is put at 300 €/ha and fixed overheads at 100 €/ha. In the following graph (**figure 1**) costs are calculated in each case based on the usable amount of silage produced from an average yield and for a high yield.

Based on the amount of fresh material produced, sugar beet costs are slightly below those for forage maize. Especially where the yields are high there's a more pronounced reduction in the specific costs for beet production. Higher yields can depend on location but also on the varieties involved, or on a later harvest.

The beet has to be available year-round for the biogas plant. Two currently common methods of conservation for this purpose are considered: liquid ensiling in a silo tower or lagoon, and ensiling of whole beets in a plastic tube system. With both variants beet is first washed and separated from any stones.

Liquid ensiling features chopping of the beet with the resultant wet mash pumped into a tower silo or lagoon and there conserved. In that resultant pH is very low, the acidity level has to be taken into account when considering storage. So far, stainless steel tanks are being used for tower silos entailing an investment of approx. 100 € per tonne of liquid silage storage capacity. Reinforced concrete containers with a protective inner layer of epoxy resin (approx. 50 €/t storage) offer an alternative solution, or lagoons with special plastic lining (approx. 15 €/t storage). The following calculation takes into account only the

Fig. 1



Specific production costs up to delivery at plant location, depending on yield level. Maize transport costs are included in harvesting costs.

Table 1

Substrate preparation costs from delivery to biogas plant [€/t fresh weight (fw)]

Arbeitsverfahren ***System***	**ZR-Flüssigsilierung** ***Sugar beet liquid ensiling***	**ZR-Schlauchsilage** ***Sugar beet plastic tube ensiling***	**Maissilage** ***Maize silage***
Spez. Kosten frei Biogasanlage/*Specific costs from delivery to biogas plant*	29,47 24,74[1)]	29,47 24,74[1)]	29,06
Befüllen Waschmaschine/*Filling washer*	0,56	0,56	
Waschen/*Washing*	1,39	1,39	
Rübenzerkleinerung/*Chopping beet*	1,41		
Lagerkosten Flüssigsilo Beton/*Storage costs for a concrete silo for liquids* Lagerkosten Flüssigsilo Erdbecken/*Storage costs for a lagoon silo for liquids*	4,15 1,52		
Beschickung Schlauch/*Filling of silage tube*		0,56	
Schlauchsilierung inkl. Flächenkosten/*Tube ensiling incl. area costs* Schlauchsilierung ohne Flächenkosten/*Tube ensiling excluding area costs*		6,48 4,43[1)]	
Lagerkosten Flachsilo/*Storage costs silage clamp*			4,87
Umschlag Silo Feststoffeintrag/*Handling silo solids input*		1,74	1,70
Einbringen in Fermenter über Pumpe/*Feeding fermenter via pump*	0,40		
Einbringen über Feststoffeintrag/*Feeding via solids input*			1,35
Summe frei Fermenter/*Total up to fermenter*	37,39 29,98[1)]	41,55 34,77[1)]	36,97

[1)] Optimalfall, Annahmen: günstigste Bereitstellungskosten für die Rübe; geringe Investitionskosten für das Flüssigsilo; kein Anfall von zusätzlichen Flächenkosten bei der Schlauchsilage.
Optimal case with assumed factors: lowest preparation costs for beet, limited investment costs for liquid silo; no charge for addtional area costs for plastic tube silage.

last two variants. Feeding beet mash into the fermenter can be automated via pump. Moving the beet from the plastic tube is by tractor and loader or wheel loader with suitable beet basket with integrated beet chopper. **Table 1** shows the required steps for the respective variants and the costs involved. Assumed losses for the beet silages are 6 % and for the maize silage 12 %.

In terms of cost of supply to the fermenter, liquid ensiling is calculated as cheaper than the plastic tube procedure with the higher costs for the latter due to the more complicated silage withdrawal from the tube and its transport into the fermenter. Savings could be possible in this respect through optimising the chopping operation, for example. An advantage of ensiling in a plastic tube is the flexibility of the system. Often, existing surfaces can be used for the filled tubes so that required investment is limited.

Comparing costs up to point of use at the fermenter for beet and maize silage makes it clear that, on a fresh material basis, beet can only offer clear savings over maize silage where optimal conditions are assumed.

Substrate characteristics

Table 2 makes clear that, despite a higher specific yield of gas based on fresh mass, beet achieves a markedly lower methane yield than maize. In order to match methane production from a tonne of maize silage, 1.41 t of beet silage would be required. These circumstances mean that, despite applying lowest preparation costs, sugar beet involves around 14 % higher raw material costs.

Beet raw material costs are only comparable with those for maize silage where specific biogas yield for the former is 800 m^3/t ODM higher. In such a case only 1.23 t beet silage would be required to substitute a tonne of maize silage.

Table 2

Substrate characteristics yields and raw material requirement from sugar beet and maize

	Einheit ***Unit***	**Mais-silage** ***Maize silage***	**Zuckerrübensilage** ***Sugar beet silage*** **700 m³/t oTM** ***700 m³/t odm***	**Zuckerrübensilage** ***Sugar beet silage*** **800 m³/t oTM** ***800 m³/t odm***
TM/*dm*	% of FM *% of fw*	33	23	23
oTM/*odm*	% of TM *% of dm*	95	90	90
Biogasertrag *Biogas yield*	m³/t oTM *m³/t odm*	650	700	800
Methangehalt *Methane content*	%	52	52	52
Methanertrag *Methane yield*	m³/t oTM *m³/t odm*	338	364	416
Methanertrag *Methane yield*	m³/t FM *m³/t fw*	106	75	86
Energieäquivalenz *Energy equivalent*	t FM *t fw*	1:	1,41	1,23

Through the results so far available, only the KTBL standard of 700 m³/t ODM is, however, statistically verified. There are a number of reports giving higher yields than this, but also reports of yields that are lower.

Effects in the biogas plant

The effects on economic viability when sugar beet is used are calculated using the example of a 500 kW biogas plant. In the basis variant this plant is fed with cattle manure and maize silage. In two "sugar beet variants" part, or all, of the maize silage is replaced by sugar beet silage (**table 3**). For the calculations, the most cost-effective variant for supply of sugar beet to the fermenting point from **table 1** is used (29.98 €/t fresh matter). Along with the supply costs, the following four points influenced economic viability of the plant:

- Working time requirement: Depending on beet conservation system, the working time requirement for feeding the fermenter can differ markedly from that of maize silage. In the case of liquid ensiling, automation is possible and this greatly reduces working time requirement. Accepting that chopping the whole beet silage from the plastic tube system would be required before fermenter feeding means working time requirement is higher than that for feeding maize silage. Labour costs for the various work procedures are taken account of in **table 1**.
- Fermenter volumes: The higher specific gas yield from beet silage means less fermenter capacity is necessary for the same throughput and performance. Investment is thus reduced, as are associated fixed costs. In example II (manure and beet only) it is assumed that the clearly shorter process period (50 days) because of the faster degradation of the substrate means a higher throughput (approx. 4 kg ODM/m³ • d) is realisable, whereby necessary fermenter volume may be considerably reduced.
- Fermenter residue storage volumes: Compared with maize, sugar beet has a lower DM content and less energy density based on fresh mass. For the same performance there is therefore a larger volume of fermentation residue thus a need for higher investment and fixed costs.
- Agitation energy: The low DM content and the faster breakdown of ODM lead to a lower DM content in the fermenter and so to less agitation/stirring requirement. For calculations it is assumed that energy requirement for agitation sinks in line with the reducing DM content of the substrate mixture.

The calculations indicate that, according to the current level of information (KTBL standard gas yields for maize 650 m³/t ODM, sugar beet 700 m³/t ODM), biogas production from maize is more profitable (**table 3**). This applies to the cofermentation of maize, beet and manure as well as for the individual fermen-

Table 3

Effects on economic viability of a 500 kW biogas plant

	Einheit *Unit*	**Mais** *Maize*	**Mais + Rübe** *Maize + Sugar beet*		**Rübe** *Sugar beet*	
			700 m³/t oTM *700 m³/t odm*	**800 m³/t oTM** *800 m³/t odm*	**700 m³/t oTM** *700 m³/t odm*	**800 m³/t oTM** *800 m³/t odm*
Gülle *Liquid manure*	t	3 000	3 000	3 000	3 000	3 000
Mais *Maize*	t	9 200	7 200	7 200	-	-
Zuckerrübe *Sugar beet*	t	-	2 820	2 470	13 000	11 300
TM-Gehalt *dm content*	%	26,9	25,1	25,1	20,2	19,9
Substratkosten frei Fermenter *Substrate costs up to fermenter*	€/a		+10.604	-200	+49.616	-1.350
Benötigter Fermenterraum *Required fermenter area*	m³	3 708	3 656	3 569	2 200	1 970
	€/a		-184	-494	-12.610	-13.495
Benötigter Gärrestlagerraum *Required fermenter waste material storage area*	m³	5 496	5 963	5 764	7 659	6 714
	€/a		+1.196	+687	+5.373	+3.067
Benötigte Rührarbeit *Required agitation*	kWh/a	140 000	130 600	130 600	105 100	105 100
	€/a		-1.405	-1.405	-5.230	-5.230
Kostendifferenz *Cost difference*	€/a		+10.211	-1.412	+37.149	-11.778
Gewinn *Profit*	€/a	85.634	75.423	87.046	48.485	97.412

tation of beet and manure. Only where the beet can be cost-efficiently harvested and stored and where resultant gas yields are well over the KTBL guideline values can its fermentation achieve a similar or better result than that for maize.

Conclusions

Information available so far indicates that only under very positive assumptions for the fermentation of sugar beet can a better economic result be achieved for beet compared with maize as substrate. These assumptions include favourable supply and conservation conditions as well as high gas yield.

Liquid ensiling is the most cost-effective conservation system, above all through the time-efficient and cost-efficient delivery into the fermenter. But the plastic tube silage approach is more flexible and ties up less capital. Alongside optimisation of beet delivery to the fermenter, a way has still to be found for loading into the fermenter the leaching liquid from plastic tube beet silage.

Database figures for calculations on economic viability are, however, still somewhat insecure. This applies, above all, to DM losses in the conservation procedures and the level of gas yields for headed, defoliated and whole plant beet.

If the sugar beet potential is to be fully exploited in future then not only the data situation will have to be worked on. There is also a great need for further development and testing of future technology with the potential of reducing labour requirements and costs and therefore enabling an efficient processing chain. The future lies in a reduction of the labour input and in full automation of the substrate logistics within the plant.

In practice,first plants are now working on getting by without having to wash the beet. Possibly, extraction systems within the fermenter could be integrated here. Indispensable, however, is stone separation.

Similarly, high performance fermenters without agitation technology are being tested. These exploit the rapid degradability of beet silage with very short production periods and high throughput. The in-part parallel utilisation of tower silos for storing raw material and fermentation residues could also represent a possibility for further cost reductions.

Breeding input is required too. The shape of the beet could be changed so that dirt attachment is minimised, as well as all possibilities of increasing yield of methane per hectare (e. g. a stubble turnip type of root that improves possibilities for whole plant exploitation of root and foliage, increasing the proportion of high-degradation contents for shortening the process period, winter hardiness).

Currently there are numerous and in some cases very promising developments which could strengthen the competitiveness of sugar beet as biogas substrate.

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