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How location decisions influence the transport cost of processed and unprocessed bioenergy digestates: the impact of plant size and location on profitability of biogas plants in Germany*

Ruth Delzeit and Ulla Kellner

Abstract: The production of bioenergy is considered to be a promising energy source for a sustainable energy mix and it is politically promoted in many countries. With the exception of Brazilian ethanol, bioenergy not competitive to fossil energy sources, and therefore needs to be subsidised. Several types of bioenergy are based on bulky raw biomass with high per unit transport costs, importantly impacting on the plant's production costs and profitability. In addition, considerable quantities of digestates are released, causing disposal costs. Various studies in the past aimed primarily at analysing transport costs of inputs. In this paper we focus on disposal costs of fermentation digestates from biogas production in Germany and analyse different processing techniques and their impact on profitability for three plant size in three case study areas.

Our results show that especially in regions with only a small amount of agricultural land and a large heterogeneity in its agricultural area, processing of digestates increases the profitability of biogas production. The same accounts for regions with high livestock density, where the area needed for disposal is comparatively large. The cost efficiency is enforced by a high share of animal excrements on input and the biogas plant size.

Keywords: transport costs, biogas profitability, digestates processing, choice of location

JEL classification: C69, Q16, Q55

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1 Introduction

The production of bioenergy is considered to be a promising energy source for a sustainable energy mix and it is politically promoted in many countries. It gained even more importance in Germany, where after the Fukushima nuclear accident a transition of energy sources towards renewable energies has politically been decided. The political (and financial) support for bioenergy is necessary because these bioenergy pathways, except Brazilian ethanol, are not competitive to fossil energy sources. Therefore, the profitability of these new technologies is important to get them into the market without being subsidised.

Second generation biofuel production or first generation biogas production from agricultural biomass is mainly based on bulky raw products with high per unit transport costs, and has an important impact on the plant's production costs and profitability. For goods with high transportation costs, [1] argue that demand for biomass is local and stems from location decisions for bioenergy processing plants. These are driven to a large degree by regional differences in transport and production costs of feedstock, especially if there is little spatial variance in other important factors such as output prices, investment costs and other operational costs.

Besides transports of biomass or waste products used as an input, the application and distribution of residual products from the transformation process contribute costs. (These residual products can usually be spread on the field or used as e.g. animal feedstuff.) An example for bioenergy pathways where transport costs of digestates may be high and thus have an influence on total profitability is the production of bioethanol from sugar cane, where vinasse, a residual material from the fermentation process is transported back to the sugar cane fields as a fertiliser. Here it also provides water supply. In order to reduce transport costs, a fairly new technology is to process vinasse to concentrated molasses stillage (CMS) and supplement it with nitrogen. This reduces transportation costs but increases processing costs [2].

The problem of high transportation cost also appears for digestates stemming from the fermentation process of biogas production. In Germany, biogas production is supported by the so-called German Renewable Energy Source Act (EEG), which implements attractive feed-in tariffs for electricity produced by this type of source, guaranteed for 20 years and adjusted depending on inputs used, plant size and plant technology. The EEG, created in 1991 and reformed in 2000, 2004 and 2008 [3-6], led to a sharp increase in electricity production from biogas and an increase in average plant sizes. However, costs to the tax payers subsidising biogas production according to the reform in 2008 are high [7] and ways to reduce production costs need to be considered. Several studies analyse per unit transport costs of biomass to processing plants [8-10].

In case of biogas digestates, different plant sizes are considered in [11]. The impacts of digestates application and distribution on the overall profitability taking into account different plant sizes has not been analysed precisely yet. Furthermore, analysis of the influence of regional factors such as the distribution of land on transport costs of digestates is missing. The present study therefore focuses on the impact of the disposal of digestates on total profitability of different plant types. Furthermore, we consider the influence of regional factors on the costs of the disposal of digestates and consequently on the profitability of plants by using a transport cost model for different regions in Germany. The results are important for policy makers, since they show how regional factors influence bioenergy production and so give hints on regionally different working policy instruments. It also gives insights in other biomass production projects, in which high transport cost for digestates or “by-products” appear.

The paper is structured as follows: In section 2 we motivate our research question by providing the problem setting and relating it to relevant studies. In section 3, we describe in detail the method applied as well as the underlying data and assumptions. In section 4, we discuss results on plants’ productivity for different plant size, technologies for the disposal of digestates and implications of regional factors. Finally, we draw conclusions for the consideration of transport of digestates.

2 Background and Problem Statement

Biogas can be produced from a wide variety of input sources. Due to its cost efficiency, the dominating feedstock observed in reality is green maize which is often combined with manure and grain (see e.g. [12] and [13] who provide an explanation of this). According to the concept of von Thünen Rings, the profitability of different inputs for biogas production is calculated and it can be shown that despite high transport costs of ensilaged maize (in the following we call it maize), its land rent (von Thünen’s so-called “Lagerente”) is the highest up to a transport distance of 24 km. At longer distances, grain is the most profitable input [13].

Green maize is generally cultivated on fields surrounding a biogas plant and the harvest can be stored centrally at the biogas plant or de-centrally on the field. Biogas plants using manure as an input are usually located in the direct vicinity of livestock or dairy farms. Alternatively, small amounts of manure are transported to biogas plants to improve their fermentation performance. After fermentation, digestates have to be transported back to the field and are used as a substitute for mineral fertilisers. The German regulation on fertilisers restricts the application of manure fertiliser from animal production on cropland to 170 kg Nitrogen per hectare [14], whereas the application of digestates from the fermentation of renewable raw materials needs to be in line with “good agricultural practices”. Therefore, farmers are obliged to measure ammoniacal nitrogen and nitrogen every year and phosphate every sixth year in order to detect available nutrients in soil. Based on these analyses, farmers fertilise as needed [14]. If a biogas plant is fed with a certain share of manure the restriction of 170 kg nitrogen per hectare is only charged in proportion to the manure share. This fact limits the amount of digestates allowed to be spread on each hectare and therefore increases the hectares needed.

The share of manure input has a major impact on the amount of digestates produced during the fermentation process, since the energy content of manure is low. In a reform of the EEG in 2008, an additional bonus per produced energy unit was introduced. Plants receive this bonus if they apply a minimum share of 30% manure as an input [6]. Hence, it can be expected that the share of manure and therefore the amount of digestates will increase. For the German federal state of Lower Saxony, [15] conclude that transport costs of manure and other animal excrements have a significant impact on the profitability of farms. This indicates that transports of digestates could pose similar effects on profitability of biogas plants. In order to decrease transport costs of digestates, there are several technologies to reduce the water content with screw press separators, screening drum presses and decanter centrifuges being the most common ones. These techniques are sub-processing techniques and do not process the digestates to water or dry productions, but to a thin phase and a more or less solid phase [16]. Both need to be spread on field, though the solid phase contains a much higher amount of nutrients and less water. Because of its nutrient content, the economic value of the solid phase is comparable to mineral fertilisers. Processing and transport costs of digestates are plant size specific, and there might be trade-offs between economies of scale in processing costs and diseconomies of scale in transportation costs. Therefore, our first objective is to compare the profitability of different biogas plant sizes with and without processing of digestates. In addition, we aim to examine the impact of digestates’ disposal with different techniques on total profitability.

Another issue is whether there are regionally different costs for transportation of digestates which affect total disposal costs. Furthermore, we elaborate whether these different costs need to be taken into account when the profitability of a biogas plant is assessed. Regional factors, affecting costs for digestates transports are availability of land the digestates can be disposed to as well as restrictions in disposal per area unit. Restrictions, in turn, are mainly determined by nutrients in manure from livestock production. Lower Saxony like other north-western parts of Germany is faced with (too) high nutrient concentrations in soil from livestock production, causing restrictions in manure and digestates disposal. In addition, particularly in these regions an extension of biogas production is observed and still expected to grow [17,18], adding additional pressure on land availability of the disposal of digestates [19]. These restrictions cause transport costs of digestates that differ regionally. Based on this, our second objective is to analyse which impact the location of a plant poses on disposal costs of digestates and which technology for the disposal of digestates (processing or not) is the most profitable in three different locations. In the following section, we provide the theoretical background to our analysis.

3 Theory and Method

3.1 Location Theory

Questions about the optimal location, the optimal number and size of processing plants as well as about where raw material can be acquired have a long history in research. The classical location theory [20-22] explains location decisions by differences in transport costs of input and outputs. These theories have been criticised for losing their explanatory power due to decreased transport costs. Critics argue that transportation costs have diminished significantly during the last century and therefore are not considered as relevant influencing factors for the location decision anymore. In this context [23] found out that the transportation costs of industrial goods have decreased by up to 90% during the 20th century.

It is doubtful that these findings can be applied to the agricultural sector, since here products are transported by special agricultural machinery transport units. Therefore the transportation costs should not be disregarded [24]. In addition, due to constantly rising oil prices and tolls as well as to newly arising environmental regulations, it can be expected that the transportation costs will continue to increase [25]. Since the regional demand for a product like electricity cannot be considered as a location determining factor, instead the transportation costs and digestates (besides substrates) have to be included in the decision-making process regarding the location and size of the biogas plant.

3.2 The Modelling Framework

To analyse effects of digestates processing on transport costs for different plant types, we set up a linear transportation-costs-model. First, the required input of maize ($dmz_{c,s}$) and manure ($dm_{c,s}$) is calculated for three different manure shares s and biogas plants with three different capacities c. From the resulting amounts of maize and manure for the four plant sizes we deduce nutrient composition of the digestates $ncd_{c,s,n}$ as show in equation (1).

Equation (1): $ncd_{c,s,n} = (dmz_{c,s} * snmz_n + dm_{c,s} * snm_n) / d_{c,s}$

With $snmz_n$ representing nutrient n loss caused by maize cultivation, snm denoting the averaged nutrient content of manure from different animals, and $d_{c,s}$ standing for the total amount of degistates. We use this information, to calculate in a third step the area required for the application of the nutrients contained in digestates ($area_{r,c,s,n}$):

Equation (2): $area_{r,c,s,n,} = d_{c,s} * ncd_{c,s,n} / y_r * snmz_n + s$

with y_r denoting the yield per region *r*, $snmz_n$ representing nutrient loss caused by maize cultivation, and *s* for an additional supplement for nutrient per hectare, because of leaching effects.

Deriving the average transport distance (radius) of $area_{r,c,s,n}$ it is then used to calculate the digestate transport costs $tc_{r,c,s,n,t}$ for different plant types and regions depending on whether digestates are processed and if so with which kind of technique *t*. The digestate transport costs *tc* are determined by the time needed for disposal of digestates, the driving time, which depends on the driving distance, labour costs and machinery costs (details on underlying data are provided in section 3.2.2).

Total disposal costs of digestates $costs_{r,c,s,,n,t}$ (€/m^3) are then calculated from:

Equation (4): $costs_{r,c,s,,n,t} = f_{t/} d_{c,s} + vc_{t+} tc_{r,c,s,n,t}$

Where f_t are fixed costs and vc_t are variable costs excluding transport costs. In this a purely cost-based approach, potential further advantages, which might come along with the acquisition of a digestates treatment plant, like, e.g., the opportunity to use the processed digestates as substrate (in recirculation), or possible income from further processing are not taken into account. In the following sections, assumptions regarding the transportation-cost-model, its data basis and preparation as well as three case studies are explained in detail.

3.2.1 Assumptions for the transportation-cost-model

The three processing techniques screw press separator, screening drum press and decanter centrifuge are analysed. These are only sub-processing techniques, which divide the digestate in a liquid and a solid phase. We presume that the solid phase leaves the nutrient cycle cost-neutral. We do not see a significant drawback in this assumption, since diverse further processing possibilities are promoted by the EEG[1].

We distinguish three possible size classes (150, 500 and 1,000 kW_{el}) operating with three different manure shares (1%, 10%, 35%) in three regions. The plants differ in the total substrate requirement as well as in input shares and therefore in the resulting amount of digestate per produced electricity as well as in their energy efficiency. According to Zimmer et al. (2008) the latter increases with the installed power of the biogas plant [26].

[1]According to the amendment of the EEG in 2008, a bonus for heat and power generation is granted for dehydration of digestates

Revenues from electricity according to the EEG 2008 are divided into a basic payment per kWh_{el} (refers to the German expression “Grundvergütung” meaning basic remuneration) and additional fees adjusted depending on input, plant size and plant technology. To provide an incentive to use a larger share of waste small scale plants using at least 30% manure receive a special bonus. The variant of a manure proportion of 35 per cent serves for demonstrating the influence of the amendment of the EEG (30 plus 5 per cent buffer quantity) [19].

Regarding the maize input, a loss of 12% for transport and storage is taken into account [27]. To calculate the area required for the application of the nutrients contained in digestates ($area_{r,c,s,n}$), it is assumed that fertilisation is performed according to the nutrient requirements of maize. According to [14] losses of 30 kg/ha of nitrogen and a phosphorous balance of a surplus of 20 kg/ha are taken into account (cp. section 4.2)

In the theory of agricultural land use by VON THÜNEN [20] , in absence of a transportation infrastructure, the distance between a market and surrounding agricultural areas is referred to as “beeline distance” [20]. In a modified way we adopt this assumption for the distance between the area applied with digestates and the biogas plant. Furthermore, we assume that the agricultural area needed for disposal is in direct vicinity of a biogas plant.

Since the transport units do not always go to the outer edge of the radius, a medium transport distance at a ratio of 0.707 of the radius is used. This factor results from the fact that, when moving outwards starting from the centre of the catchment area circle, the surrounding area increases more significantly than the distance covered. In case of a radius of 100 m, for example, the surface area is 3.14 ha ($\pi * r^2$), whereas in case of a radius of 200 m the surface area already amounts to 12.56 ha. Conversely, this means that it is possible to convert from the area needed to the medium distance covered. This serves for the calculation basis of the medium distance between the plant and the field. In order to account for the fact that the transport route does not correspond with the linear distance, a distance charge of one third is added [1]. Furthermore, additional driving distances for spatial homogeneity are included, taking into account the varying spatial characteristics of a region. The so-called homogeneityindex is composed of a factor, which considers the distribution of the arable land within a region, and of a second factor, which takes different shares of arable land on total land into account. The exact calculation of the homogeneity index is described in detail in section 4.3. The length of the medium transportation distances is therefore influenced by the various proportions of manure, by the plant size and by the plant location (region).

We furthermore assume that digestates can be applied with two different application methods. A single-stage method involves a manure tanker and a tractor application, for long driving distances a two-stage application method employing a manure tanker pulled by a tractor for application as well as an additional transport truck can be chosen.

3.2.2 Profitability of biogas production

The profitability of biogas plants returns are a function of revenues, on the one hand, and variable and fixed operation cost as well as cost for feedstock and transportation, on the other hand. (1) guaranteed output prices for electricity according to the EEG, (2) spatial availability of feedstock and resulting transportation costs, (3) plant operation costs. Location decisions for biogas plants are driven to a larger degree by regional differences in transport and production costs of feedstock, especially if there is little spatial variance in other important factors such as output prices, investment costs and other operational costs.

4 Case Studies and Underlying Data

4.1 The three case study regions

Three regions were selected to perform case studies. Their spatial scale is the NUTS[2] 3 level (counties) and they are located in the German federal state of North-Rhine-Westphalia (NRW). In NRW, 6-7% of German electricity from biogas is produced [28], while biogas production in NRW is distributed extremely uneven. Areas in the Rhineland (in the south of NRW), which are dominated by cropping farms, show a low amount of installed capacities from biogas plants, whereas in Westphalia with high livestock densities and a high density of biogas plant is observed [29]. In order to capture different natural conditions within NRW, we selected the county of Aachen with intensive cropping activities, the county of Borken, a county with very high livestock densities and sandy soils and Siegen-Wittgenstein, a county characterised by grassland on a low mountain range.

4.2 Data

The economic parameters of the biogas plant are shown in Table 1. The revenues one gets form biogas plants are mainly based on selling the electricity and the heat. In order to compensate for varying proportions of manure in practice we chose 35% to ensure the special bonus for manure input while possible higher proportions of manure are ignored in the present study. Costs included are mainly input costs for maize and capital costs. Note, that disposal costs for digestates are not considered here.

[2] (Nomenclature of Territorial Units for Statistics) For a description see: http://ec.europa.eu/eurostat/ramon/nuts/basicnuts_regions_en.html

Table 1: Economic parameters of the biogas plants in cent per kWh

		150 kW			500 kW			1,000 kW		
		Manure input share								
		1%	10%	35%	1%	10%	35%	1%	10%	35%
Revenues	**Electricity**	23.67	18.67	22.67	22.28	16.18	17.18	19.76	14.25	14.25
	Heat	0.60	0.80	0.80	2.70	3.20	3.20	4.40	5.80	5.80
Variable costs	**Input costs**	11.15	11.10	10.86	9.34	9.29	9.10	9.46	9.41	9.01
	Others	3.40	3.40	3.40	4.10	4.10	4.10	6.80	6.80	6.80
Fixed costs	**Capital costs**	4.40	4.40	4.40	4.90	4.90	4.90	5.80	5.80	5.80
	Others	0.50	0.50	0.50	0.40	0.40	0.40	0.40	0.40	0.40
Profit		4.82	0.07	4.31	6.23	0.69	1.88	1.70	-2.36	-1.96

Average maize yields from 1999-2007 of the respective county are taken from the Statistics Office of NRW [30]. Average maize yields are in Siegen 44 t/ha, in Borken 49 t/ha and in Aachen 43 t/ha. Based on shares of livestock units in 2007, nutrient contents of manure are calculated (see Table 2).

Table 2: Characteristics of inputs into biogas plants

Parameter	*Unit*	**Animal excrements**						**Silaged maize** (30-32% DS[1])
		Cattle	**Cow**	**Hog** (up to 50 kg)	**Hog**	**Sow**	**Laying hens** (dry excre-ments)	
Nitrogen	*kg/m³*	6.2	5	7	5.6	4.3	15.6	5.9
Phosphorus	*kg/m³*	3.4	2	6.9	3.7	3.4	15.9	2.5
Potassium	*kg/m³*	14.2	6.8	8	3.7	3.1	12	7.6
DM[2]	*kg/m³*	61	110	40	60	40	50	320
Organic DM[2]	*%*	80	80	80	80	80	75	95
Degradiation rate	*%*	21	21	22	22	22	19	79
DM[2] **after fermentation**	*%*	51.28	93.24	33.19	49.97	33.19	43.18	0.11
Biogas yield	*l/kg oDM*	380	380	420	420	420	500	620
Methane content	*%*	55	55	60	60	60	55	52
Methan yield per ton fresh mass (FM)	*1/t FM*	10.20	18.39	8.06	12.10	8.06	10.31	98.01
Fugat factor		0.990	0.982	0.993	0.989	0.993	0.993	0.760

(*Source: calculated according to [26][31][32][33]*

[1] DS= dry substance

[2] DM= dry matter

Data on technical and economic parameters for the different processing techniques of digestates are displayed in Table 3. The considered techniques are exemplary while parameters differ among suppliers of those techniques. The listed fixed costs already include the investment costs.Table 3 illustrates that there are considerable differences between the costs of the three different processing methods. In addition, their efficiency in separation rate varies significantly.

Table 3: Technical and economic parameters of solid separations

Parameter	Unit	Screw press separator	Screening drum press	Decanter centrifuge
Fixed costs[1]	*€/a*	3,795	4,455	26,895
variable costs[1]	*€/m³*	0.47	0.48	1.46
Degree of separation				
Nitrogen	*%*	16.5	11.0	22.0
Phosphorus	*%*	18.0	25.0	53.0
Potassium	*%*	9.5	11.0	

Source: own calculations, after [32]
[1] without VAT and labour costs

Data for transport costs are taken from [31]. The distances that are to be covered, are set off against the application methods, which are most cost-effective for the medium distance between the biogas plant and the application area. That means that for longer distances as from about 11.5 km a two-stage application method employing a manure tanker pulled by a tractor as well as an additional transport truck was chosen. In case of the single-stage method that involves only a manure tanker and a tractor, machinery costs of €101.40 per hour incur. In contrast, in case of the two- or multi-stage method that employs an additional transport truck, the costs amount to €168.53 per hour.

For the calculation of the homogeneity index, data stems from the European CORINE land cover (CLC) database, which was calibrated with the CAPRI model (Common Agricultural Policy Regional Impact) by [34]. In this study, "homogenous spatial mapping units" (HSMU) with a resolution of 1x1 square kilometres (km^2) respecting soil, slope, land cover and administrative boundaries were generated. Since HSMUs cover a wide range of sizes and often contain multiple features, they are split in order to increase the comparability of analysis results between regions.

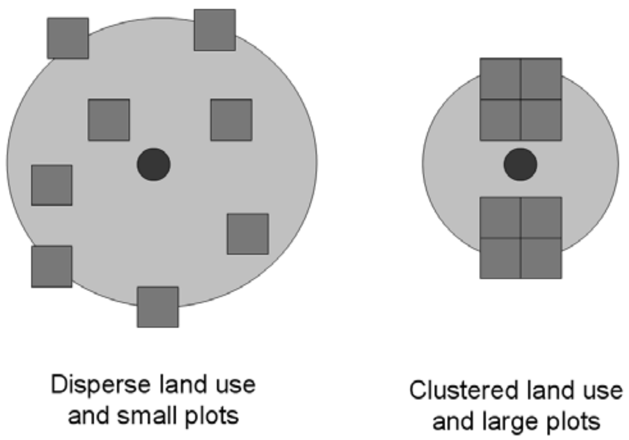
4.3 Data Processing

The regional differentiation in the transport-cost-model does not only stem from regionally differing yields, nutrient contents of manure and the *distribution* and *share* of arable land within a county resulting in different driving distances for the disposal of digestates. This difference in homogeneity is determined by two parameters: first, arable land is distributed differently within a county, which can be captured by the "Global Moran's I" index. This index is a measure for global spatial autocorrelation of attributes [35]. In this case the attributes are shares of arable land. A Global Moran's Index of 1 denotes total homogeneity among the attributes, whereas in case of a dispersed distribution of the attributes the Moran's Index is -

1. Exemplarily, a Moran's I index of 0.9-1 characterises a county, where arable land is clustered. Raster cells with arable land create larger plots, which are not mixed with other types of agricultural land use such as permanent grass land or perennials. In this case, the transportation distances are smaller than in the case of dispersed land use, where raster cells with arable land create single plots. A possible spatial layout for the clustered case is shown on the right hand side of Figure 1.

Besides the *distribution* of the arable land, the *share* of arable land on total land cover needs to be taken into account in determining transport distances. This is respected in the second factor of the homogeneity index. The lower the share, the higher are the average transport distances from a randomly given location to plots of arable land. The driving distance factor for a county with 50% of arable land is therefore doubled, whereas distances in a county with 10% of arable land are multiplied with a factor of 10. Accordingly, the homogeneity index consists of the Moran's I index and the factor of share of arable land.

Figure 1: Spatial distributions of arable land around a biogas plant



5 Results

In the following section we present and discuss regional transport distances for the disposal of digestates, disposal costs of digestates, resulting values for profitability of different biogas plant sizes with and without processing of digestates, and compare results for different processing techniques. Furthermore, we show the influence of location decisions on profitability depending on processing technique.

5.1 Regional transport distances

The three case study regions show regional-specific composition of livestock and therefore manure (see Table 1) as well as different maize yields and spatial distribution of arable land (see section 4.2). Table 4 illustrates impacts of these regional differences on land needed for the disposal of digestates (see equation 2), which result in different transportation distances and therefore cause different disposal costs (see equation 3). Beside the regional view, we also show the effects of a change in manure input.

With an increasing input share of manure, more land is needed for the disposal of digestates in all three regions. In Borken, compared to using 99% maize as an input for a 150 kW plant, the area needed for disposal triples when 35% of manure is applied by increasing from 60 ha to 176 ha. The reason for this is the low energy content of manure in relation to maize: energy content of manure is more than six times lower than the energy content of maize. Therefore, an increase in the share of manure as input for biogas production does not lead to the same amount of decrease in maize input manure. Consequently, more digestates are produced during the fermentation process. Furthermore, the share of nutrients in manure is high in Borken (cp.Table 2).The phosphate balance of 20 kg/ha is a limiting factor for disposal per ha in Borken, resulting in a larger area for digestates disposal compared to the other two regions. In Siegen and Aachen, this increase in disposal area is not as tremendous; it is only 1.5fold.

On the input side, the reduction of land cultivated with maize decreases very little when substituting maize with manure: applying 35% manure compared to 1% into a 150 kW plant reduces the maize area by 3.4 ha in Borken. In Siegen, the area is decreased by 4.5 ha, in Aachen by 5.4 ha (this is a reduction of 5% of the total area needed for a 150 kW plant).

Hence, increasing the share of manure as an input, leads to a strong increase in the area needed for the disposal of digestates and, at the same time, to a small reduction in maize area. These results are comparable with the findings from [19].

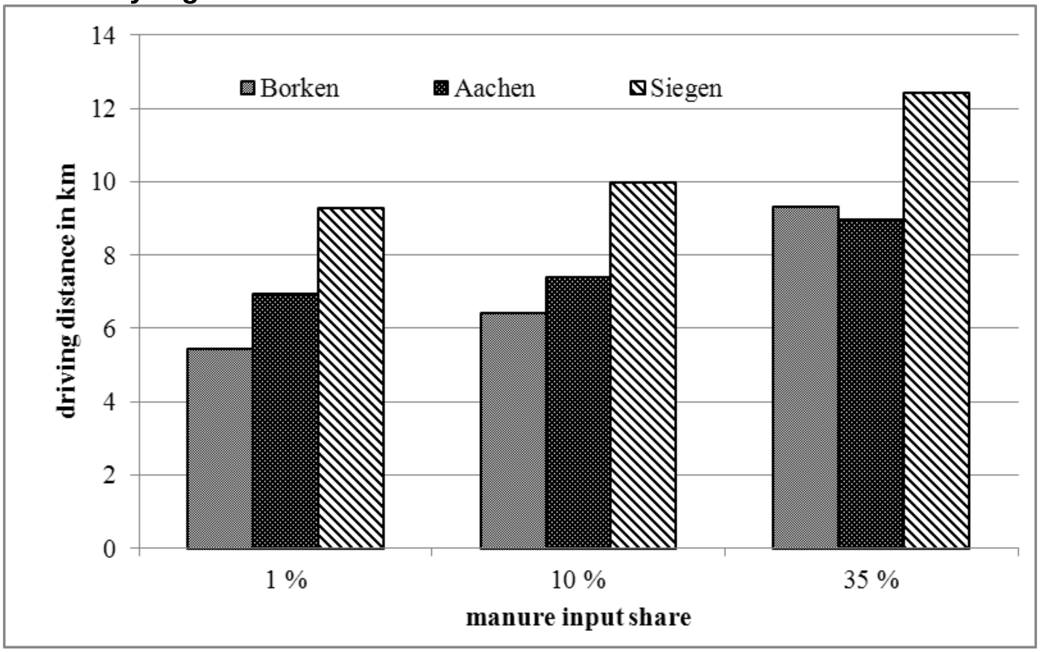
Table 4: Area needed for biogas plant without processing in three regions[3]

Plant size (in kw_{el})	Input share manure	Area needed for maize cultivation (in ha)			Area needed for disposal of digestates (in ha)		
		BOR	SI	AC	BOR	SI	AC
150 kW	1%	71.1	78.6	80.4	60.4	64.0	65.0
	10%	70.4	77.7	79.3	83.4	74.1	73.8
	35%	67.7	74.1	75.0	176.1	114.5	108.6
500 kW	1%	211.7	233.9	239.4	179.8	190.5	193.7
	10%	209.7	231.3	236.2	248.3	220.7	219.9
	35%	201.6	220.6	223.4	524.2	340.8	323.3
1,000 kW	1%	401.9	444.2	454.6	341.4	361.8	367.7
	10%	398.1	439.1	448.4	471.4	419.0	417.5
	35%	382.8	418.9	424.1	995.4	647.2	613.8

Resulting average transport distances for digestate disposal in the three case study regions for different manure shares without processing are displayed in Figure 2. A first effect is that transport distances increase with a rising share of manure input in all regions. Secondly, average transport distances vary substantially among the regions: in Siegen for all manure shares average transport distances are considerably higher compared to those in Aachen and Borken. Main reasons are a low share of arable land on total land, and a scattered distribution of arable land. While the disposal area in Borken is largest for plants using 10% and 35% of manure input (cp. Table 4), average driving distances are smaller compared to Siegen (cp. Figure 2).

[3] Table 4 only accounts for the additional area needed for the disposal of digestates from a biogas plant, since the manure applied in a biogas plant would have to be disposed anyway if not fermented in the biogas plant.

Figure 2: Average driving distances for digestate disposal (500 kW biogas plant) in the three case study regions

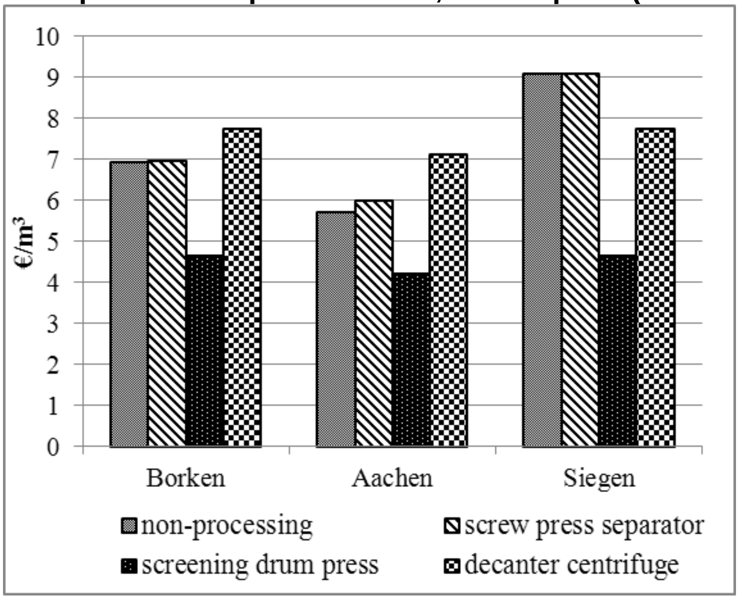


In order to test the sensitivity of the assumption that manure is disposed in the direct vicinity of a plant, we run scenarios in which we reduce the area available for disposal by 50% around biogas plants. First results show enormous effects on disposal costs, especially in case of Borken with high nutrient contents in digestates. Taking a 500 kW plant and using 35% of manure as an example, disposal costs increase by 11%.

5.2 Disposal costs of digestates

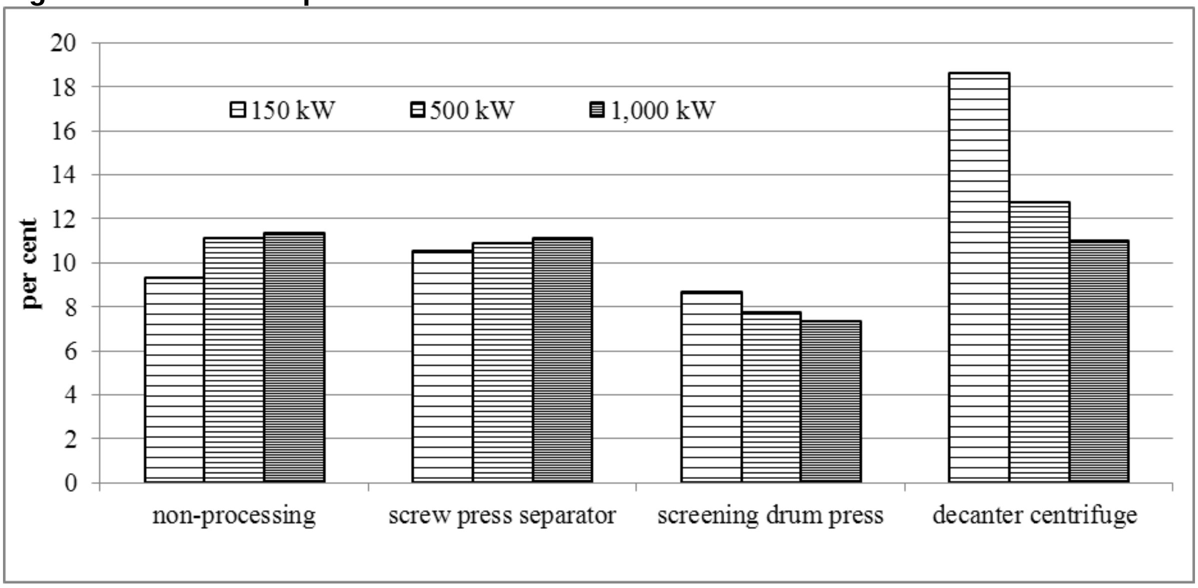
Disposal costs for digestates depend on the regionally different transport distances, the size of the biogas plant, the manure input share, and also on the processing technique. In order to keep the results concise, input share and plant size are not varied, and results for a 1,000 kW plant using 10% of manure are presented. Figure 3 illustrates disposal costs for the three regions and different processing techniques. In all three regions, processing of digestates with the screening drum press leads to lower costs of the disposal of digestates compared to non-processing. Highest cost reductions are achieved in Siegen, where the distribution of land is heterogeneous and the share of arable land on total land is low. The decanter centrifuge is the most expensive alternative, which is driven by high processing costs (cp. Table 3), whereas the degree of separation is best among the processing techniques. This is why compared to non-processing, processing costs are higher in Borken and Aachen, but lower in Siegen. We explain this by very long average driving distances in Siegen, so that the sum of transport costs of processed digestates plus processing costs are lower than transport costs of non-processed digestates.

Figure 3: Digestate disposal costs per m³ for a 1,000 kW plant (10% manure input)



In order to compare the impact of different types of processing by plant size, Figure 4 displays the share of disposal costs on total costs in case of non-processing, and the three processing techniques. Again, the region Borken is displayed and numbers for 35% of manure input are presented. The figure illustrates that the share of disposal costs on total costs varies between about 7% in case of a screening press drum applied in a 1000kW plant and 19% when the decanter centrifuge technology is used in a 150kW plant. Disposal costs increase with the plant size for non-processing and the screw press separator technique, whereas there are economies of scale in case of the screening drum press and decanter centrifuge technique.

Figure 4: Share of disposal costs on total costs



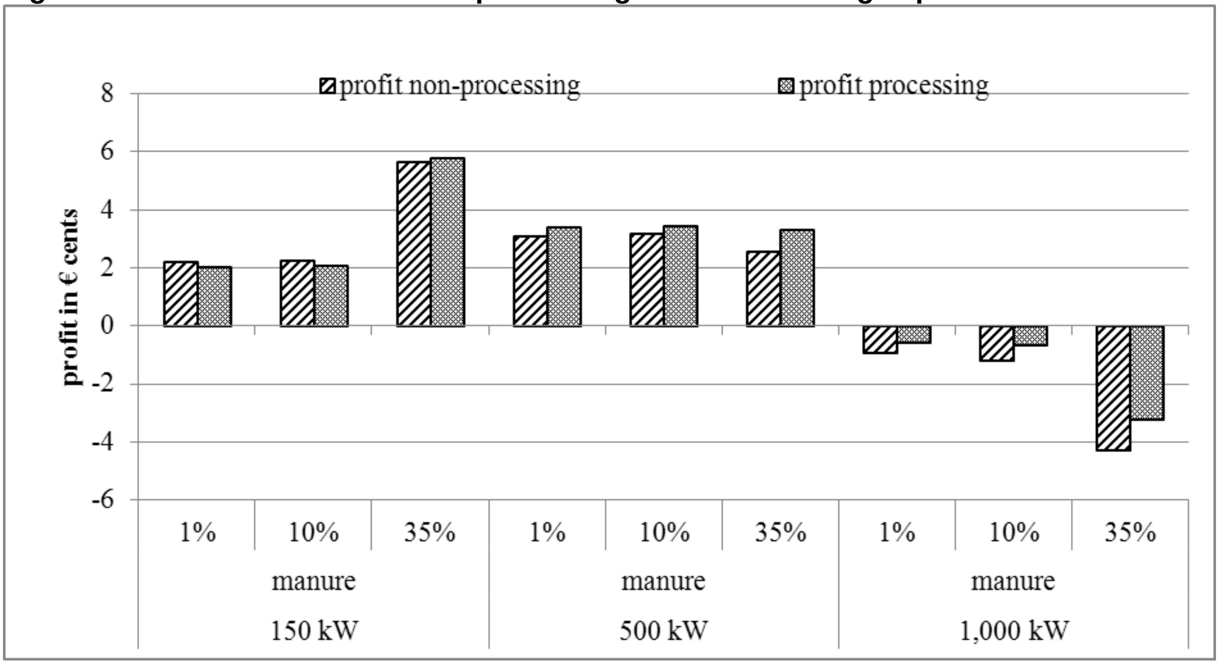
In the following section, we analyse the impact of driving distances for digestate disposal on transport costs and the profitability of biogas plants.

5.3 Profitability of biogas plants under non-processing and different processing techniques

The profitability of biogas plants is determined by seducing profits from biogas production (see Table 1) by regional specific disposal costs for non-processing and processing with a screening drum press.

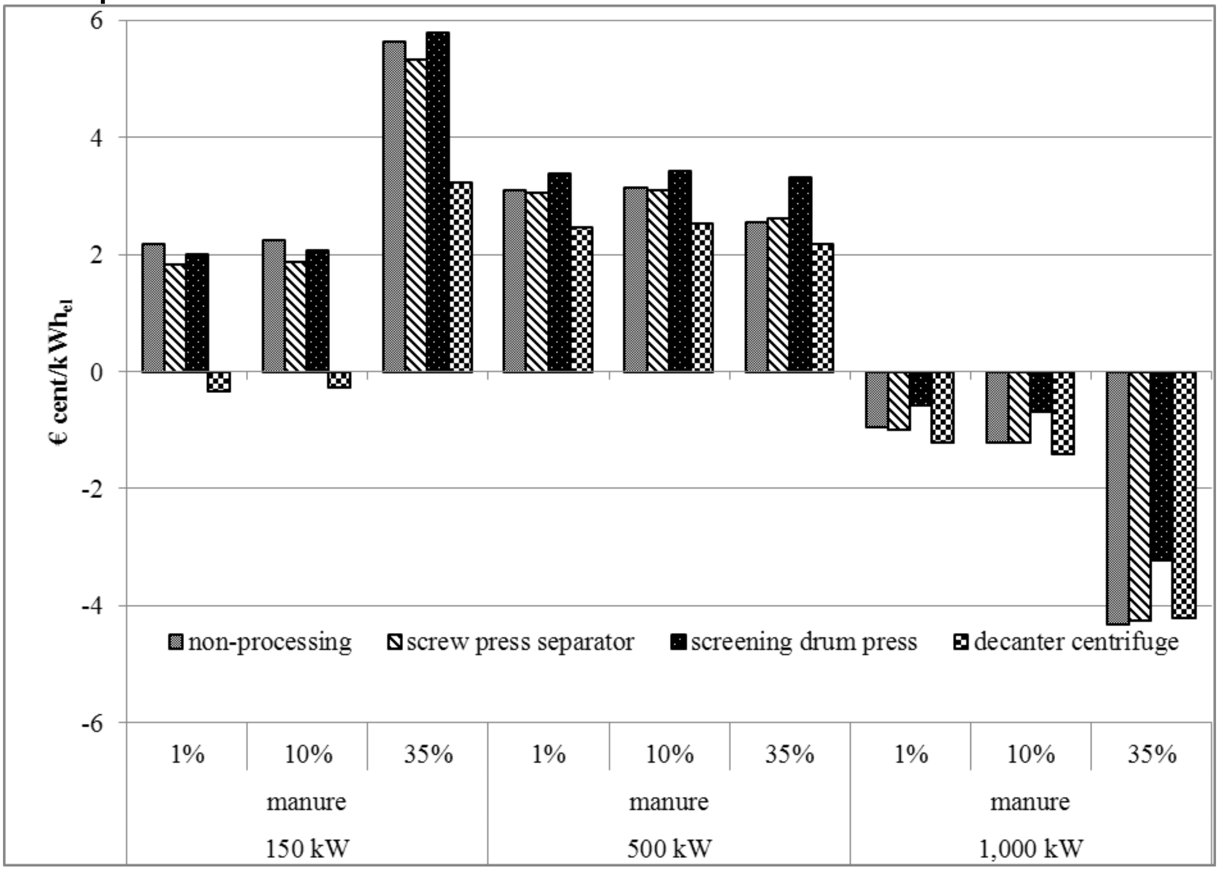
In a first analysis, we focus on one region (Borken) and compare the plants' profitability when costs for digestate disposal are not considered, with a version where digestates are not processed and another version, where digestates are processed. Figure 5 illustrates that under the given assumptions small scale plants with 150 kW that can claim the manure bonus (using a 35%-share of manure as input) are the most profitable plants. For all plant sizes results show that improvements in profits by processing are the higher the manure input and the bigger the plant size. In case of 150 kW plants, at manure shares of 1% and 10%, non-processing is more profitable than processing, whereas at a manure share of 35% processing becomes more favourable. Larger plants with 500 and 1,000 kW all benefit more from processing. Due to diseconomies of scale in transports, profits of 1,000 kW plants decrease with higher manure shares.

Figure 5: Profits with and without processing for different biogas plant sizes



Profits when considering different processing techniques are displayed in Figure 6. In addition to findings gained from Figure 5, we see that among the processing techniques, the application of a screening drum press results in highest profits. However, due to economies of scale in processing, small scale plants with 150 kW at manure input shares of 1 and 10% make highest profits without processing digestates. Profits can be increased by processing digestates especially, when the manure input share is high and therefore transport distances in case of non-processing are long, and the larger the plants are. In case of a 500kW plant, profits in case of non-processing decrease the more manure is used (see Figure 6), whereas profits keep constant when they are processed with the screening drum press. The effect of decreasing profits with a rising manure input share can be illustrated best for the 1000kW plant.

Figure 6: Total profits for different plant sizes and manure shares by processing technique



In practice, the medium transportation distances could be calculated more precisely. In that way, it would be possible to consider further or modified aspects for single farm biogas plants, for example, by determining concretely how the cultivated area is arranged: scattered or surround the farm. The present calculations are only exemplary, to show the regional trends. Moreover, the routes, that have to be taken to spread the manure, might be only limited passable or long detours might be necessary. This fact is meant to be considered in a variant calculation, which requires a larger distance radius of the catchment area. That would also allow detecting possible fluctuation margins in the results.

6 Discussion and Conclusion

This paper aims to determine whether the processing of digestates increases profitability of biogas plants or not and which technique is the most cost efficient alternative to non-processing digestates. Furthermore, the paper targets to determine the impact of the plant's location on the biogas plants' profitability.

The comparison of three processing techniques with the case of non-processing shows that screening drum press is the most cost efficient alternative of disposing digestates. Non-processing of digestates can be more profitable than processing, especially for larger plants, but this depends on regional factors such as the nutrient content in manure, the availability of land for disposal and the distribution of arable land.

Disposal costs are regionally differentiated by transport distances. We have applied a straight forward approach in determining these distances, but in practice, the medium transportation distances could be calculated more precisely. In that way, it would be possible to consider further or modified aspects for single farm biogas plants, for example, by determining concretely how the cultivated area is arranged: scattered or surrounded the farm. The present calculations are only exemplary to show the regional trends. Moreover, the routes that have to be taken to spread the manure might be only limited passable or long detours might be necessary. This fact is meant to be considered in a variant calculation, which requires a larger distance radius of the catchment area. That would also allow for detecting possible fluctuation margins in the results.

The impact of processing on profit is most significant in regions with nutrient surpluses (Borken) or regions with high heterogeneity of land and a low share of agricultural land on total land area (Siegen). For solid digestates, the value of nutrients and consequently its possibility to substitute mineral fertilisers depends on regional nutrient balances and prices of mineral fertilisers. Presumably, disposal costs are thus higher in regions with high livestock densities (nutrient surpluses). Therefore, it is crucial to determine nutrient values on a regional basis in order to compare processing with non-processing. This should be taken into account in further studies applying single-farm analysis.

Processing of digestates is a rather young technique, and therefore there is potential for improvements in efficiency: e.g. better degrees of separation, lower machinery costs. Hence, profitability can be increased in the future. Nevertheless, our study points out that processing is profitable for certain types of processing techniques and that disposal costs strongly depend on the plants' location.

Considering the shares of disposal costs on total costs and on profit, we argue that when addressing the profitability of plants, it is important to not only consider transport costs for inputs, but also to take into account transport costs of digestates or by-products. The choice of location is a crucial factor for addressing cost reduction.

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