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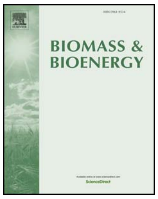

Research paper

Analysis of selected economic and environmental impacts of long distance manure transports to biogas plants

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ABSTRACT

In regions with high livestock density, manure supply often exceeds demand and complete local deployment would lead to severe environmental damage due to over-nutrification. One solution is to use the surplus in other regions, which have lower nutrient-levels. To decrease costs associated with transport the manure can first be used in biogas plants of those regions. To date, however, the economic and ecological consequences of this solution are unclear. Here, we develop a model of the consequences from the perspective of a biogas plant owner and apply it to a case study in Lower-Saxony, Germany. The model determines the maximal profitable manure transport distance from a financial point of view. Furthermore, it examines selected environmental impacts for various scenarios with an assumed transport range of 150 km, a typical distance. For dry poultry manure transport distances up to 700 km and more can be financially advantageous. Emission reductions occurred in all scenarios in the impact categories *Greenhouse Gas* and *Acidification*. The model can support decision-makers in the livestock and biogas industries in determining whether to transport manure and, if so, how far.

1. Introduction

In traditional agriculture, livestock manure is used to fertilize local farmland. Indeed, in Germany, half of the total agrarian demand for phosphorus is satisfied in this way [1]. In regions with high livestock density, however, this can lead to a significant excess of nutrients and thus to environmental damage. Regions with low livestock density, in contrast, often suffer from nutrient scarcity and must compensate by purchasing mineral fertilizer. Transporting the surplus manure from regions of high to low livestock density represents one possible solution for this nutrient imbalance.

Naturally, long transport distances represent an expensive logistical challenge and result in greenhouse gas emissions. Thus, it is unclear under what circumstances such transport is financially and ecologically beneficial. One way to improve the financial and ecological balance is to consider cascade utilization of the manure. For example, the manure can first be used in a biogas plant in a region low in nutrients for biogas production [2]. The resulting fermentation residues can then be used to fertilize local farmland.

The ecological impact of deploying large quantities of nutrients in agriculture has been widely researched. It can lead to a high concentration in water, which in turn results in water eutrophication and groundwater pollution [3,4]. In Germany, the high nitrogen concentrations in groundwater close to the surface mainly results from agricultural use [5]. Excessive manure deployment on farmland also results in high ammonia and nitrous oxide emissions, two greenhouse gases that drive climate change [3,4]. Nitrous oxide is particularly harmful, since it has a greenhouse effect 265 times greater than that of carbon dioxide [6]. Deploying large quantities of nitrogen-rich manure also endangers biodiversity due to soil eutrophication. In general, the number of species decreases with increasing nitrogen deployment [7]. According to [8] and [9], the negative effects have accumulated to such an extent that the costs of nitrate pollution now exceed the benefits of nitrate fertilization. The extensive deployment of phosphorus is also problematic, since it too contributes to eutrophication [3], in this case, by disrupting the ecological equilibrium through an explosive growth in algae [10].

A concentration of intensive animal production has led to an oversupply of manure into some regions, with a gradual build-up of the phosphate content of soils and increased risks of water pollution [11]. Legislation on nutrient management and cross compliance stipulate the transport of manure into other regions. One possible solution is to transport the excess manure to regions with little livestock farming, which, in fact, is already being done in some locations [12]. Here [13], developed a linear cost optimization model for the total flow of manure from regions of high to low livestock density. Still, the question remains open as to which economic and ecological consequences follow from individual manure transports from issuing farms in the stock farming

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region to biogas plants in the farming region. Thus, for example, it is not certain that the emissions saved by mineral fertilizer substitution outweigh the emissions added by transport. Nor is it clear whether transport costs can be offset by cost reductions elsewhere, such as a lower demand for energy crops. The transport of manure with a high water content is particularly costly [14]. This expense is, in turn, highly important for businesses deciding whether to sell or purchase manure: only if the transport results in financial advantages will businesses decide in its favor.

In this study, we present a model that quantifies selected effects of individual manure transports from an issuing farm to a biogas plant. We first examine various aspects (substitution of energy crop, transportation, etc.) affected by the use of manure and then analyze selected resulting ecological and economic effects. With regard to the ecological effects, the model allows to calculate resulting emission differences. These may, for example, refer to CO_2-equivalent or SO_2-equivalent, but is not limited to them. Our analysis is performed from the perspective of a biogas plant owner in a region with little livestock farming who obtains manure from regions with high animal density and substitutes it for locally-grown energy crops. The calculation assumes that energy crops are substituted by manure to the extent that the biogas output of the biogas plant remains unchanged. Furthermore, it is assumed that the manure would otherwise be deployed locally on fields with high livestock farming without any discernible fertilizing effect. This model offers support to biogas plant owners in deciding whether to obtain manure from regions with intensive animal farming.

To validate the model, we present a case study in which the model is applied. Therefore, the model was implemented in Microsoft Excel. The starting point for the case study is an agricultural biogas plant from Ref. [15]. It is located in the farming region of Lower Saxony, Germany and does not use manure yet. The annual substrate mix is 8040 t of silage maize, 1800 t of whole crop silage, 1800 t of sugar beets and 360 t of grains. The annual quantity of produced biogas is 1325512 Nm^3. In the case study, different scenarios are considered, to investigate selected economic and ecological effects of different sorts of manure. One sort of manure is pig manure, which is obtained from liquid pig manure by separating the manure into a solid and a liquid fraction to increase the nutrient concentration [16,17]. This is done, because liquid manure is mostly water and therefore a manure payload's share of nutrients is relatively small [18]. Furthermore, it can be transported via tipping truck, which allows for return transport of other solid matters.

This paper is structured as follows: Chapter 2 presents the model for selected ecological and economic effects of manure transport. Chapter 3 introduces the case study and presents the results. Chapter 4 discusses the results from the case study. And Chapter 5 offers some conclusions drawn from our work.

2. Analysis of selected economic and ecological impacts

In the following, we present a model to analyze selected financial and environmental impacts of the manure transport. As mentioned in the introduction, the aspects which are influenced by this are examined first. The following model contains the calculations to be performed. The calculations are designed in such a way that the financial and ecological changes are calculated for each aspect. In the end, the changes are added up and result in the overall financial and ecological change resulting from the transport. This has, for example, the advantage that no life cycle assessment of the biogas plant has to be carried out in order to calculate the changes in emissions.

The model is based on the following basic assumptions. We assume that manure substitutes for energy crops so that the production level of the biogas plant remains unaffected. Therefore, the use of biogas does not need to be considered in the model. We also assume that the manure, if it were to be deployed locally in stock farming regions, has no further fertilizer effect, so that neither the manure does substitute for mineral fertilizer nor increases the yield. Furthermore, the analysis is performed from the perspective of a biogas plant owner. Therefore, financial and environmental impacts resulting from decisions taken by the issuing farm, such as the separation of liquid manure, are not taken into account. However, the model can serve as a basis for modeling these decisions or other aspects in a model extension.

Since the present model serves as a basic model, which can be extended, only one location, one type of manure and one substituted

Table 1
Nomenclature.

Symbol	Explanation	Unit
Indices		
ai	manure	i
bj	energy crop	j
k	mode of transportation k	
Parameter		
d	distance of transportation d	km
d_e	distance of empty trips	km
e_j	emissions due to production of energy crop j	$kg\cdot t^{-1}$
e_l	emissions of diesel consumption	$kg\cdot l^{-1}$
e_K	emissions of mineral potassium fertilizer production (per kg potassium)	$kg\cdot kg^{-1}$
e_N	emissions of mineral nitrogen fertilizer production (per kg nitrogen)	$kg\cdot kg^{-1}$
e_P	emissions of mineral phosphate fertilizer production (per kg phosphate)	$kg\cdot kg^{-1}$
e_G	emissions for deployment losses of fermentation residue (per kg nitrogen)	$kg\cdot kg^{-1}$
e_M	emissions for deployment losses of mineral fertilizer (per kg nitrogen)	$kg\cdot kg^{-1}$
e_W	Emissions for deployment losses of manure (per kg nitrogen)	$kg\cdot kg^{-1}$
f_k	fixed transportation costs of mode of transportation k	€
fc_{AG}	diesel consumption for fermentation substrate deployment	$l\cdot ha^{-1}$
fc_{AM}	diesel consumption for mineral fertilizer deployment	$l\cdot ha^{-1}$
fc_k	diesel consumption per km for empty trip of mode of transportation k	$l\cdot km^{-1}$
fcf	diesel consumption per km with full load (40t)	$l\cdot km^{-1}$
h_G	costs for deployment of fermentation substrate	$€\cdot ha^{-1}$
h_M	costs for deployment of mineral fertilizer	$€\cdot ha^{-1}$
K_{ai}	potassium content of mineral fertilizer i	$kg\cdot t^{-1}$
K_{bj}	potassium content of energy crop j	$kg\cdot t^{-1}$
$m_{ai,bj}$	quantity of energy crop j substituted by one ton of manure i	t
Me	mineral fertilizer equivalent	$kg\cdot kg^{-1}$
me_{ai}	methane yield of manure i	$kg\cdot t^{-1}$
me_{bj}	methane yield of energy crop j	$kg\cdot t^{-1}$
N_{ai}	nitrogen content of manure i	$kg\cdot t^{-1}$
N_{bj}	nitrogen content of energy crop j	$kg\cdot t^{-1}$
NB	quantity of nitrogen for single deployment	$kg\cdot ha^{-1}$
nl_k	payload of mode of transportation k	t
p_{bi}	price of energy crop j	$€\cdot t^{-1}$
p_K	price of mineral potassium fertilizer (per kg potassium)	$€\cdot kg^{-1}$
p_N	price of mineral nitrogen fertilizer (per kg nitrogen)	$€\cdot kg^{-1}$
p_P	price of mineral phosphate fertilizer (per kg phosphate)	$€\cdot kg^{-1}$
P_{ai}	phosphate content of manure i	$kg\cdot t^{-1}$
P_{bj}	phosphate content of energy crop j	$kg\cdot t^{-1}$
v_k	variable costs of transportation of mode of transportation k	€
Dependent Variables		
ΔE	total emission adjustment	kg
C	costs/reimbursement for manure	€
D^e	emissions due to diesel consumption of deployment	$kg\cdot t^{-1}$
E	financial effect	€
E_f	fixed part of the financial effect	€
E_v	variable part of the financial effect	€
L^e	emissions due to storage losses	$kg\cdot t^{-1}$
M	cost difference for savings in mineral fertilizer	€
M^e	emission difference of savings in mineral fertilizer production	$kg\cdot t^{-1}$
mpd	Maximum profitable distance	km
S	cost difference for saving energy crops	€
S^e	emission difference of energy crop production	$kg\cdot t^{-1}$
T	cost difference of transportation	€
T^e	emission difference of transportation	$kg\cdot t^{-1}$
U^e	emission difference of modification	$kg\cdot t^{-1}$
V^e	emission difference of deployment losses	$kg\cdot t^{-1}$