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Greenhouse gas and energyassessment of the biogas from co-digestion injected into the natural gas grid: A Swedish case-study including effects on soil properties

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ABSTRACT

In this study, a large, farm-based, co-digestion plant in southern Sweden, using manure and various food industry wastes is investigated concerning its use of energy and its emissions of greenhouse gases from a life cycle perspective based on measured, site-specific data. The biogas is upgraded and utilized as a vehicle fuel, distributed via the natural gas grid. The case-study also includes a novel approach in which potential changes in soil compaction and soil carbon levels are assessed, based on farm-specific conditions, when digestate replaces mineral fertilizer. An additional objective is to identify potential technical improvements leading to further GHG reductions, and the cost of such measures. According to this case-study, biogas produced from food industry waste and manure in a modern co-digestion plant could reduce GHG emissions by approximately 90% compared to conventional fossil fuels. The corresponding energy input:output ratio is calculated to be about 25%, where the use of electricity in the biogas process, upgrading and pressurisation is the dominating energy input. Finally, several possible technical improvements to further reduce GHG emissions were identified. The economic prerequisites of the specific improvements varied, from profitable from a business perspective to unprofitable from a socio-economic point-of-view.

1. Introduction

In the European Union, at least 10% of the energy used in the transportation sector should be renewable by 2020 according to the Renewable Energy Directive (RED) [14]. For comparison, the amount of biofuels used in EU-27 was 4.7% in 2010 [17]. Although the current use of biofuels is dominated by ethanol and biodiesel of different origins, biogas from waste and manure is mentioned as one of the most promising fuels available today from the point-of-view of potential reduction of greenhouse gas (GHG) emissions [9,10,14,35]. The European Commission has also suggested changes in the RED that would favour such production even more. Thus, interest in biogas production based on manure and waste could increase dramatically. However, the implementation of new or revised policy instruments promoting the use of various waste and residual biomass for biofuel and biogas production should be based on the most recent results possible. This includes updated and detailed data on energy balances and GHG performance of existing biogas plants using manure and waste as feedstock. Several studies have been published in which such data are calculated for biogas production based on different feedstocks [9,10,35]. In general, however, these studies are based on literature reviews, LCA databases and information from different commercial actors. Although these studies have been successful in presenting the pros and cons of different biogas systems in general, production and utilization of biogas involves complex systems with a wide variety of feedstock, scale, plant design and utilization pathways for biogas and digestate. For a more comprehensive understanding of biogas production and utilization it is therefore necessary to complement these general studies with detailed case studies.

In this study, a large, farm-based, co-digestion plant in southern Sweden, using manure and various food industry wastes is investigated concerning its use of energy and emissions of GHG's from a systems perspective. The biogas is upgraded and utilized as a vehicle fuel, distributed via the natural gas grid. This kind of distribution is applied for approximately 25% of the biogas used as vehicle fuel in Sweden today, equivalent to 684 TJ [55].

The overarching purpose is to analyse the energy and GHG performance for this particular biogas plant from a life cycle perspective based on measured, site-specific data. The case-study

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also includes a novel approach in which potential changes in soil compaction and soil carbon levels are assessed, based on farm-specific conditions, when digestate (the effluent from the biogas plant) replaces mineral fertilizer. An additional objective is to identify potential technical improvements which could lead to further GHG reductions, and the cost of such measures.

2. Methodology and assumptions

The biogas plant analysed in this study was established in 2006 and is located on a farm in southern Sweden (WramsGunnarstorp, 20 km east of the city of Helsingborg). The dominating supplier of feedstock is a large, food processing industry located 2 km from the biogas plant, from which feedstock (mostly vegetable waste) is transported by truck and in a pipeline (sludge from the internal waste-water treatment plant). Vegetable waste and other feedstock transported by truck from this industry represent approximately 33% of the total amount of treated feedstock, whereas the amount of sludge pumped via the pipeline represents 7%. The feedstock consists among other things of slaughter house waste (25%), pre-treated household waste (6%) and manure (18%). The biogas produced is upgraded and distributed via the natural gas grid, which passes close to the biogas plant, and the digestate is utilized as fertilizer in the surrounding area. The cropland surrounding the biogas plant has been intensively cultivated with annual crops for a long period of time, and has mostly been fertilized with mineral fertilizers, leading to a decline in the soil carbon level. Thus, the content of organic matter in the digestate will increase the soil carbon level and could improve soil fertility. However, the high clay content in the soil makes the cropland sensitive to compaction, which should be considered when mineral fertilizers are replaced by digestate, which requires heavier field equipment for transport and spreading. In addition, an increase in the soil carbon content leads to an increased resistance against soil compaction. In Table 1, the input of feedstock and output of biogas and digestate from the biogas plant during 2011 are summarized.

Calculations of GHG emissions and energy balance are based on the ISO standard 140 44 for LCA [30].The functional unit (FU) is set to 1 MJ upgraded and compressed vehicle gas distributed via the natural gas grid. The assessment includes transport of feedstock, biogas production, upgrading, compression and distribution of the gas via the natural gas grid, as well as storage, transport and application of the digestate on cropland.

The assessment in this study applies a systems expansion approach, in accordance with the recommendation in the ISO standard of LCA [30]. In the reference system, where no biogas is produced, petrol is assumed to be used as vehicle fuel. The reference system also includes the conventional handling of manure and sludge that took place before the biogas plant was established, as well as the utilization of some vegetable residues as animal feed. Potential alternative treatment methods for the remaining part of the organic waste used as feedstock in the biogas plant is, however, not included since anaerobic digestion is considered to be the most likely treatment method in Sweden today for the feedstock in question. The digestate produced in the biogas plant is assumed to replace mineral fertilizers, except for the part originating from the manure and the sludge from the food processing industry which was used as fertilizer also before the establishment of the biogas plant. The system expansion regarding the replacement of mineral fertilizers by digestate includes the factor that the production of mineral fertilizers is avoided, the increased input of organic matter into the soil and the increased risk of soil compaction due to heavier field equipment. Changes in the carbon levels in the soil and soil compaction will affect the soil fertility and thereby crop yields, leading to indirect effects on energy and GHG performance in crop cultivation on the farm in question.

The primary energy factors for the energy carriers used in this study, and related GHG emissions are shown in Table 2. The calculations are based on typical average values for energy carriers currently used in Sweden. In the sensitivity analysis, additional calculations are based on corresponding data for the Nordic and European energy systems. Calculated life cycle emissions of GHG's include carbon dioxide (CO_2) of fossil origin, methane (CH_4) and nitrous oxide (N_2O). When expressed as global warming potential (GWP_{100}), 1 kg of CH_4 and 1 kg of N_2O correspond to 25 and 298 kg CO_2-equivalents, respectively [21].

Table 1
Annual input of feedstock and output of biogas and digestate from the analysed biogas plant.[a]

Input/output	
Feedstock treated	50,900 t
Upgraded biogas produced	90 TJ
Gas injected into the natural gas grid[b]	113 TJ
Digestate produced	48,000 t

[a] Based on data from 2011 provided by Reihnhold [46] and Jonasson [34].
[b] Including additional LPG to fulfil the requirements of energy content equivalent in the natural gas distributed.

Table 2
Primary energy factors and GHG emissions for the energy carriers included in this study.

Energy carrier	Primary energy factor (MJ/MJ)	GHG emissions (g CO_2-eq./MJ)
Diesel[a]	1.09	83.8[e]
Electricity	2.10[b]	10.1[b] (34.9/119)[c]
LPG[d]	1.12	73.7
Natural gas[a]	1.09	69
Wood chips[a]	1.03	2.2

[a] Ref. [24].
[b] Swedish average mix [24].
[c] Nordic/EU-27 average mix [28,54].
[d] Ref. [35].
[e] Ref. [14]

3. The biogas system

The following sections describe the biogas system in detail and the specific input data utilized in the assessment.

3.1. Transport of feedstock

The major part of the feedstock is transported to the biogas plant by truck (see Table 3). Trucks with loading capacities of 35 or 12 t

Table 3
Input data regarding the transport of feedstock to the biogas plant by trucks.[a]

	Loading capacity (t)		
	35	25	12
Amount of feedstock (t)	26 700	17 100	3 600
Average transport distance (km)	118	10	88
Time for loading and unloading (h)	0.22		0.17
Fuel consumption			
MJ/km[b]	18		0.9
MJ/h[c]	540	14	540

[a] Input data of the amount of various feedstock and transportation distances are provided by Jonasson [34] and the type of trucks is based on Lantz et al. [41].
[b] Average fuel consumption including empty return transport [18,41].
[c] Average fuel consumption when loading/unloading [18,41].