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Research paper

Production efficiency of Swedish farm-scale biogas plants

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ABSTRACT

Biogas from agricultural waste streams represents an important way to produce fossil-free energy, allow nutrient recycling and reduce greenhouse gas emissions. However, biogas production from agricultural substrates is currently far from reaching its full potential. In Sweden, the number of biogas plants and their output have increased in recent years, but they are still experiencing harsh economic conditions. A recent evaluation (2010–2015) of 31 farm-scale biogas production facilities in Sweden sought to identify parameters of importance for further positive development. In this paper, data on plant operation, gas yield and digestate quality for 27 of these plants are summarised and statistically analysed to investigate factors that could allow an increase in overall biogas production and in nutrient content in the digestate. The analysis showed that addition of co-substrates to manure results in higher gas production, expressed as both specific methane potential and volumetric gas production, than when manure is the sole substrate. Use of co-substrate was also found to be influential for the nutrient content of the digestate. These observed improvements caused by co-digestion should be considered when subsidy systems for manure-based biogas processes are being created, as they could also improve the economics of biogas production. However, to achieve higher efficiency in existing biogas plants and to improve the situation for future investments, a more detailed, long-term evaluation programme should also be considered.

1. Introduction

Biogas, produced through anaerobic digestion of organic materials, is a versatile renewable energy source that can be used to replace fossil fuels in power and heat production and can also be converted to vehicle fuel. Biogas production also reduces greenhouse gas (GHG) emissions, in amounts that vary depending on the source of energy replaced by biogas and alternative use of the biogas produced by the system [1–3]. Moreover, nutrients are retained in the biogas process, making the digestion residue suitable as an organic fertiliser that can replace fossil energy-requiring mineral fertilisers [4,5]. Biogas production is highly interesting for the agricultural sector, as it represents one way for European agriculture to produce local energy, replace fossil fuel and become self-sufficient in energy supply [6]. The Swedish government has a long-term vision for a sustainable energy supply involving zero emissions of GHG and a transportation sector supplied by-non fossil fuels by 2030 [7]. The domestic energy demand in Sweden in 2013 was 375 TWh, with 52% renewable energy [8], while the level of renewable energy for the European Union (EU) as a whole was approximately 12% in that year [9]. Even though Sweden has already made good progress in conversion to renewable energy, use of direct energy in the agriculture sector is still around 4 TWh per year, mainly as fossil fuels for machinery and transportation [10]. The contribution of agriculture to total GHG emissions in the EU is currently 9%, mainly as methane (CH_4) and dinitrogen monoxide (N_2O) [11], and the corresponding percentage in Sweden is approximately 13% of overall emissions [12]. Introducing biogas production into farm systems, where manure also can be utilised as a substrate, has great potential to reduce GHG emissions and simultaneously reduce the demand for fossil energy [13]. Manure management, including storage, spreading of manure and replacement of mineral fertiliser, has been shown to affect the level of GHG emissions from on-farm biogas systems [3,14,15].

European biogas production has increased during the past years

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Abbreviations

FSBP	Farm-scale biogas plant
VS	Volatile solids [%] of wet weight
TS	Total solids [%] of wet weight
t	Tonne, one metric ton 1000 kg
SMP	Specific methane potential; amount methane per tonne VS added [m^3 CH^4 t VS^{-1}][a]
m	Mass flow wet weight of substrate [t day^{-1}]
HRT	Hydraulic retention time [days]
OLR	Organic loading rate [kgVS m^{-3} day^{-1}]
DD	Degree of degradation [%]
ML	Nitrogen mineralisation level [%]
MP	Methane production [m^3][a]

[a] Gas volume corrected to standard pressure (1 atm) and temperature (0 °C)

in terms of number of plants and installed capacity. Germany, United Kingdom (UK), Italy, Spain and France produce most biogas in Europe [16]. In Germany, most of the biogas is produced from agricultural waste streams and energy crops [17], whereas the UK, Italy, Spain and France mainly produce biogas from landfill [16]. Denmark and the Netherlands also produce a large proportion of their biogas from agricultural substrates, approximately 70% and 59%, respectively [18,19]. However, there is a great potential to further increase biogas production from agricultural waste and energy crops. According to the European Biomass Association (EBA), the realistic potential for biogas production from the EU is about 465 TWh, which is equivalent to 40 million tonnes of fossil oil [16]. Today, total biogas production in Sweden is 1.8 TWh, produced at 277 biogas plants, including only 37 farm-scale biogas plants (FSBP) producing 44 GWh [20]. However, the total energy potential of anaerobic treatment of agricultural wastes in Sweden is estimated to be 14 TWh, divided into 2.7 TWh from manure, 3 TWh from crop residues and approximately 8 TWh from energy crops [21]. Thus, biogas production from agricultural substrates is far from reaching its full potential. The main reason is relatively high production costs and expenditure to comply with laws and regulations [22,23]. Until 2014, there was an investment subsidy covering 30% of the costs for farm-scale biogas plants in Sweden (2008). In 2015, a new subsidy for manure digestion was introduced to decrease the environmental impact of GHG emissions from manure [6,24]. However, to further decrease production costs, efforts are needed to increase the resource efficiency of FSBP. The overall aim of this study was thus to evaluate existing Swedish FSBP and identify important parameters for achieving high biogas production efficiency and high nutrient concentrations in digestate from agricultural waste streams in Sweden.

2. Material and methods

During 2011–2014, the Swedish Rural Economy and Agricultural Society conducted a project entitled "*Assessment of Swedish Farm-scale Biogas Plants*", funded by the Swedish Board of Agriculture, in which 31 FSBP were evaluated in terms of economic output, technology operation and performance [25]. Most of these FSBPs are located in south-west Sweden, but with a few in the east and north. Data for 27 of these biogas plants were included in the present analysis, with four plants excluded due to insufficient information or data collection.

2.1. Description of biogas plants and sampling

Advisers from the Rural Economy and Agricultural Society in Sweden evaluated the different FSBPs using a data collection manual developed within the project. Each plant was visited 3–4 times per year. Data on temperature in the digester (°C), gas production [m^3 day^{-1}] and substrate amount [tonne day^{-1}] were collected using on site equipment installed at the biogas plant i.e. flow- and temperature meters. The flow meter measured gas from the whole biogas system, including all digesters. The equipment was installed after a water condensation step and registered gas at standard conditions. Samples (250 mL) for chemical analysis of the digestate were collected from the main digester and, if present, also from the second digester or from the post-digester. Samples of the substrate (250 mL) were also collected, either from storage containers for individual substrates and/or from the substrate mixing tank. Before sampling, the substrate was blended by the mixer unit in the tank. Substrate and digestate samples were chilled (approx. 7 °C) and sent by mail to the Agrilab laboratory in Uppsala, Sweden, for further chemical analysis (see section 2.2). Analysis of raw biogas was performed at the end of the FSBP pipe system. In addition to manure, 16 of the 27 FSBP used various co-substrates (Table A1). Amounts of these co-substrates varied greatly between different plants and corresponded to 1–75% of total volatile solids (VS) in the substrate mix. Co-digestion plants were defined in this study as plants having additional substrate/s comprising at least 10% of VS in the substrate mix, where the main substrate was cattle or pig manure. Based on the feedstock, the plants were separated into four different groups (Table 1): two groups of plants using only a single substrate, either cattle manure (C) or pig manure (P) and two groups of co-digestion plants, still with cattle manure (CO) or pig manure (PO) in the substrate mixture.

2.2. Analytical methods

Composition of the raw gas, i.e. levels of oxygen, methane, carbon dioxide and hydrogen sulphide, was determined using a portable gas analyser (*Sewerin Multitec 540; PPM Mätteknik, Industriell Gasmätning AB, Hisings Back*) directly connected to the raw gas pipeline. Total solids (TS) and volatile solids (VS) content of the digestate and substrate were determined by drying according to APHA [26]. Total nitrogen and ammonium-nitrogen, including ammonium and free ammonia, were analysed by standard ISO methods 13878:1998 [27] and 11732:2005 [28], respectively. Total carbon was analysed according to standard ISO 10694 [29] and total phosphorus, total sulphur and total potassium were analysed according to Swedish standard SS 28311 [30]. Volatile fatty acids (VFA) were analysed by HPCL analysis [31].

2.3. Calculations

Values for gas production, methane content and composition of digestate and substrate for the FSBPs included in the study are presented as averages of the 3–4 different sampling occasions per year of operation. Operating and performance parameters were calculated according to equations Eqs. (1)–(6) below. For these calculations, the heated active volume of the main digester (V_{act}) was used. If a second digester was present, the active volume for both the main and the secondary digester (V_{tot}) was included in the calculations. The ratio between the two volumes, i.e. active and total volume, was defined as RatioV. To convert the energy content in the methane gas produced to energy units of kilowatt-hours (kWh), a factor of 9.97 kWh per m^3 methane gas was used [32]. Gas volumes were normalised to standard conditions for temperature and pressure.