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Influence of different practices on biogas sustainability

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ABSTRACT

Biogas production and use are generally regarded as a sustainable practice that can guarantee high greenhouse gas (GHG) savings. However, the actual carbon footprint of biogas is strongly influenced by several factors. The aim of this study is to analyse the environmental performance of different biogas to electricity scenarios. Two criticalities are identified as important: the choice of feedstock and the operational practice concerning the digestate. Maize, manure and co-digestion of them are the different feedstocks chosen. Maize has higher yields, but its cultivation has to be accounted for, which consists of 28–42% of the GHG emissions of the whole process of producing electricity. Manure is considered a residue and as a result benefits from no production stage, but also from avoided emissions from the normal agricultural practice of storing it in the farm and spreading it as fertiliser, but has lower methane yields. Co-digestion combines the benefits and disadvantages of the two different feedstocks. Digestate storage in open or closed tanks and further use as fertiliser is analysed. The environmental impact analysis shows that a substantial reduction of GHG emissions can be achieved with closed digestate storage. The GHG emissions savings vary from about 3% in the maize pathways with open storage up to 330% in the manure pathway with closed storage. The biogas pathways, though, have worse environmental performances in all other environmental impacts considered but ozone depletion potential when compared to the European electricity average mix.

1. Introduction

The interest in anaerobic digestion (AD) and biogas production technology has grown rapidly over the years, mainly due to the increasing importance of renewable energy as a way for Europe to reduce greenhouse gas (GHG) emissions and improve the security of its energy supply [1].

Generally, biogas production and use are regarded as a very sustainable practice that can guarantee GHG savings [2]. It can be used directly for heating and electricity generation and as a substitute for other fossil fuel applications, e.g. transportation fuel. The potential utilization of the digestate as fertilizer can also reduce dependence on energy intensive mineral fertilisers, to further mitigate GHG emissions [3,4]. However, the mitigation of climate change is strongly dependent on many factors, such as the choice of feedstock and operational practices. Energy and materials are consumed for cultivation and transport of feedstocks and emissions arise from the

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biogas plant operation, biogas utilisation and demand for transportation and disposal of the process residues [5]. All these factors have to be considered in the quest for environmental friendly and sustainable energy production from biogas and should be properly evaluated when formulating policies regulating the sector or providing subsidies.

Biogas can be produced from nearly all kind of biological feedstock types, within those from the primary agricultural sectors and from various organic waste streams from the overall society. AD has mainly been associated with the treatment of animal manure and slurries from cattle and pig farming units [6,7], due to ready availability and ease of handling. However, the total potential production and yield of biogas from manure is limited and coupled to other upstream emissions. As a result, many stand-alone large-scale biogas plants rely on energy crops [8] and, mainly, on maize [6].

A number of papers about biogas production by AD have been published within the last decade. Issues that have been analysed are the methane yield of different solid agricultural feedstocks, single or co-digested [9,10], the energy consumption and emissions due to slurry management [11], the end-use of the biogas [12,13], the optimisation of methane production [14] and the environmental, agronomic and societal benefits of on-farm biogas production [2]. Several papers have focused their study on specific regions or countries [8,15]. Börjesson and Berglund [16–18], although focussing on the case of Sweden, gave the most complete overview of the biogas system referring to different raw materials and considering both energy balance and environmental impacts. They mentioned that the environmental impact from biogas systems can vary significantly due to factors such as the raw materials used, energy service provided and reference system replaced, but they did not analyse the impact of such factors. Last but not least, Pöschl et al. [5,19] evaluated the impact of different feedstocks, single or co-digested, and process chains (production, conversion and utilisation) on the energy balance of small and large-scale biogas systems existing in Germany. However, no specific data on manure management were included, and although they recommended the use of closed tanks for the digestate, they did not analyse this parameter further.

To the authors' knowledge, most of the research literature has not benchmarked the potential impacts of different practices to enable accurate assessment of the biogas sustainability. The different studies have generally focused on the specific feedstock or biogas production plants by geographical regions, or on the individual processes in biogas production chains. The aim of this study is to analyse the impact of several criticalities on the GHG emissions of a biogas plant and its sustainability, using a Life Cycle Assessment (LCA) perspective. Our analysis is based on a plant producing electricity via a reciprocating combined heat and power (CHP) engine, taking into consideration the different feedstocks, the management of the digestate and the emissions from the end use of both the biogas and the digestate. The impacts of this system are assessed by checking the results related to human health, natural environment and resource depletion, and correlating them with the criticalities that are important for a sustainable performance. Finally, a sensitivity analysis is conducted to verify some aspects of the analysis. This work is part of a larger effort aimed at comparing the environmental impacts of several biogas pathways, so as to provide a scientific basis for decision making by policy makers, stakeholders and the agro-industrial sector.

2. Materials and methods

The LCA is of the attributional type [20], i.e. it describes the environmental impact related to the (steady state) operation of a system for biogas production and use for electricity. It is performed according to the ISO 14040 and 14044 standards [21,22], using GaBi 5 [23] as software. The following sections describe the LCA methods and the results obtained, according to the scheme provided by the ISO standards.

2.1. *Goal and scope definition*

The goal of this study is to analyse the environmental performance of different biogas production and use scenarios, in order to help assess the environmental sustainability of the production of energy from biomass in a typical European plant. The target audiences are stakeholders, policy makers and the scientific community involved in environmental assessment of energy from biomass through anaerobic digestion. The study includes comparative assertions.

The scope of the Life Cycle Inventory (LCI) includes different biogas production systems using energy crops (maize silage) and manure, both single and multiple feedstocks in co-digestion, and different biogas pathways according to the digestate management. The final utilisation of biogas is combustion in a CHP engine for the production of heat and power.

The requirement to represent the typical European context made the collection of new information a necessity and in the case of lack of data assumptions had to be made. The most significant parameters that are assumed to be valid for all pathways concern biogas properties. It is assumed that biogas consists of 55% CH_4 and 45% CO_2 by volume [24], as well as some traces of H_2S [25]. Methane density and lower heating value (LHV) are 0.668 kg m^{-3} [26] and 50 MJ kg^{-1} [1] respectively (at 20 °C and 100 kPa), from which the density and LHV of biogas are calculated (1.28 kg m^{-3} density and 18.37 MJ m^{-3} both at 20 °C and 100 kPa).

The impact categories to be covered by the present LCA are climate change, ozone depletion, acidification, abiotic depletion, photochemical ozone, eutrophication and toxicity.

2.1.1. *Functional unit, boundaries and reference system*

The functional unit of the system refers to the final product of the chain considered (output-related functional unit), and therefore it is 1 MJ of electricity. The same functional unit is valid for the reference system. No allocation is applied in this analysis, as electricity is considered to be the only product. Heat is assumed to be used only internally and to be by no other way exploited.

The approach of the study is from cradle to grave. The chain of processes covers all the phases from cultivation (only in the case of energy crops) to the final utilisation of biogas to produce energy. Digestate management is included in the boundaries. Fig. 1 summarises the system boundaries of a generic pathway.